Geologic Map of the Red Bluff 7.5-Minute Quadrangle, Eddy County, New Mexico

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Scale 1:24,000

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1. Introduction

1.1. Geologic and geographic setting

The Red Bluff quadrangle lies in far southeastern New Mexico south of the city of Carlsbad along the Pecos River (**FIGURE 1**). The quadrangle is named for the Red Bluff geographic feature along Red Bluff Draw just upstream of the confluence of the draw and the Pecos River (**FIGURE 2**). Relief is generally low, and topography is mainly associated with the drainages in the area, including the Pecos and Delaware Rivers and Red Bluff Draw.

Geologically, the study area lies within the Delaware basin, one of the three major structural/sedimentological basins of the informal Permian basin oil and gas region of southeastern New Mexico and west Texas (**FIGURE 3**). Development of the Delaware basin as a distinct entity began in the Pennsylvanian (Hill, 1996), and subsidence continued through at least the Guadalupian (Upper Permian) (Ewing, 1993). The rim of the basin is commonly mapped along the Capitan reef complex, which developed in Guadalupian time. Ochoan evaporites, particularly those of the Castile Formation, subsequently filled the basin, and subsequent Ochoan rocks of the Salado, Rustler, and Dewey Lake Formations blanketed the area both within and outside the Delaware basin (**FIGURE 4**). Of this history, only rocks of the Castile, Salado, and Rustler Formations are preserved within the quadrangle at the surface today.

Mesozoic strata of the lower Cretaceous rocks at one time covered the area (Lang, 1947), but have subsequently been removed by erosion; whether or not Triassic or Jurassic sediments once buried the study area is not clear. Upper Cenozoic alluvial and eolian sediments later blanketed the region, sediments that are here referred to as the lower Gatuña Formation (Powers and Holt, 1993; Hawley, 1993). Later incision and local backfilling by an ancestral Pecos River and its tributaries deposited inset alluvial sediments and sedimentary rocks that are here referred to as the upper Gatuña Formation (cf., Cikoski, 2019). Gatuña sedimentation along the lower Pecos River valley is strongly influenced by variable dissolution and karst development in the underlying Ochoan strata (cf., Bachman, 1987), and as a consequence deposit preservation is highly variable. However, rocks of the Gatuña are commonly found within the quadrangle along the Pecos and its tributaries.

Tectonically, the area has been largely quiescent since Guadalupian time (Powers et al., 1978). However, dissolution of Ochoan evaporites in the shallow subsurface has resulted in substantial, localized karst structures that deform the exposed Ochoan and late Cenozoic deposits (Vine, 1960; Bachman, 1980; Bachman, 1987). All of the structure apparent on the Red Bluff quadrangle is interpreted to be the product of dissolution of subsurface Ochoan deposits, principally of the Salado Formation. Hence, the abundance of 'structural features' such as folds and tilted strata shown on the map are inferred to be shallow features lacking deep roots or tectonic underpinnings.

1.2. Methods

Geologic mapping was performed during the years 2017–19 using standard methods (e.g., Compton, 1985). Field mapping was supplemented with remote mapping using 2009-vintage digital stereo aerial imagery using the ERDAS StereoAnalyst extension to the ESRI ArcMap software package. Data was compiled into a geographic information systems (GIS) geodatabase using ESRI's ArcGIS software platform. Geologic terms used herein are after Compton (1985), soil terms after Birkeland (1999), carbonate horizon stages after Gile et al. (1966) and Machette (1985), and color notation after Munsell Color (2009). Coordinates are given in Universal Transverse Mercator (UTM) coordinates after the NAD83 Zone 13S datum.

Stratigraphic nomenclature follows established names in common usage to the area (cf., King, 1948; Hayes, 1964; Kelley, 1971; Powers et al., 1978; Bachman, 1980; Powers and Holt, 1993; Hawley, 1993; Scholle et al., 2007). Pazzaglia and Hawley (2004) imply that the lower Gatuña Formation, as used here, may be better referred to the Ogallala Formation (e.g., their figure 10; compare with figure 2 from Hawley, 1993), given the apparent overlap in ages and similarity in deposits. While I recognize this age correlation, I choose to continue to use the term Gatuña for these rocks, in large part due to the difficulty in accurately referring any given outcrop to the upper or lower Gatuña. See discussion in Cikoski (2019).

1.3. Acknowledgements

I thank J. Michael Timmons, Geologic Mapping Program Manager at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), and the United States Geological Survey (USGS) STATEMAP program for funding to conduct this study. Cartography was provided by the NMBGMR map production group, coordinated by Phil Miller.

2. Figures

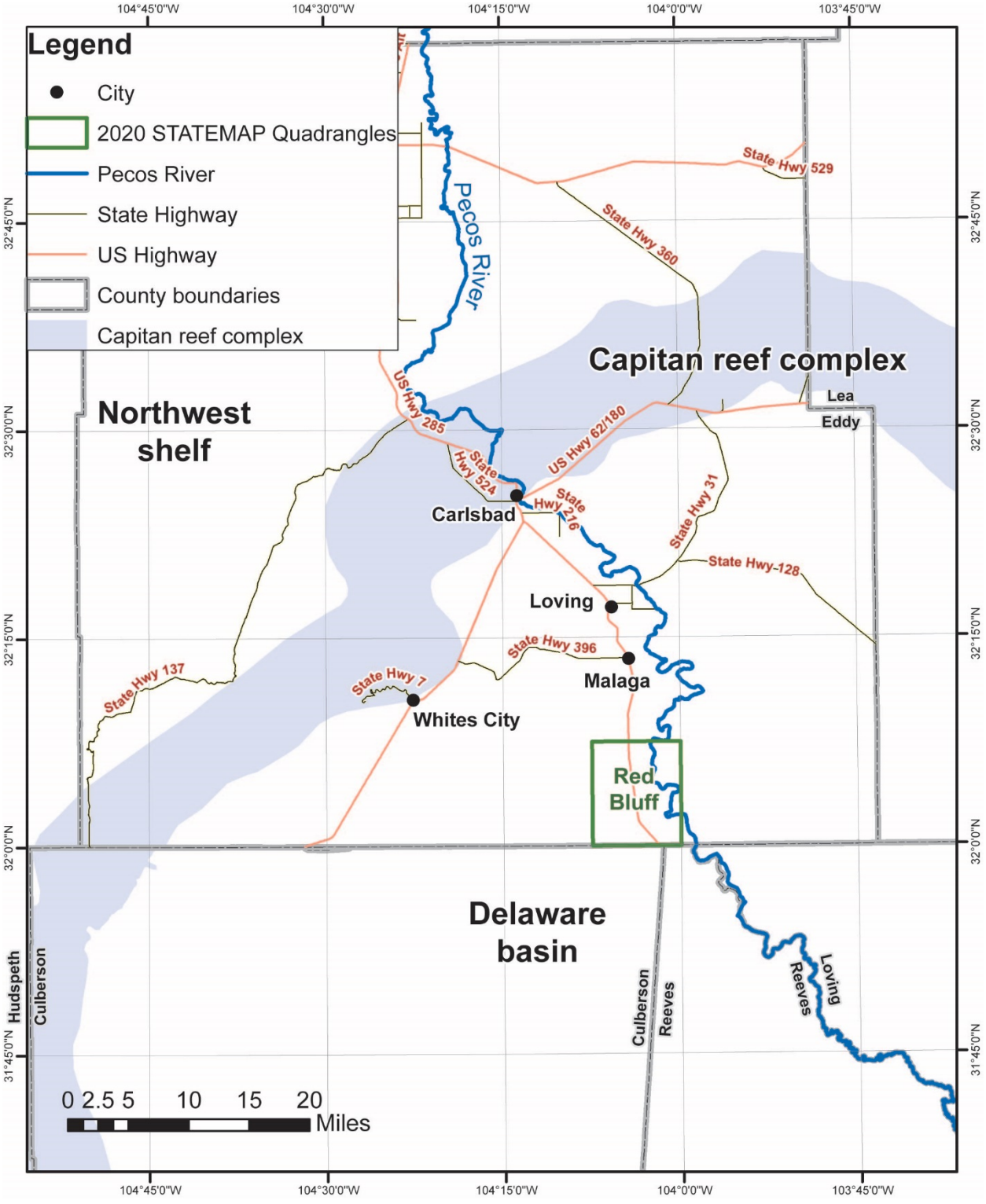

FIGURE 1—Geographic location of the study area. Capitan reef complex extent from Standen et al. (2009).

FIGURE 2—The eponymous Red Bluff exposes the Los Medaños mudstones, sandstones, and gypsum overlain by Culebra dolomite beds along Red Bluff Draw.

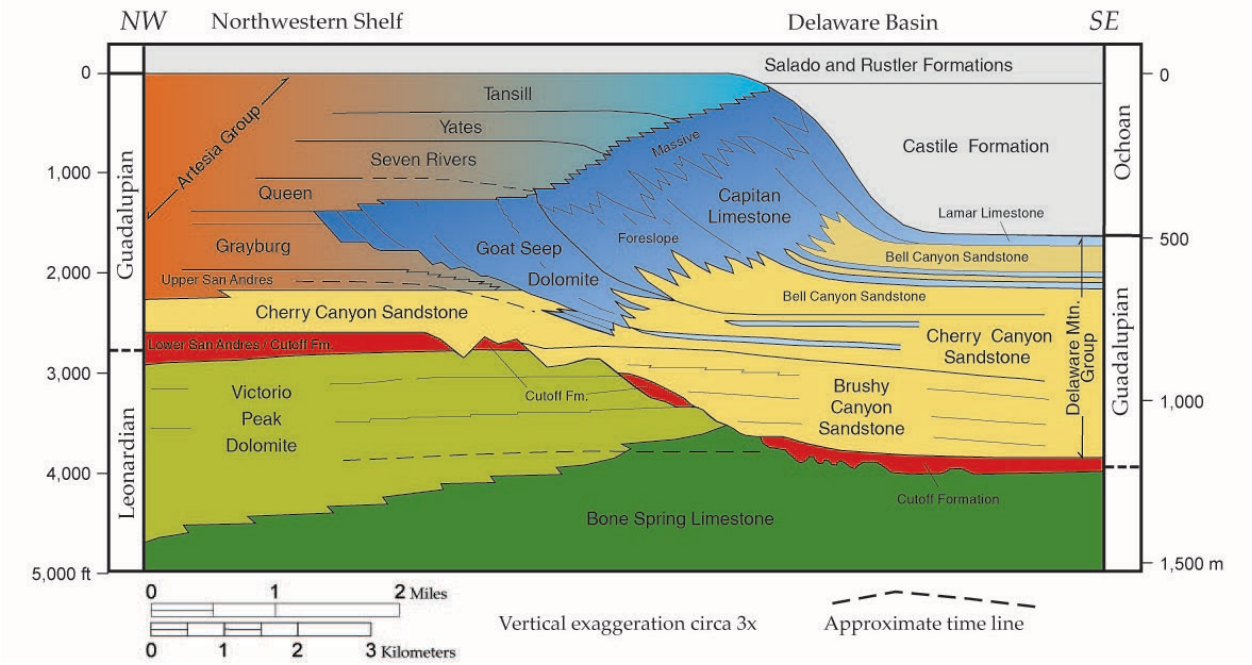

FIGURE 3—Classic depiction of the stratigraphy of the Permian strata occurring within and around the Delaware basin. Modified from Scholle et al. (2007). Abbreviations: Fm. = Formation, Mtn. = Mountain.

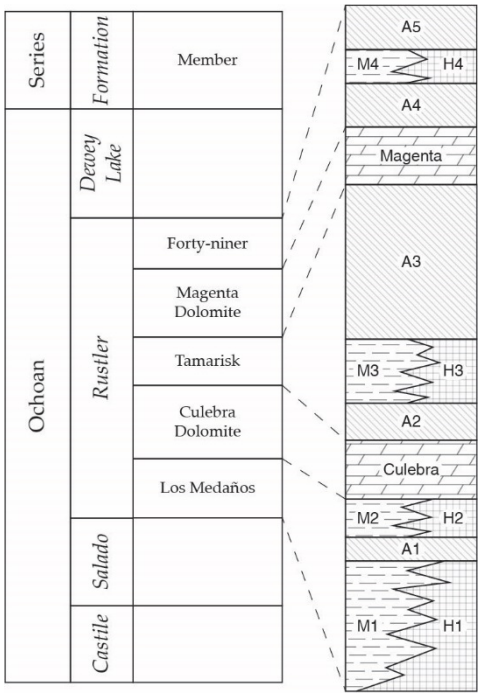

FIGURE 4—Ochoan Series stratigraphy, modified from Holt and Powers (1988). The Dewey Lake Formation and Forty-niner Member are not found on the Malaga quadrangle. Lithologic abbreviations: **A**—anhydrite (gypsum at the surface), **H**—halite, **M**—mudstone.

A—Outcrops of the Mescalero caliche; exhibiting upper tabular-banded zones, thicknesses <1 m, and gradational lower contacts.

B—Outcrops of the Pierce Canyon caliche; exhibiting uppermost intervals of pure carbonate cement, thicknesses >1 m, and brecciation and recementation features.

C—Small-scale features of the Pierce Canyon caliche: pisolites (left) and laminae around pebbles (right).

FIGURE 5—Comparison of features of the Pierce Canyon and Mescalero caliches of the Gatuña Formation.

FIGURE 6—Exposure of the Pierce Canyon caliche (**Tgpc**) underlying upper Gatuña sedimentary rocks (**Qgf**) and the Mescalero caliche (**Qgmc**). Outcrop is located on the Malaga quadrangle to the north.

3. Map Unit Descriptions

Map Unit	Unit Name	Age	Description
	Cenozoic Erathem		
	Anthropogenic units		
af	Artificial fill	Historic	Compacted gravels, sands, and muds underlying dams, roads, and other artificial constructions. Only mapped where extensive. Deposits are 0 to about 3 m thick.
	Miscellaneous deposits		
Qae	Eolian and alluvial sediments	Holocene	Slope-blanketing windblown and slope wash-transported very pale-brown silts and fine sands variably mixed with colluvial and residual sediment. Deposits are loose and poorly exposed, and no evidence of notable surface soil development was observed. Colluvial and residual sediment may include gravels and clays derived from underlying deposits or nearby hillsides. Deposits are 0 to perhaps 2 m thick.
Qed	Dune deposits	Holocene	Windblown fine sands underlying dune fields and wind-sculpted hummocky terrain. Deposits are loose and poorly exposed. No evidence of notable soil development was observed. Deposits are 0–6 m thick.
Qdf	Depression fill	Holocene	Silts, sands, and clays accumulating in closed or nearly closed depressions. Dominantly slope wash- and eolian-transported muds and very fine sands, with trace coarser material, accumulating under ephemeral lacustrine (playa) conditions along the floors of the depressions. Surface soils were not observed in outcrop, but no evidence of significant soil development was found. Deposits are 0 to perhaps 2 m thick or more.

Map Unit	Unit Name	Age	Description
	Alluvial deposits		
Qa	Post-Gatuña Formation alluvial deposits, undivided	Holocene and Historic	Cross-sections only. Consists of sands, muds, and gravels underlying terraces, fans, and active floodplains and river channels. Deposits are 0 to perhaps 8 m thick.
	Unconfined alluvial deposits		
Qfy	Fan alluvium	Holocene	Sands, muds, and gravels underlying coalescing alluvial fans emanating from small-scale, low-order drainages. Deposit characteristics vary with the nature of the materials exposed upgradient. Deposits are unconsolidated and poorly exposed. No evidence of significant soil development was observed. Deposits are 0 to perhaps 4 m thick.
Qsw	Slope wash alluvium	Holocene	Sands, muds, and trace gravels transported by slope wash and eolian processes and blanketing low-gradient slopes and swales. Deposit characteristics vary with the nature of the materials exposed upgradient and underlying the deposit. Deposits are unconsolidated and poorly exposed. No evidence of significant soil development was observed. Deposits are 0 to perhaps 4 m thick.
	Confined alluvial deposits		
Qah	Historic alluvium	Historic	Unvegetated or poorly vegetated sands, muds, and gravels along active drainage channels. Includes areas submerged beneath water on 2009-vintage aerial imagery. Deposits are unconsolidated and no soil development is apparent. Deposits are 0 to perhaps 2 m thick.
Qay	Younger alluvium	Holocene	Sands, muds, and gravels underlying low terraces and floodplains along active drainage channels. Includes historic alluvium that cannot be mapped separately at this scale. Deposits are unconsolidated, and no evidence of significant soil development was observed. Deposits are 0 to perhaps 4 m thick.

Map Unit	Unit Name	Age	Description
Qayh	Younger and historic alluvium, undivided	Holocene	Unvegetated or poorly vegetated active drainage channels, adjacent floodplain sediments, and younger alluvial sediment, undivided. Used where map units Qah and Qay cannot be mapped separately at the map scale along the Delaware River and Red Bluff Draw drainages. Locally includes areas submerged beneath water on 2009-vintage aerial imagery. Deposits are 0 to perhaps 4 m thick.
	Terrace and floodplain alluvium		
Qtf	Undivided youngest terrace and floodplain deposits	Late Holocene and Historic	Brown thinly laminated silts and very fine sands underlying low terrace treads and modern floodplains exhibiting no surface soil development. Sands are dominantly siliceous. Terrace treads are up to about 6 m above the Pecos River channel, and where these treads are lower they are likely overtopped in large flood events. Deposits are up to perhaps 8 m thick.
Qt	Undivided pre-historic terrace deposits	Holocene	Brown to light-brown thinly bedded silts, silty sands, and lesser pebbly channel fills underlying terrace treads along the Pecos and Delaware Rivers. This map unit is laterally equivalent to both Qt2 and Qt1, and individual deposits of Qt may exhibit features of either of these subunits. The map unit Qt is used where the map scale and/or a lack of diagnostic features precludes assigning a deposit to either subunit. Deposits may be up to 8 m thick.
Qt2	Younger terrace deposits	Late Holocene	Brown thinly laminated silts and very fine sands underlying low terrace treads exhibiting very weak surface soil development. Sands are dominantly siliceous. Surface soils are characterized by a thin (circa 5 cm thick) darkened A horizon and trace very fine nodules and stringers of carbonate and/or gypsum in underlying sediments. Terrace tread heights are typically 7–12 m above the Pecos River channel. A fresh sand color of 7.5YR 5/4 and an A horizon color of 10YR 5/3 were measured. Deposits are 0 to perhaps 4 m thick.

Map Unit	Unit Name	Age	Description
Qt1	Older terrace deposits	Holocene	Brown to light-brown thinly bedded silts, silty sands, and lesser pebbly channel fills underlying higher terrace treads exhibiting weak surface soil development. Sands are dominantly siliceous, and beds are typically massive. Paleochannel fills are lenticular, very thin- to medium-thickness, internally massive to cross-bedded, and consist of rounded pebbles with absent to minor cobbles of lithologies including quartzites, cherts, limestones/dolomites, and sandstones. Where lying upon bedrock, paleochannel fills are commonly cemented by phreatic carbonates. Surface soils are characterized by a darkened A horizon up to about 25 cm thick overlying a thin Stage I to weak II carbonate horizon characterized by fine nodules and filaments of carbonate and/or gypsum and preferential accumulation of carbonate on the undersides of gravels. Terrace tread heights are typically 8–15 m above the Pecos River channel. Colors of 7.5YR 5/3–6/4 were measured for the silts and sands. Deposits are 0 to perhaps 8 m thick.

Map Unit	Unit Name	Age	Description
	Gatuña Formation		
QTg	Undifferentiated Gatuña Formation	Late Miocene to Middle Pleistocene	Poorly exposed, light-reddish-brown to pink, white, yellow, or pale-brown, locally gypsiferous siltstones, sandstones, claystones, and conglomerates. This map unit is used where poor exposure, poor stratigraphic control, and uncertain deposit characteristics preclude assigning a deposit to a more specific Gatuña Formation subunit; these deposits, therefore, may bear characteristics comparable to any of the Gatuña Formation subunits. Surface characteristics suggest that finer-grained facies deposits (QTgf, Qgf, Tgf) dominate, however. Gatuña Formation deposits may be as much as about 20 m thick.
QTgc	Undifferentiated coarser-grained deposits of Gatuña Formation age	Late Miocene to Middle Pleistocene(?)	Poorly exposed pebble conglomerates and lesser sandstones. This map unit is used where poor exposure and a lack of diagnostic features precludes assigning a deposit of coarse-grained Gatuña Formation sediments to one of Qgc or Tgc, and individual deposit characteristics may resemble those of either subunit. Deposits are characteristically poorly exposed, and thicknesses are poorly constrained; deposits are likely 0 to perhaps 10 m thick or more.

Map Unit	Unit Name	Age	Description
QTgf	Undifferentiated finer-grained deposits of the Gatuña Formation	Late Miocene to Middle Pleistocene(?)	Light-reddish-brown to pink, to less commonly white, yellow, or pale-brown, locally gypsiferous siltstones to very fine-grained sandstones with rare claystones, fine- to medium-grained sandstones, and pebble conglomerates. Dominantly very thinly to thinly planar-tabular-bedded siltstones and very fine-grained internally massive or planar- or cross-laminated sandstones; locally these strata are lenticularly bedded and/or bear ripple marks. Coarser-grained sandstones and pebble conglomerates are more common in undulatory-tabular or lenticular beds, but similarly very thinly to thinly bedded. Typically thinly planar-laminated claystones. Moderately sorted and rounded to well-rounded pebbles with lithologies including quartzites, cherts, sandstones, felsic to intermediate volcanic rocks, and limestones. Colors circa 5YR 6/4 dominate; overall, color measurements include 2.5YR to 7.5YR 6/3–6/4 (mudstones, sandstones); 5YR to 7.5YR 7/3 (sandstones); 2.5YR to 5YR 5/4 (claystones); 5YR 8/2–8/3 (mudstones, sandstones); rarely 2.5Y 7/3–8/3 (mudstones); and trace stronger colors up to 10YR 6/8–7/8. Undifferentiated map unit QTgf is used where the assignment of a deposit to the upper or lower Gatuña Formation is unclear. Deposit thicknesses are difficult to assess due to common subsidence-related deformation; further north on the Malaga quadrangle, cross-section interpretations suggest deposits may be as much as 45 m thick (Cikoski, 2019).

Map Unit	Unit Name	Age	Description
QTguc	Undifferentiated caliche of Gatuña Formation age	Pliocene(?) to Middle Pleistocene	Petrocalcic soil horizon typically exhibiting Stage V carbonate horizon morphology developed in pre-Gatuña Formation sediments and sedimentary rocks, or with an unexposed or unclear parent material. Caliche-impacted zones are characteristically thin (<1 m thick, typically ≈0.5 m thick) and capped by an undulatory-tabular-banded interval that is 20–40 cm thick of nearly pure carbonate cement, with bands typically 1–8 cm thick. Brecciation, recementation, and pisolitic or nodular structures vary in abundance from absent to abundant. Fine-grained parent materials (muds to fine-grained sands) are typically unidentifiable due to small size and ubiquitous engulfing carbonate cement; typically well-rounded, fine pebble-sized entrained gravels are present but sparse and are of siliceous or locally derived lithologies. The caliche-impacted zone typically ends abruptly down-profile, lacking the gradational base that is common with the Mescalero and Pierce Canyon caliches. This map unit is only used where pure or nearly pure caliche is found; carbonate-cemented breccias that are dominated by breccia blocks of identifiable bedrock are mapped as the bedrock unit. This caliche is interpreted to mostly be developed in an erosion surface that is age correlative to the top of the upper Gatuña Formation, but this erosion surface may be diachronous. These caliches are up to 1 m thick.
Qg	Upper Gatuña Formation	Lower(?) to Middle Pleistocene	Dominantly pink to white very fine-grained sands/sandstones and silt/siltstones, with lesser coarser-grained sandstones to conglomerates and gravels, that overlie or are inset against the Pierce Canyon caliche and underlie the Mescalero caliche. As compared to lower Gatuña sandstones and mudstones, the upper Gatuña sandstones and mudstones tend to be 1) lighter colored, 2) less well-cemented, 3) less deformed (commonly subhorizontal), and 4) overall thinner. Where the assignment of a Gatuña deposit to the upper or lower subunit is not clear, undifferentiated QTg units are used in lieu of a specific assignment.

Map Unit	Unit Name	Age	Description
Qgmc	Mescalero caliche of the upper Gatuña Formation	Middle Pleistocene	Petrocalcic soil horizon exhibiting Stage V carbonate horizon morphology. This horizon is characterized by a 15–30 cm thick undulatory-tabular-structured zone at the top that is composed predominantly of carbonate cement often with only trace incorporated parent material. Tabular bands are 0.5 to 7 cm thick each. Below the tabular zone is 60–100 cm of massive cemented carbonate, with cementation decreasing and the abundance of incorporated parent material increasing gradationally down-profile (**FIGURE 5A**). Brecciation, recemented fractures, and degradation features are found locally but are overall rare. The caliche is most commonly cementing sand or gravel deposits comparable to those described for map units Qgf and Qgc; where the caliche appears to be developed in fine-grained pre-Gatuña bedrock, map unit QTguc is used. The caliche zone is typically 0.5–1.25 m thick.

Map Unit	Unit Name	Age	Description
Qgf	Finer-grained facies of the upper Gatuña Formation	Lower(?) to Middle Pleistocene	Pink to white to locally reddish-brown sands/sandstones and muds/mudstones and trace pebble gravels/conglomerates overlying or inset against the Pierce Canyon caliche; interfingering with or overlying upper Gatuña gravels/conglomerates; or otherwise exhibiting upper Gatuña Formation characteristics (**FIGURE 6**). Generally weakly cemented and poorly exposed. Sands/sandstones generally dominate, and are very fine- to medium-grained (locally coarser-grained where adjacent to conglomerates), commonly silty/muddy and poorly sorted but locally clean and moderately sorted, and dominantly of siliceous material with subordinate limestone/dolomite lithics. Muds/mudstones are poorly sorted, commonly clayey and sandy, less commonly gypsiferous, and occur in poorly expressed planar-tabular mostly medium-thickness beds. Fine rounded pebbles of chert, quartzite, and felsic to intermediate volcanic material are a trace component of both mud/mudstone and sand/sandstone beds. Trace gravel/conglomerate beds are comparable to those of unit Qgc. Colors of 5YR 7/4 and 8/2–8/3, 7.5YR 7/4, 10YR 8.5/1, and less commonly 7.5YR 6/3 and 2.5YR–5YR 4/4 were measured, with white (carbonate) mottling locally occurring adjacent to Qgmc or Qgc conglomerates. Deposits are 0 to perhaps 6 m thick.

Map Unit	Unit Name	Age	Description
Qgc	Coarser-grained facies of the upper Gatuña Formation	Lower(?) to Middle Pleistocene	Pink to white pebble conglomerates and lesser sandstones and cobbly pebble conglomerates inset against lower Gatuña Formation deposits and/or underlying the Mescalero caliche. Gravels consist of poorly to very poorly sorted, rounded to well-rounded pebbles with absent to minor cobbles and absent to trace boulders, of mainly carbonate lithologies with absent to minor sandstone and quartzite, absent to rare chert, and absent to trace fine-grained felsic to mafic volcanic rocks, coarse-grained felsic plutonic (?) rocks, and reworked pebble conglomerates. Cobbles and boulders are typically from locally exposed strata (e.g., Culebra and Magenta dolomites), while conglomerate clasts are interpreted to be reworked from upstream lower Gatuña outcrops. Clast-supported gravels are in cross-stratified lenticular medium-thickness beds that are commonly moderately well-indurated by pink to white carbonate cement that commonly weathers smooth, as opposed to the more angular 'tear-pants' weathering texture of Tgc conglomerates. Sandstones are most often in thin cross-stratified lenticular beds. Both conglomerate and sandstone intervals wedge out laterally along broad continuous outcrops. Sandstone and conglomerate matrix colors of 5YR 7/3–7/4 and 8/2, 2.5YR 8/2–8/3, and 7.5YR 7/3–8/3 and 9/1–9/2 were measured. Deposits are thickest along the Pecos River, where they are as much as 10 m thick or greater; deposits thin to 0 m away from major drainages.
Tg	Lower Gatuña Formation	Late Miocene to Pliocene	Vertically exaggerated cross-section only. Dominantly light-reddish-brown mudstones and sandstones, with lesser conglomerates, that underlie the Pierce Canyon caliche. As compared to upper Gatuña mudstones and sandstones, the lower Gatuña mudstones and sandstones tend to be 1) darker/stronger colored, 2) better cemented, 3) moderately to strongly deformed or tilted, and 4) overall thicker. Where the assignment of a Gatuña deposit to the upper or lower subunit is not clear, undifferentiated QTg units are used in lieu of a specific assignment.

Map Unit	Unit Name	Age	Description
Tgpc	Pierce Canyon caliche of the lower Gatuña Formation	Pliocene	Petrocalcic soil horizon exhibiting Stage VI carbonate horizon morphology. This horizon is characterized by a diverse array of cementation, degradation, brecciation, and recementation features that extend 3.5–5 m below the top of the horizon, grading down-profile into typical lower Gatuña deposits (**FIGURE 5B**). A typical complete profile bears a conspicuously undulatory-tabular-structured uppermost zone up to 0.5 m thick with tabular bands 3–30 cm thick of nearly pure carbonate cement. Fracturing and recementation of these bands is common, and thin laminae of pure cement commonly occurs in the swales or low areas in undulations. Concentrically laminated structures are locally apparent in weathered faces, either as pisolites or as laminae around carbonate-engulfed gravels. Below the tabular zone lay a cemented/fractured/recemented zone 3–5 m thick, with carbonate abundance generally decreasing down-profile. Most often, the caliche is cementing poorly sorted, well-rounded pebble gravels of lithologies including quartzite, chert, limestone, sandstone, and volcanic rocks, and well-cemented pebble conglomerates directly underlying the caliche zone are included in the Tgpc map unit. In some locations, where gravel clasts are rare or unapparent, the caliche may be forming in Tgf sandstones and mudstones. Caliche zone is typically 3.5–5 m thick.

Map Unit	Unit Name	Age	Description
Tgc	Coarser-grained facies of the lower Gatuña Formation	Late Miocene to Pliocene	Light-brown to light-gray, moderately well- to well-cemented pebble conglomerates and lesser sandstones inset upon by upper Gatuña Formation deposits and/or underlying or grading into the Pierce Canyon caliche. Gravels consist of poorly to moderately sorted, rounded to well-rounded pebbles with absent to rare cobbles of varying lithologies that are in clast-supported, lenticular, commonly cross-stratified thin- to medium-thickness beds that are moderately well-indurated by carbonate cement. Most commonly, gravel are dominated by siliceous material (quartzite, chert) with subordinate to subequal carbonate lithologies (limestone, dolomite) and absent to rare sandstone clasts; however, some outcrops are dominated by carbonate lithologies and subordinate sandstone clasts with trace to subordinate siliceous clasts. Both clast suites bear accessary absent to trace felsic to intermediate volcanic rocks and granitic clasts. The carbonate cement is not uncommonly mottled in color, and weathers to a jagged limestone-like 'tear-pants' surface texture, unlike the typically smooth-weathering surface textures of Qgc conglomerates. Cement/matrix colors of 2.5YR 7/3 and 7.5YR 9/2–9/1 with mottles of 7.5YR 6/4–6/1 were measured. Sandstones are thin, lenticular, and comparable to those of unit Tgf. Deposits are typically less than 2.5 m thick but may be as much as 10 m thick where filling paleovalleys.
Tgf	Finer-grained facies of the lower Gatuña Formation	Late Miocene to Pliocene	Light-reddish-brown, and less commonly pink, yellow, or pale-brown, locally gypsiferous siltstones to fine-grained sandstones, mudstones, claystones, and rare medium-grained sandstones and trace pebble conglomerates underlying the Pierce Canyon caliche. Deposits are similar to those described for map unit QTgf, but with age constrained to upper Tertiary by the level of soil development in the overlying caliche zone. Preserved, exposed deposit thicknesses are up to about 14 m.

Map Unit	Unit Name	Age	Description
	Permian System		
	Ochoan Series		
	Rustler Formation		
Pr	Rustler Formation, undivided	Ochoan (Upper Permian)	Unexaggerated cross-section only. Consists of interbedded fine-grained clastic sedimentary rocks, gypsum/anhydrite, and carbonates. Where used on cross-section A–A', the unit mostly consists of the Los Medaños and Culebra Dolomite Members; Tamarisk and Magenta Dolomite Members are present in more strongly subsided karst depression fills. The maximum preserved thickness of undivided Rustler Formation deposits may be as much as about 80 m.
Prf	Forty-niner Member of the Rustler Formation	Ochoan (Upper Permian)	White to dark-gray gypsum. Gypsum has commonly planar-laminated to very thinly planar-tabular beds; mottled white, light-gray, and dark-gray; variably nodular; and commonly weathered and not uncommonly exhibiting karstic dissolution features. Holt and Powers (1988) report that regionally the unit consists of two gypsum/anhydrite intervals to either side of a medial claystone and/or halite interval; within the quadrangle, it is likely that only the lower of these gypsum intervals is preserved. Preserved on-quadrangle thickness is no more than about 5 m; Holt and Powers (1988) report a regional maximum of about 32 m thick.

Map Unit	Unit Name	Age	Description
Prm	Magenta Dolomite Member of the Rustler Formation	Ochoan (Upper Permian)	Laminated pale-gray to pale-reddish-brown arenaceous dolomite and lesser siltstones. In complete sections, the unit consists of two pale-reddish-brown dolomite intervals with a medial pale-gray siltstone. The lower dolomite is distinctly undulatory- or wavy-laminated crystalline dolomite with common very fine to fine sand grains. The upper dolomite is interlayered dolomicrite, arenaceous dolomite, and crystalline dolomite in variously internally massive or planar- or cross-laminated thick laminae to very thin planar-tabular beds. Fresh colors of 5YR 6/3, 2.5YR 6/4, and 7.5YR 7/3 were measured for these rocks. Planar-laminated to very thinly planar-tabular bedded medial siltstone has a fresh color of circa 2.5Y 8.5/1–8/1. Laminations and beds are not uncommonly contorted. The preserved maximum exposed thickness is about 6 m; Holt and Powers (1988) state that regionally the unit thickness is not great but that the variability is significant.
Prmb	Brecciated Magenta Dolomite Member of the Rustler Formation	Ochoan (Upper Permian)	Brecciated Magenta Member dolomites and siltstones. Commonly found mixed with other brecciated Rustler Formation lithologies, breccia blocks are as much as 1 m across and are commonly internally deformed and/or brecciated. Breccia intervals are as much as 6 m thick vertically.
Prt	Tamarisk Member of the Rustler Formation	Ochoan (Upper Permian)	Light-gray nodular gypsum and lesser reddish-brown gypsiferous claystones. Poorly exposed, and often identified by the presence of gypsum and gypsiferous muds in colluvial/residuum slopes overlying the Culebra Dolomite. Where exposed, the gypsum is commonly weathered, mottled white, light-gray, and dark-gray, and commonly massive but locally bearing a weak wavy tabular bedding. Claystones are massive in outcrop; a color of 2.5YR 5/4 was measured for these rocks. Holt and Powers (1988) report a thickness of about 30–50 m in 'normal sections', with a maximum regional thickness of about 82 m; on-quadrangle exposures indicate the thickness here may be as little as 1 m, with preserved thicknesses up to about 40 m in the subsurface along cross-section A–A'.

Map Unit	Unit Name	Age	Description
Prc	Culebra Dolomite Member of the Rustler Formation	Ochoan (Upper Permian)	Cream-colored to white to locally pale-brown, ledge-forming, commonly conspicuously vuggy dolomite. Dolomite beds have thin- to medium-thick planar-tabular and commonly internally massive beds, are near-white in color, and aphanitic under a hand lends (dolomicrite). Locally, these dolomites grade laterally into internally planar- or trough-cross-stratified, pale-brown (circa 2.5Y 7/3), very fine- to fine-grained dolomite grainstone. Abundant to rare vugs are fine in size (1–10 mm in diameter) and distinctive to the unit, but commonly absent from grainstone beds. Not uncommonly this unit is highly fractured, with fractures variously filled with caliche/carbonate cement, particularly adjacent to Gatuña Formation caliches; in some places, outcrops consist of carbonate-engulfed dolomite breccia. Preserved unit is about 8–14 m thick.

Map Unit	Unit Name	Age	Description
Prl	Los Medaños Member of the Rustler Formation	Ochoan (Upper Permian)	Interlayered mudstones, gypsum, and lesser sandstones. In well-exposed undeformed sections, a typical outcrop consists of a basal interval of reddish-yellow to pale-red, laminated to thinly bedded, poorly indurated siltstones, silty mudstones, and rare silty very fine-grained sandstones overlain by a subequal to slightly thinner interval of mottled white to gray, variably finely crystalline, variably nodular, variously thinly tabular bedded to laminated to brecciated gypsum, capped by a thinner interval (commonly about half as thick as the lower intervals) of mudstones that are similar to those of the basal interval. Less common lithologies include thin lenticular pale-brown to pinkish-white very fine- to fine-grained cross-laminated siliceous sandstones that are moderately well-indurated by carbonate cement, and irregular masses of brecciated gypsum. Trace thin laminae of waxy claystones are also present. Colors of 5YR 6/6–7/6 (mudstones, claystones), 2.5YR 7/2–7/1 and 7.5YR 8/2 (siltstones/very fine-grained sandstones), and 2.5Y 7/4–7/6 and 10YR 6/4 (lenticular sandstones) were measured. This unit is generally poorly exposed and often identified by abundant reddish muds with trace irregular gypsum masses in colluvial/residuum slopes underlying Culebra Dolomite ledges. Where present and exposed, **Prl** has an interbedded basal contact with **Prl2**, and appears unconformably inset against **Prb**. At Red Bluff, the unit is about 10 m thick, and map patterns indicate the unit thins southward to perhaps as little as 2 m thick. Northward, the base of the unit is not exposed, and the unit may thicken.

Map Unit	Unit Name	Age	Description
Prl2	Lower Los Medaños Member of the Rustler Formation	Ochoan (Upper Permian)	Light-gray to light-grayish-brown, locally pebbly siltstones to very fine sandstones, mudstones, and shales. Siltstones to sandstones are dominant, and consist of moderately sorted grains in poorly indurated, commonly cross-stratified, thin- to medium-thick lenticular beds that bear absent to minor well-rounded outsized granules to pebbles of gypsum and clayey gypsum that are similar to the materials observed in outcrops of map unit Pcs. Mudstones and shales are more common toward the base of exposures, and are thinly planar-bedded to laminated and commonly limey, with local mottling apparent on some bedding planes. Colors were measured to be 2.5Y 5/2 fresh, weathering to 10YR 6/2–7/2 for the siltstones/sandstones, and 7/N for the basal mudstones. Deposits grade upsection into reddish-brown siltstones of unit **Prl** across an interbedded contact. This unit is only locally preserved, and only observed at exposures at Red Bluff. Preserved, exposed deposits are 0 to about 5 m thick.

Map Unit	Unit Name	Age	Description
Prb	Basal beds of the Rustler Formation	Ochoan (Upper Permian)	Pale-brown to light-gray to locally pinkish-white thinly bedded carbonates and lesser siltstones and sandstones, with variable abundance of gypsum. Thinly to very thinly bedded, planar- to undulatory-tabular carbonate mudstones to wackestones dominate, which commonly bear absent to minor very fine sand-sized carbonate grains and poorly expressed internal planar laminations. Clastic beds are silty very fine sandstones to sandy siltstones that are similarly bedded and internally laminated. Gypsum occurs as very thin beds and laminae between carbonate beds, as well as irregular spar within carbonate beds. Gypsum content is highly variable, transitioning from minor to absent within a single outcrop laterally; overall, gypsum appears sparse. Colors of 2.5Y 7/1 to 10YR 8/1 and Gley 1 7/5GY (limestones) and 10YR 7/4–7/6 (clastics) were measured. The unit is only locally preserved; one outcrop suggests the unit was incised into prior to deposition of later Rustler Formation deposits, while another outcrop suggests the unit is principally preserved in subsidence features inset into underlying Salado Formation strata. Unit thicknesses are highly variable, potentially as a consequence of both erosion and variable gypsum content; preserved deposits vary from 0 to as much as about 10 m thick.
Prg	Gypsiferous members of the Rustler Formation, undivided	Ochoan (Upper Permian)	Undivided Prl, Prt, and Prf. Variably weathered gypsum, commonly nodular and massive in outcrop but generally poorly exposed. This map unit is used where unclear stratigraphic relationships and a lack of diagnostic features precludes assigning a deposit to a specific gypsiferous Rustler Formation map unit, and an outcrop may belong to any of the three gypsiferous members.

Map Unit	Unit Name	Age	Description
	Castile and Salado Formations		
Pcs	Castile and Salado Formations, undivided	Ochoan (Upper Permian)	Gypsum, gypsiferous residuum and breccia, and trace claystones and clayey gypsum. Where well-preserved and well-exposed, deposits consist dominantly of irregularly deformed gypsum and gypsum breccia blocks with light-red to red clays occurring as trace constituents between angular gypsum crystals in breccia blocks and in the gypsiferous matrix cementing breccia blocks. Gypsum varies from crystalline, with well-developed laminations and angular crystal shapes, to microcrystalline, nodular, and mottled white to medium-gray. Deposits are commonly highly weathered, and often crop out as stiff, punky gypsiferous muds and fine sands. Both preserved and weathered outcrops are typically massive. Individual gypsum breccia blocks may exhibit internally subparallel laminations, but lamination attitudes between blocks rarely parallel each other. Fresh gypsum is white to medium-gray; weathered gypsiferous residuum colors were measured to be 7.5YR 8/2–9/2 (pinkish-white), while clayey gypsum colors were measured to be 10R 4/6 to 7/6–7/8. The base of the unit is not exposed on the quadrangle; well data along cross-section A–A' suggest an overall thickness, including each of subsurface units Ps, Pcu, Pcm, and Pcl, of about 590–850 m for this interval, thickening eastward.

Map Unit	Unit Name	Age	Description
Ps	Salado Formation, undivided	Ochoan (Upper Permian)	Cross-sections only. Consists of variably brecciated and/or karst-impacted halite/rock salt, anhydrite/gypsum, potassium salts, and lesser fine-grained clastic rocks and carbonates. Regionally, Jones et al. (1973) describe a dissolution front impacting the Salado from above and up-dip (to the west) and thinning the formation from east to west. Above the dissolution front, rock salt is preferentially removed, and the unit consists mainly of clay, shattered gypsum, and fine-grained sandstone breccia (Jones et al., 1973). Geophysical log interpretations suggest this breccia dominates the western extent of cross-section A–A', while more intact Salado may be present in the eastern extent at depth. Carbonates (magnesite?) and red siltstone occurs in some sample logs near the base of the unit that may belong to the Fletcher Anhydrite and La Huerta Silt Members of Lang (1942; see also Adams, 1944). Surface structures in the Rustler Formation are interpreted to be the result of localized karstification of the Salado, as depicted illustratively in cross-section A–A'. Well data along A–A' indicate an eastward thickening of the Salado from about 115–310 m; however, the location of the basal contact in the available well data is imprecise.
Pc	Castile Formation	Ochoan (Upper Permian)	Consists of commonly laminated, variably calcareous anhydrite/gypsum with subordinate halite/rock salt and minor carbonates and clastic rocks. Generally separable into informal upper, middle, and lower members based on the presence of a medial halite-enriched zone (cf., Jones et al., 1973). Isopach maps by Bachman (1980) suggest an overall thickness beneath the quadrangle of about 445–585 m, generally thickening south-southeastward.

Map Unit	Unit Name	Age	Description
Pcu	Upper anhydrite-dominated subunit of the Castile Formation	Ochoan (Upper Permian)	Cross-sections only. Upper anhydrite- and/or gypsum-dominated interval, consisting of anhydrite interlaminated with calcareous anhydrite and calcitic limestone, with lesser massive anhydrite, rock salt, and carbonates (Jones et al., 1973). Gypsum replaces anhydrite where the unit is closer to the surface (within about 150 m [500 ft] depth: Adams, 1944). Well data along cross-section A–A' suggest unit is about 285 to as much as 360 m thick.
Pcm	Middle halite-rich subunit of the Castile Formation	Ochoan (Upper Permian)	Unexaggerated cross-section only. Middle halite-enriched interval, consisting of halite/rock salt with interbedded and interlaminated anhydrite and limestone (Jones et al., 1973). Jones et al. (1973) report that rock salt dominates this interval, although sample logs from wells along cross-section A–A' are equivocal, and in some places, anhydrite may dominate. Well data along cross-section A–A' suggests the unit is about 110–180 m thick.
Pcl	Lower anhydrite-dominated subunit of the Castile Formation	Ochoan (Upper Permian)	Unexaggerated cross-section only. Lower anhydrite-dominated interval, consisting of generally well-laminated anhydrite, calcareous anhydrite, and lesser carbonate beds (Jones et al., 1973). Well data along cross-section A–A' suggests unit is about 50–70 m thick.

Map Unit	Unit Name	Age	Description
	Guadalupian Series		
Pdm	Delaware Mountain Group, undivided	Guadalupian (Upper Permian)	Unexaggerated cross-section only. Dominantly arkosic to subarkosic, very fine- to fine-grained sandstones and siltstones, with lesser detrital carbonates. For cross-section A–A', the top of the unit is identified as the top of the Lamar Limestone Member in geophysical and sample logs, and includes each of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations and their constituent members. Thickness measurements for the individual formations by King (1948) suggest an overall thickness of about 980–1,200 m in the vicinity of the Guadalupe Mountains. Well data acquired from driller's reports suggest the unit beneath the quadrangle is about 1,060–1,240 m thick.

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