GEOLOGIC MAP OF THE

RAYO HILLS 7.5-MINUTE QUADRANGLE,

SOCORRO AND TORRANCE COUNTIES, NEW MEXICO

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September 2022

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 300

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement G21AC10770 and the New Mexico Bureau of Geology and Mineral Resources.

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GEOLOGIC AND GEOGRAPHIC SETTING

The Rayo Hills 7.5-minute quadrangle is located in central New Mexico east of the Los Pinos Mountains, approximately 6 km south of U.S. Highway 60. The map area includes the headwaters of Cañada Montosa, a tributary of Abo Arroyo which drains to the Rio Grande 31 km to the northwest, and Rancho Viejo and Sand Draw, ephemeral streams that terminate in the internally drained Jornada del Muerto basin some 60 km to the south. The Rayo Hills and westernmost portion of Chupadera Mesa are found in the southeast part of the quadrangle.

No perennial water bodies are found in the map area and ephemeral flow is prone to infiltration into poorly consolidated valley-floor deposits as evidenced by the lack of well-incised channels in most places. Pelon Canyon, Montosa Canyon, and Cañada Montosa in the northwest corner of the map area are exceptions, with well-defined, gravelly channels formed during a more recent incision episode that has not yet reached the headwaters of Red Tanks Canyon.

The Rayo Hills quadrangle was previously mapped at 1:63,360 by Wilpolt et al. (1946) and 1:125,000 by Bates et al. (1947). These authors emphasized the Permian section and prominent Oligocene dikes; the current effort refines these contacts (including the Los Vallos Formation of the upper Yeso Group), identifies previously unmapped structures, and delineates Quaternary surficial units in the map area. Surrounding quadrangles mapped at 1:24,000 include Abo (Oviatt, 2010), Becker (Luther et al., 2005), Cerro Montoso (Allen et al., 2014), and Scholle (Scott et al., 2005).

The oldest rocks exposed in the quadrangle are limestones and mixed siliciclastic sediments of the Bursum Formation (Upper Virgilian to Lower Wolfcampian). These are poorly exposed but appear to be lithologically similar to beds described in adjacent quadrangles (Luther et al., 2005; Allen et al., 2014). Limestones were deposited in low-energy, open marine or shallow shelf environments while siliciclastics were deposited on a coastal plain (Krainer and Lucas, 2009). Terrigenous sediments were derived from rejuvenated orogenic uplift in central and northern New Mexico (Kues and Gile, 2004; Krainer and Lucas, 2013; Lucas et al., 2013a). About 60 m of Bursum Formation are found in the northwest corner of the map area.

The Abo Formation (Middle to Upper Wolfcampian) lies disconformably above the Bursum. The northwest corner of the quadrangle is approximately 8 km southwest of the Abo type section at Abo Pass (Needham and Bates, 1943) and the Abo Formation here is lithologically similar, consisting of dark red to maroon sandstone and siltstone ranging from massive to low-angle planar cross-stratified. Mudstones prominent at the type section are not well-exposed in the map area but probably underlie slopes between ledgy exposures of more resistant lithologies. Abo deposition occurred on alluvial plains formed by south-flowing rivers in a tropical climate (Kues and Giles, 2004). It attains a maximum thickness of approximately 235 m in the map area.

Lying conformably on the Abo Formation is the Meseta Blanca Formation of the Yeso Group (Leonardian). The Meseta Blanca, also called the Arroyo Alamillo Formation (Lucas et al., 2005), comprises whitish to buff or pinkish tan, commonly cross-stratified siltstones and sandstones inferred to represent fluvially reworked eolian sediments deposited on an arid coastal plain during an interval of low sea level (Baars, 1974; Mack and Suguio, 1991; Stanesco, 1991; Mack and Dinterman, 2002; Lucas and Krainer, 2012). Commonly mantled by thin alluvial or eolian-sheetflood deposits, the Meseta Blanca is up to 97 m thick.

The Los Vallos Formation lies above the Meseta Blanca and comprises, in ascending stratigraphic order, the Torres, Cañas, and Joyita members. The Torres is a lithologically diverse unit consisting of mixed siliciclastic and marine sediments. At least four cycles of mudstone/siltstone-sandstone-dolostone are present, with the latter forming laterally continuous marker beds up to kilometers long. Intervals of gypsum in the Torres commonly exhibit highly contorted textures with intraformational sinkholes evident in places. Depositional environments include coastal plains, mud flats, sabkhas, and shallow-shelf marine settings (Baars, 1962; Lucas et al., 2013b). Fossil-poor and occasionally gypsiferous dolostones indicate deposition under restricted marine conditions. Oligocene dikes and sills, discussed below, have preferentially intruded weakly resistant strata in the Torres Member. The Torres Member is up to approximately 170 m thick in the quadrangle.

The Cañas Member of the Los Vallos Formation is dominated by massive to nodular or laminated (sometimes enterolithic) gypsum (Fig. 1) with minor, thin beds of dolostone, siltstone, and mudstone deposited in a hypersaline lagoonal environment (Hunter and Ingersoll,

Figure 1. Laminated to enterolithic gypsum of the Cañas Member of the Los Vallos Formation of the Yeso Group. These deposits formed in restricted lagoonal or sabkha environments on an arid coastal plain. Thick intervals of weakly resistant gypsum have facilitated pervasive sinkhole development in the Los Vallos Formation. The juniper above the outcrop is approximately 3.75 m tall. 13S 373134mE 3794117mN NAD83.

1981). It usually forms slopes between benches or ridges of the Joyita Member and carbonates capping the Torres Member. The Cañas is 30–55 m thick.

The Joyita Member comprises siliciclastic beds formed by eolian and fluvial processes. Reddish to reddish yellow siltstones and sandstones were deposited on a large eolian sand sheet that prograded southward during a time of low sea level (Mack and Dinterman, 2002; Lucas et al., 2013b). Abundant gypsum blades and nodules suggest reworking of the Cañas Member. The Joyita is no more than about 12 m thick but is readily distinguished from the overlying Glorieta Sandstone by its dominantly reddish color, presence of gypsum flakes, and litharenitic sandstones.

The Glorieta Sandstone (Leonardian) forms bold cliffs and ledges and conformably overlies the Joyita Member of the Yeso with a gradational zone comprised of sandstone and mudstone approximately 1.5–3 m thick (Fig. 2). The Glorieta is dominated by very fine- to fine- or, less commonly, medium-grained quartz arenites that range from massive to low-angle or trough cross-bedded. Cross-stratification, relative lithologic homogeneity, and the scarcity of fossils in the Glorieta have resulted in competing interpretations of its depositional environment from shallow marine to eolian (e.g., Baars, 1961, 1962, 2000; Kelley, 1971; Milner, 1978; Mack and Dinterman, 2002; Mack and Bauer, 2014). Lucas and others (2013c) suggest that Glorieta sands were initially deposited by eolian processes, either in coastal dunes or on nearshore bars and shoals, and subsequently reworked during sea level rise. The Glorieta reaches a thickness of 70 m.

The San Andres Formation (Upper Leonardian) lies disconformably on the Glorieta Sandstone. The lower part, generally 25–40 m thick, consists of gypsum with one or two dolostone and at least two sandstone marker beds; the sandstones are similar to the Glorieta Sandstone and have been interpreted as tongues of the Glorieta derived from dune fields and shallow marine nearshore

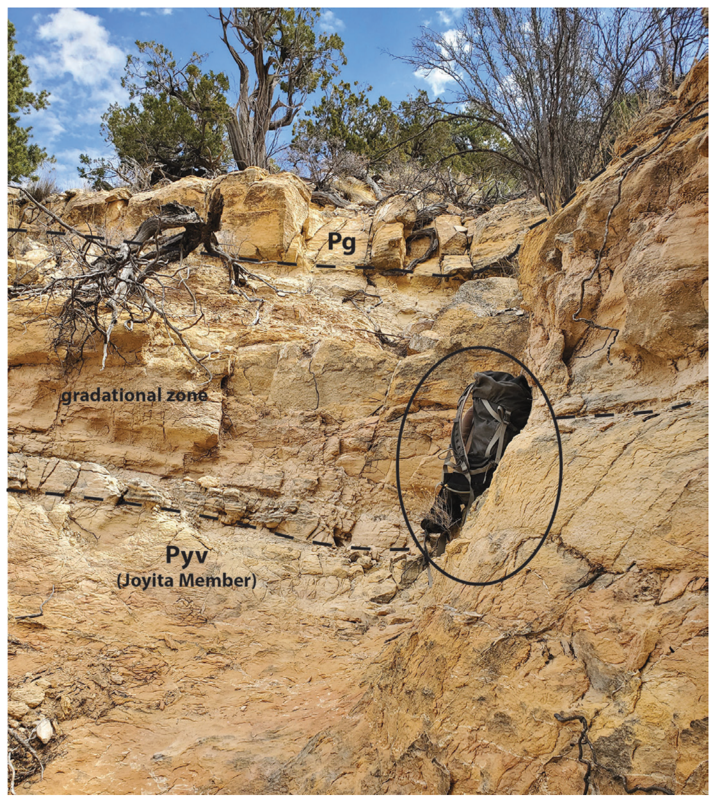

Figure 2. Conformable contact between the Glorieta Sandstone (Pg) and Joyita Member of the Los Vallos Formation of the Yeso Group (Pyv). The contact is gradational over 1.5–3 m. Sandstones in the upper Los Vallos Formation typically contain a greater proportion of lithic grains and are more poorly cemented than the Glorieta Sandstone. Elsewhere, the contact occurs at a thin interval of interbedded sandstone, mudstone, and shale. Note backpack (black circle) for scale. 13S 373151mE 3794069mN NAD83.

environments during brief episodes of sea level fall (Krainer et al., 2012). Above this interval is a sequence of limestone and dolostone capping ridges and plateaus of the Rayo Hills and Chupadera Mesa. San Andres carbonates formed in an offshore, normal marine setting (Krainer et al., 2012; Brose et al., 2013). High surfaces underlain by the San Andres are erosional and nowhere on the quadrangle is the entire formation exposed. The San Andres is 45–50 m thick in the map area.

No strata of Mesozoic through Eocene age are exposed on the quadrangle. The map area lay just east of the Laramide Montosa uplift (Cather, 1992) in an area of weakly positive topography that was sufficiently high and long-lived to prevent deposition of Cretaceous (Campanian) to Eocene sediments.

Dikes up to 170 m wide intrude Permian rocks throughout the southern and eastern quadrangle and several sills are observed within beds of the Torres Member of the Los Vallos Formation. Geochemical results indicate that these are monzonitic (Table 1). They vary from fine-grained and aphanitic to phaneritic with phenocrysts of hornblende, plagioclase, and altered pyroxene and biotite.

At least two different orientations, NE-SW and ENE-WSW, are observed among the dikes but cross-cutting relationships are difficult to determine because late Quaternary erosion has been focused in locations where these features intersect. However, one dike south of the Rayo Hills clearly transitions from NE-SW to ENE-WSW and we speculate that all are of similar age but with orientations controlled, at least in part, by the spatial distribution of weak versus competent strata within the Yeso Group.

Dikes are particularly prominent in the Torres Member, although they are also observed intruding the Cañas and Joyita members as well as the Meseta Blanca Formation approximately 5 km southwest of the quadrangle (Wilpolt and Wanek, 1951). Dikes are not observed to propagate upward into the Glorieta Sandstone, but a large sill is present at the base of the unit to the east and southeast (Wilpolt et al., 1946). Aldrich and others (1986) obtained a K-Ar age of 30.0 ± 0.2 Ma from an ENE-WSW dike in the Chupadera quadrangle to the east. Chamberlin and others (2002) noted west-to-east flow fabrics in similar dikes to the south (e.g., Jones Camp dike) and interpreted their origin as a dike swarm emanating from the Socorro-Magdalena caldera cluster approximately 55 km southwest of the map area.

The sill-like nature of certain intrusions is exemplified by U-Butte in the southwest part of the quadrangle. The contact between the monzonitic rock and siltstone of the Torres Member can be traced around the entire outcrop. It is therefore possible that some or many of the "dikes" in the quadrangle are actually large sills confined to the upper Yeso Group (see Cather, 2009, fig. 7).

A variety of Quaternary units are found in the Rayo Hills quadrangle. These are broadly categorized into hillslope/mass-movement, alluvial, and eolian deposits, and gradational relationships are recognized between many units transitioning from hillslope to valley-floor settings. Lithologies generally vary according to transport capacity, with eolian and sheetflood deposits consisting of very fine to fine sand and silt-clay with rare to occasional pebble lags at the surfaces. Alluvial and hillslope deposits are coarser grained—very fine to coarse sands and pebble-cobble gravels—with the exception of the younger alluvium deposit described below.

Hillslope deposits include debris flows, landslides, and colluvium and talus found in the hilly topography of the eastern map area. No geochronological data is available for these deposits but they are presumed to be middle or late Pleistocene to Holocene in age based on laterally gradational relationships with alluvial-fan and valley-floor deposits. Hillslope deposits are primarily mapped where they obscure contacts between Permian bedrock units.

Alluvial units include valley-fill and alluvial-fan sediment. A carbonate-cemented gravel is found near Chupadera Gap and similar deposits feature Stage IV carbonate accumulation at their surface to the west. These are thought to be middle or late Pleistocene in age based on soil development and landscape position. Alternatively, the carbonate-cemented may be buried by more poorly consolidated gravel and is perhaps related to an erosional surface lying 55–60 m above modern grade in the southeast part of the quadrangle.

Younger valley fill in the upper Sand Draw and Red Tanks Canyon (Cañada Montosa) drainages returned radiocarbon ages of 3800 to 1470 cal yr BP (Table 2). These deposits feature several buried stage I or II horizons but surface soils are generally eroded. A historical alluvial-fan deposit prograding onto the younger alluvium unit north of Chupadera Gap returned a radiocarbon age of about 140 cal yr BP.

Multiple Pleistocene to Holocene and recent cycles of incision are recognized in Abo Arroyo, a Rio Grande tributary and the terminus for all drainages in the northern part of the quadrangle (Hall et al., 2009; Love and Rinehart, 2016; Rinehart and Love, 2016). At least two to three cycles of incision are evident in the map area in the headwaters of Red Tanks Canyon, Sand Draw, and Rancho Viejo Arroyo. Radiocarbon ages indicate that these episodes took place in the late Holocene after about 3300, 1450, and 150 cal yr BP. Valley fill in drainages integrated to the Rio Grande returned younger radiocarbon ages, 2250–1600 cal yr BP, than deposits in the internally drained upper Sand Draw basin dated at 3800–3350 cal yr BP, despite samples collected from similar positions below deposit surfaces. The discordance in ages could reflect greater responsiveness to regional sedimentation-incision cycles in the upper Cañada Montosa watershed. The older ages of the Sand Draw deposits broadly correspond to a wet and cold interval inferred from pluvial lake records in southern New Mexico and glacial evidence in the southern Rocky Mountains (Armour et al., 2002; Castiglia and Fawcett, 2006). Sediment of a similar age may be buried by the younger Red Tanks Canyon alluvium.

In most places downstream of headwater locations, drainages are poorly channelized with a significant component of eolian sediment capping historical deposits. Outside of these shallow channels are broad sheets and occasional dune ridges of eolian sand found throughout the western and northern parts of the quadrangle. Sheetflood deposits near the base of slopes in these areas typically consist of reworked eolian sand. Charcoal from beneath a buried Stage II horizon in eolian sand near the center of the map area was dated at 1950 cal yr BP (Table 2).

The dominant structures in the quadrangle are a series of NE-SW folds with some anticlines cored by dikes intruding the upper Yeso Group (Fig. 3). Larger, km-scale folds are typically upright, gentle to open, and symmetric with a subset of folds that are gently plunging. Smaller folds, ranging from sub-km to outcrop-scale, exhibit a wider range of geometries though most are open and upright to slightly inclined.

The origin of large anticlines in the map area appears to be related to Oligocene dike intrusion based on spatial coincidence between the two (Bates et al., 1946, p. 40; Cather, 2009). Chaotic folding occurs in the Torres Member south of U-Butte between two intrusions

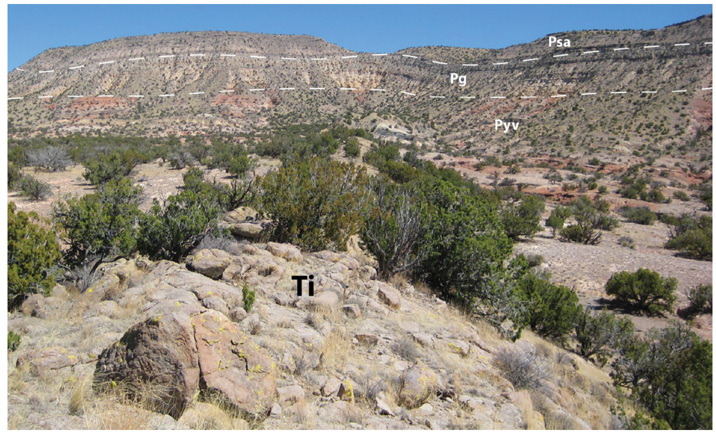

Figure 3. Permian stratigraphy and an Oligocene dike on the south side of the Rayo Hills. The monzonitic dike (Ti) intrudes and warps the Los Vallos Formation of the Yeso Group (Pyv) but does not breach its upper contact with the Glorieta Sandstone (Pg). Instead, a gentle anticline has formed over the dike in the Glorieta and overlying San Andres Formation (Psa) that can be traced for at least 4 km to the northeast. View is toward the north. Photo taken from atop the dike at approximately 13S 366975mE 3792700mN NAD83.

approximately 0.6 km apart. Elsewhere, small or outcrop-scale folds are probably the result of dissolution in gypsum of the upper Yeso Group. The origin of a NE-SW trending syncline in the Abo Formation, counter to most structural grains observed in the quadrangle and vicinity, is uncertain.

There are few exposed faults in the Rayo Hills quadrangle, but several are observed cutting strata of the Yeso Group, Glorieta Sandstone, and/or San Andres Formation, or are inferred from well logs. Stratigraphic throw on these faults is less than 100 m and commonly less than 50 m. One fault in the eastern map area is interpreted as a low-angle normal fault possibly offsetting the core of a syncline. Low-angle faults are common in the Permian section 20–25 km southwest of the quadrangle and interpreted as part of a large, top-east regional detachment system (Cather, 2009). However, the low-angle structure in the map area is top-northwest and more likely the result of gypsum dissolution and collapse in the upper Yeso Group, as are most other local faults given their low stratigraphic offset, short length, and poor and/or discontinuous surface expression.

Groundwater flow in the map area is generally northwest to southeast based on well data and derived largely from aquifers in confined sandstones of the Abo and Meseta Blanca Formations or, less commonly, the Torres Member of the Los Vallos Formation. Recharge occurs on the east side of the Los Pinos Mountains several kilometers west of the quadrangle; few if any wells drilled in the map area since the 1980s have encountered artesian conditions.

Yield is typically low, reaching only 20–40 gallons per minute in sandstones of the Abo and Meseta Blanca formations. Water quality data from the quadrangle is limited but total dissolved solids range from 525 to 3,800 mg/L (Spiegel, 1955). Saline groundwater observed in the Abo and Meseta Blanca aquifers is likely due to seepage from gypsiferous intervals of the overlying Los Vallos Formation and perhaps also slow rates of lateral flow.

METHODS

Geologic mapping of the Rayo Hills quadrangle consisted of traditional field techniques (Compton, 1985) coupled with newer digital approaches. Stereogrammetry software (Stereo Analyst for ArcGIS®, version 16.6.0) permitted accurate placement of geologic contacts using aerial photography obtained from the National Agricultural Imagery Program (NAIP). Planimetric and vertical accuracy of this dataset is approximately 5 m (USDA, 2008).

Descriptions of individual units were made in the field utilizing both visual and quantitative estimates based on outcrop and hand lens inspection. For clastic sediments, grain sizes follow the Udden-Wentworth scale and the term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter (Udden, 1914; Wentworth, 1922). Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to Munsell soil color charts (Munsell Color, 2009).

Surface characteristics and relative landscape position were used in mapping middle Pleistocene to Holocene units, i.e. hillslope, alluvial-fan, and valley-floor deposits. Surface characteristics dependent on age include desert pavement development, clast varnish, soil development, and preservation of original bar-and-swale topography. Soil horizon designations and descriptive terms follow those of Birkeland and others (1991), Birkeland (1999), and Soil Survey Staff (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile and others (1966) and Birkeland (1999).

ACKNOWLEDGMENTS

Mapping of the Rayo Hills quadrangle was funded by the STATEMAP program, which is jointly supported by the U.S. Geological Survey and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR). We thank Dr. J. Michael Timmons of NMBGMR for logistical support and coordination. Cartography was provided by the NMBGMR map production group, coordinated by Phil Miller. We are grateful to Mr. Ernest Thompson and Mr. James Broome for access to their properties.

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Table 1—Major-element geochemistry of intrusive rocks in the Rayo Hills 7.5-minute quadrangle.

Sample #	UTM N[a]	UTM E[a]	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SO_3	SiO_2	TiO_2	Total	LOI 1000[b]
22RH-093A	3796214	363079	16.78	4.5	6.69	1.64	3.4	0.07	6.84	0.55	0.03	55.24	1	99.14	2.1
22RH-093B	3796214	363079	17.44	3.95	6.81	1.99	3.24	0.06	6.7	0.65	0.02	55.7	1.1	99.6	1.64

NOTE: All values given in wt %.

[a]Coordinates given in UTM Zone 13S, NAD83.

[b]LOI = loss on ignition.

Table 2—Summary radiocarbon geochronology for Holocene deposits in the Rayo Hills 7.5-minute quadrangle.

Sample #	Lab #[a]	Deposit	Material Dated	UTM N[b]	UTM E[b]	Conventional Age (^{14}C yr BP_{1950})[c]	2σ Calibrated Age Range (cal yr BP_{1950})[d]	Median Age (cal yr BP_{1950})[e]	$\delta^{13}C$ (‰)
22RH-231A	Beta-626858	Qay	charcoal	3793906	371907	3530 ± 30	3894–3714 (0.940) 3708–3699 (0.014)	3800 ± 100	-20.9
22RH-231B	Beta-626859	do.	charcoal	3793906	371907	3140 ± 30	3447–3327 (0.792) 3295–3254 (0.162)	3350 ± 100	-20.8
22RH-520	Beta-626861	Qfh	charcoal	3797629	370482	160 ± 30	286–242 (0.167) 231–164 (0.316) 158–131 (0.098) 118–58 (0.179) 44–0 (0.194)[f]	140 ± 140	-21.4
22RH-521A	Beta-626862	Qay	charcoal	3797726	370311	2250 ± 30	2341–2296 (0.306) 2264–2153 (0.648)	2250 ± 90	-20.3
22RH-521B	Beta-626863	do.	charcoal	3797726	370311	1600 ± 30	1534–1405 (0.954)	1470 ± 60	-21.0
22RH-522	Beta-626864	Qe	charcoal	3799464	367635	2020 ± 30	2047–2020 (0.053) 2007–1872 (0.895) 1848–1844 (0.005)	1950 ± 100	-11.1

[a]All samples dated by AMS analysis, Beta Analytic Inc., Miami, FL.

[b]Coordinates given in UTM Zone 13S, NAD83.

[c]Conservative error of ± 30 ^{14}C yr BP_{1950} is given for all samples due to 1σ < 30 ^{14}C yr BP_{1950} in each case.

[d]2σ calibrated age ranges calculated as relative probability using Bayesian methodology of Ramsey (2009) and IntCal20 calibration curve of Reimer et al. (2020).

[e]Median age reported by averaging entire age range and rounding to nearest 10 yr. Error is difference between median and end values of range.

[f]33-0 cal yr BP range implies possibility of post-1950 age (including modern) indicating the influence of ^{14}C from above-ground nuclear weapons testing.

APPENDIX A

Detailed descriptions of lithologic units on the
Rayo Hills 7.5-minute quadrangle

QUATERNARY

Anthropogenic Units

daf Disturbed land and anthropogenic fill (Recent, <100 years old) – Sand and gravel that has been moved by humans to form berms and dams or has been reworked/remobilized for construction purposes.

Eolian, Hillslope, and Debris-Flow Units

Qe Eolian sand (Holocene) – Loose to weakly consolidated, thin- to medium-bedded sand underlying broad sheets and dune ridges. Exposed in rare blowouts up to 0.35 m deep and sometimes forming transverse to slightly barchanoid ridges. Sand consists of light to strong brown or reddish yellow (7.5YR 5-6/4-6) or yellowish red (5YR 5/6), internally massive to low-angle planar or ripple cross-laminated, moderately well to well-sorted, subangular to rounded, vfU-fU grains composed of 90–95% quartz and gypsum, 3–5% orange feldspar, and 1–3% lithics (mostly carbonate). Deposit features at least one buried Bw or Bwk horizon up to 0.2 cm thick. A charcoal sample from near the base of one deposit returned a conventional radiocarbon age of 2020±30 14C yr BP. Maximum thickness is at least 1.2 m but variable based on location relative to lee-side topography.

Qea Eolian and alluvial deposits, undivided (Holocene) – Loose silt to medium-grained sand that fills shallow, generally unincised drainageways. Deposit consists primarily of eolian sediment reworked by alluvial processes. 0.5–3.0 m thick.

Qes Eolian and sheetflood deposits, undivided (Holocene) – Loose to weakly consolidated silty sand and subordinate silt-clay in massive to medium (>12 cm), tabular beds underlying sheets and gently incised surfaces of low to moderate slope. Sand consists of strong brown (7.5YR 4/6), internally massive, well-sorted, vfL-fL grains with 3–5% rounded to well-rounded mL-mU grains composed mostly of quartz (>90%) and trace subangular to rounded granules and fine pebbles of carbonate and sandstone. Silt-clay is yellowish red (5YR 5/6) to strong brown (7.5YR 5/6), vaguely laminated (≤0.8 cm), and contains 2–5% floating grains of subangular, fU-mL sand composed of carbonate or dark lithics. Deposit is bioturbated by very fine to coarse roots and medium burrows, including krotovina of sandy material up to 3 cm across. Occasional discontinuous channels incised into the unit typically disappear downstream into low-gradient swales and valley floors. Locally, weak topsoil development is characterized by very fine carbonate coatings indicating stage I carbonate accumulation. Total thickness is at least 1.0–1.5 m.

Qse Sheetflood deposits reworked from eolian sand sheets (Holocene) – Loose to weakly consolidated sand and sandy silt in massive to medium (15–20 cm), tabular to wedge-shaped beds underlying low to moderate slopes that are commonly rilled or gullied. Sand consists of brown (7.5YR 4/3-4) to strong brown (7.5YR 4-5/6), crudely horizontal-planar laminated, poorly to moderately well-sorted, subangular to rounded, vfL-fU grains (trace medium grains) composed mostly of quartz. The surface of the deposit features rare to occasional stringers of poorly to moderately sorted, subangular to subrounded (occasionally rounded) pebbles consisting of local lithologies. The base of the deposit may be marked by a thin pebble gravel where it overlies unit Qay. Commonly bioturbated by very fine to very coarse roots and/or burrows. Rare to occasional disseminated gypsum is found near areas of Yeso Group exposure. Topsoil development is characterized by: (A) dark brown (7.5YR 3/3-4), non-calcareous, sandy to silty A horizons that are 10–40 cm thick; or (B) carbonate filaments indicating stage I carbonate accumulation in the upper 30-35 cm of the deposit. Deposit is 0.5–1.0 m thick in upland areas to perhaps 2.5 m thick near the margins of shallow valleys.

Qesa Eolian and subordinate sheetflood and alluvial deposits, undivided (Holocene) – Loose eolian silt to fine-grained sand that has been reworked by alluvial processes in places. See unit descriptions for Qe, Qes, Qea, and Qse.

Qsea Sheetflood and subordinate eolian and alluvial deposits, undivided (Holocene) – Loose, silty sand on low to moderate slopes that are more commonly incised than those underlain by unit Qesa. Nearly all eolian sand has been reworked by alluvial processes. See unit descriptions for Qe, Qes, Qea, and Qse.

Qsc Sheetflood and colluvial deposits, undivided (Upper? Pleistocene to Holocene) – Loose to weakly consolidated, silty sand and pebble (rare cobble) gravel underlying moderate slopes at the base of bedrock uplands. See unit descriptions for Qse and Qct.

Qct Colluvium and talus, undivided (Upper? Pleistocene to Holocene) – Loose, poorly sorted, angular to subrounded cobble-boulder gravel forming aprons or mantles at the footslopes of bedrock uplands. <5 m thick.

Qls Landslide deposits (Upper Pleistocene to Holocene) – Weakly consolidated gravel in massive to poorly defined thick or very thick, wedge-shaped beds. Gravel is mostly matrix-supported, internally massive to chaotically bedded and/or slope-parallel, very poorly sorted, angular to subangular clasts and consists of 40–70% pebbles, 30–40% cobbles, and 5–20% boulders primarily derived from the Glorieta Sandstone or San Andres Formation. Matrix sand consists of brownish yellow to yellow (10YR 6/6-8, 7/6), non-calcareous, very poorly to poorly sorted, angular to subrounded, vfU-mU grains (5–10% cL sand to granules) composed of subequal proportions of quartz and lithics (sandstone, siltstone, and carbonate) and up to 5% orange feldspar. Locally features a surface soil with stage II carbonate accumulation (clast coatings) that is poorly exposed but presumed to occur in the upper 1.0–1.5 m of the deposit. At least 4.0 m thick.

Qdy Younger debris-flow deposits (Holocene) – Loose to weakly consolidated, reverse-graded, silty to pebbly sand and pebble-cobble gravel in massive or thick, tabular to broadly lenticular beds. Sand consists of strong brown to reddish yellow (7.5YR 5-6/6-8), weakly calcareous, moderately sorted, subangular to rounded, vfL-mL grains composed of 85–90% quartz, 5–10% lithics (dark mafics or FeOx flakes derived from the Glorieta Sandstone and subordinate sandstone and carbonate), and up to 5% feldspar. Gravel is internally massive to weakly or moderately imbricated, poorly to moderately sorted, angular to rounded, and consists of 60–90% pebbles, 10–30% cobbles, and 0–10% boulders of Glorieta Sandstone, FeOx concretions derived from the Glorieta, and San Andres limestone/dolostone. Gravel matrix is similar to sandy beds. Stage II carbonate accumulation (clast coatings) is observed in the upper 0.4–0.6 m of the deposit. Maximum thickness 8.5 m.

Qdyr Younger and recent debris-flow deposits, undivided (Holocene) – Younger (Qdy) and subordinate recent (modern + historical) debris-flow deposits. The following description is for recent debris-flow deposits that are not mapped separately in the quadrangle: loose to moderately consolidated gravel in massive or medium to thick (15–35 cm), lobate to snout- or fan-shaped beds. Gravel is open-framework to matrix-supported, internally massive to imbricated, very poorly to poorly sorted, mostly angular to subrounded, and consists of 45–95% pebbles, 5–45% cobbles, and 0–25% boulders of sandstone, siltstone, and carbonate. Open-framework texture is more common in modern deposits. Matrix consists of brown (7.5YR 5/4) to strong brown or reddish yellow (7.5YR 5/6-8, 6/8) to yellowish brown (10YR 5/4), very poorly to poorly sorted, angular to rounded silt to cL sand composed of 60–80% quartz, 10–30% lithics (carbonate, sandstone, siltstone, and minor dark mafics or FeOx flakes derived from the Glorieta Sandstone), and 5–10% orange feldspar. Historical deposits (~50 to ~200 years old) may feature an upper sandy gravel comprised of loose pebbles, cobbles, and boulders in massive to medium, lobate to broadly lenticular beds. Gravel in this bed are clast- to matrix-supported and internally massive to moderately imbricated. Clasts consist of 60–80% pebbles, 10–25% cobbles, and 10–15% boulders of sandstone, carbonate, and siltstone. The upper gravel matrix consists of brown to strong brown (7.5YR 4/4-6), moderately calcareous, very poorly to poorly sorted, subangular to subrounded, fL-vcL sand of similar composition to the lower gravel matrix but with common fine, disseminated charcoal fragments. No topsoil preserved on recent deposits, which form bar-and-swale topography of 0.4 (historical) to 2.0 m (modern) and are frequently capped by open-framework boulder trains. At least 1.4–2.0 m thick.

Qdo Older debris-flow deposits (Middle? to upper Pleistocene) – Very weakly consolidated gravel in massive, wedge-shaped beds. Gravel are clast- to matrix-supported, internally massive to vaguely imbricated, very poorly to poorly sorted, angular to subrounded (minor rounded), and consist of 45–60% pebbles, 25–30% cobbles, and 10–30% boulders of San Andres Formation carbonate and Glorieta Sandstone. Bedding is indistinct and clast-supported texture is more common than matrix-supported. Matrix consists of brown to light brown (7.5YR 5-6/4), strongly calcareous, poorly sorted, subangular to rounded, silt to mL sand (<5% mU sand). Where discernible, sand grain lithologies include at least 95% quartz with the remainder composed of sandstone, carbonate, feldspar, and micas. Deposit surface does not commonly feature notable bar-and-swale topography. At least 2.0–5.0 m thick.

Qdoy Older and younger debris-flow deposits, undivided (Middle? Pleistocene to Holocene) – Older (Qdo) and subordinate younger (Qdy) debris-flow deposits. See detailed descriptions of each individual unit.

Qdfy Younger debris-flow and alluvial-fan deposits, undivided (Holocene) – Unit mapped where younger debris-flow (Qdy) and alluvial-fan (Qfy) deposits are highly gradational. See detailed descriptions of each individual unit.

Valley-Floor Units

Qam Modern alluvium (Modern to ~50 years old) – Loose sand and sandy gravel forming longitudinal bars and underlying channels in modern, ephemeral stream courses. Gravel are very poorly to moderately sorted, subangular to well-rounded, and consist of 55–90% pebbles, 10–35% cobbles, and 0–10% boulders of local lithologies. Sand consists of light brown (7.5YR 6/4) to light yellowish brown (10YR 6/4), very poorly to poorly sorted, subangular to well-rounded, fL-cL (trace to 3% very coarse) grains composed of 80–85% quartz, 10–15% lithics, and 5–10% feldspar. Surface characterized by bar-and-swale topography exhibiting up to 0.5 m of relief. Maximum thickness 2.0–2.5 m.

Qah Historical alluvium (~50 to ~200 years old) – Loose, sandy gravel in thick (0.3–0.9 m), lenticular beds. Gravel are clast-supported, moderately to well-imbricated, very poorly to poorly sorted, subrounded to well-rounded, and consist of 45–65% pebbles, 15–30% cobbles, and 5–25% boulders of local lithologies, primarily carbonates and Glorieta Sandstone. Matrix consists of brown to light brown (7.5YR 5-6/4), weakly calcareous, angular to subrounded, vfL-mU sand composed of 80–85% quartz, 10–15% lithics (sandstone, siltstone, carbonate, and subordinate dark mafics or FeOx flakes derived from the Glorieta Sandstone), and up to 5% feldspar. Gravel occasionally underlies low-angle to horizontal-planar laminated sand that is similar to gravel matrix and is often mantled with eolian and/or sheetflood deposits. Deposit is commonly bioturbated by very fine to very coarse roots and may feature a well-developed A horizon in the upper 0.2 m. Surface characterized by bar-and-swale topography exhibiting up to 0.35 m of relief. Tread height is 0.6–1.6 m above modern grade. At least 0.8–1.6 m thick.

Qar Recent (historical + modern) alluvium (Modern to ~200 years old) – Historical (Qah) and modern alluvium (Qam) in approximately equal proportions. See detailed descriptions of each individual unit.

Qahm Historical and modern alluvium, undivided (Modern to ~200 years old) – Historical (Qah) and subordinate modern (Qam) alluvium. See detailed descriptions of each individual unit.

Qay Younger alluvium (Holocene) – Loose to weakly consolidated, silty to slightly clayey sand in medium to very thick (0.2–1.4 m), tabular to broadly lenticular beds underlying broad surfaces that are occasionally deeply incised throughout the quadrangle. Sand consists of light or strong brown to reddish yellow (7.5YR 6/4-6) to dark yellowish brown (10YR 3/6, 4/4), moderately to strongly calcareous, mostly massive, poorly to moderately well-sorted, subangular to well-rounded, vfL-mL grains (0–5% subangular to rounded mU-cU grains) composed of 75–95% quartz, 5–15% feldspar, and 5–10% lithics (carbonate and sandstone). Sandy beds contain 0–10% matrix-supported (rare clast-supported), poorly to moderately sorted, mostly subangular to subrounded granules to pebbles (rare cobbles) of local lithologies. Less common are beds of weakly consolidated pebble-cobble (rare pebble-cobble-boulder) gravel in thin to very thick (4 cm to 1.2 m), lenticular beds. Gravel are moderately well-imbricated, poorly to moderately sorted, subangular to rounded, and consist of 90–95% pebbles and 5–10% cobbles of local lithologies with matrices similar to sandy intervals. Gypsum and carbonate are preserved within the upper part of the unit and brownish carbonate may be present in the lower 3–5 m south of Rayo Hills. Deposit is commonly bioturbated by very fine to very coarse roots and contains rare to common charcoal fragments. Buried Bw or Bt horizons are indicated by rare to occasional clay argillans on larger grains and prismatic ped structures. Diffuse carbonate coatings in the upper part of the deposit indicate stage I to II carbonate accumulation. Commonly mantled by sheetflood and reworked eolian sediment. Charcoal samples from deposits in the upper Sand Draw and Cañada Montosa watersheds returned conventional radiocarbon ages of 1600±30 to 3530±30 14C yr BP. 3.5–10.0 m thick.

Qayh Younger and historical alluvium, undivided (Holocene) – Younger (Qay) and subordinate historical alluvium (Qah). See detailed descriptions of each individual unit.

Qary Recent (historical + modern) and younger alluvium, undivided (Holocene) – Recent (Qah + Qam) and subordinate younger alluvium (Qay). See detailed descriptions of each individual unit.

Qayr Younger and recent (historical + modern) alluvium, undivided (Holocene) – Younger (Qay) and subordinate recent alluvium (Qah + Qam). See detailed descriptions of each individual unit.

Qao Older gravelly alluvium (Middle to Upper Pleistocene) – Poorly exposed, weakly imbricated pebble-cobble gravel. Clasts consist of 65–95% pebbles and 5–35% cobbles. Matrix consists of strong brown (7.5YR 4-5/6), strongly calcareous, poorly to moderately sorted, subangular to rounded, silty vfL-mL sand (3–5% mU-cL sand) composed of 85–90% quartz, 10–15% lithics (sandstone and dark mafics and/or FeOx flakes derived from the Glorieta Sandstone), and trace to 3% feldspar. Unconsolidated gravel features stage IV carbonate accumulation (K horizon with laminations) at least 0.4 m thick at its surface. A conglomerate in massive to medium or thick, lobate to tabular beds is found in upper Sand Draw. The conglomerate is brown to slightly reddish gray (weathering white to pinkish white), well-indurated, calcite-cemented, matrix-supported, and internally massive. Clasts consist of poorly sorted, subangular to rounded pebbles (90–97%), cobbles (3–10%), and trace small boulders of Glorieta Sandstone (55–65%), carbonate (35–45%), and a few percent intrusive monzonite clasts. The conglomerate matrix consists of very poorly sorted, subrounded to rounded, fU-vcU sand (2–5% granules) composed of 85–95% quartz, 5–15% lithics (sandstone and carbonate), and trace to 3% feldspar. Smaller (fine to medium) sand grains in the matrix exhibit a frosted appearance. Total thickness unknown but at least 4.0–5.0 m.

Alluvial-Fan and Piedmont Units

Qfm Modern fan alluvium (Modern to ~50 years old) – Loose, sandy gravel forming bars and lobes and underlying braided channels. Gravel are clast-supported to open-framework (rare), weakly to moderately well-imbricated, very poorly to poorly sorted, angular to subrounded, and consist of 40–50% pebbles, 45–55% cobbles, and 5–10% boulders of primarily carbonates and sandstone with minor siltstone or sandstone derived from the Joyita Member of the Los Vallos Formation. Matrix consists of brown (7.5YR 5/4) to yellowish brown (10YR 5/4), very poorly to poorly sorted, subangular to rounded, vfU-cL sand (trace to 3% cU sand to granules) composed of 60–80% quartz, 15–30% lithics (carbonate, sandstone, siltstone, and minor dark mafics and/or FeOx flakes derived from the Glorieta Sandstone), and 5–10% orange feldspar. Surface characterized by bar-and-swale topography exhibiting up to 0.4 m of relief. 0.3–2.0 m thick.

Qfh Historical fan alluvium (~50 to ~200 years old) – Loose to weakly consolidated gravel in medium to thick (35–65 cm), wedge-shaped beds. Gravel are clast-supported, internally massive or weakly to moderately imbricated, very poorly sorted, angular to subrounded, and consist of 45–55% pebbles, 40–45% cobbles, and 10–15% boulders. Matrix consists of light brown (7.5YR 6/3-4) to yellowish or light yellowish brown (10YR 5-6/4), moderately calcareous, very poorly to poorly sorted, subangular to subrounded, vfL-cL sand (trace to 12% cU sand to granules) composed of 45–80% quartz, 10–45% lithics (sandstone and dark mafics and/or FeOx flakes derived from the Glorieta Sandstone), and 5–15% orange feldspar with occasional fine, disseminated charcoal. Topsoil features a 0.1–0.2 m thick A horizon where not eroded. Surface characterized by bar-and-swale topography exhibiting up to 0.2 m of relief. A charcoal sample from the upper Cañada Montosa watershed returned a conventional radiocarbon age of 160±30 14C yr BP. Maximum thickness is 3.2 m.

Qfy Younger fan alluvium (Holocene) – Loose to weakly consolidated, silty to pebbly sand and gravel in massive or medium to thick, wedge-shaped to lobate beds. Sand consists of light brown to reddish yellow (7.5YR 6/4-6), strongly calcareous, internally massive, poorly sorted, angular to rounded, vfL-mU grains (trace to 3% cU grains to granules) composed of 80–85% quartz, 10–15% lithics (dark mafics and/or FeOx flakes derived from the Glorieta Sandstone and subordinate sandstone), 5–10% orange feldspar, and 5–10% gypsum. Gravel are internally massive to weakly or moderately imbricated, very poorly to poorly sorted, mostly angular to subrounded, and consist of 55–80% pebbles, 10–30% cobbles, and 10–15% boulders of Glorieta Sandstone, FeOx concretions derived from the Glorieta, and carbonate. Underlying sand may contain stringers of such gravel. Surface soil may contain Bw or Bt horizons up to 0.3 m thick overlying Bk horizons (stage I to II carbonate accumulation) but the latter are typically eroded. Deposit contains rare to occasional charcoal fragments. Surface characterized by bar-and-swale topography exhibiting up to 0.2 m of relief. 3.9–4.4 m thick.

Qfyr Younger and recent (historical + modern) fan alluvium, undivided (Holocene) – Younger and subordinate recent (historical + modern) fan alluvium. See detailed descriptions of Qfh and Qfy. Modern fan alluvium consists of loose, clast-supported to open-framework, sandy pebble-cobble-boulder gravel forming bars and lobes and underlying braided channels.

Qfo Older fan alluvium (Middle? to Upper Pleistocene) – Poorly exposed pebble-cobble and pebble-cobble-boulder gravel in wedge-shaped beds underlying high fan remnants in the Chupadera Gap area. Clasts are nearly all Glorieta Sandstone with minor carbonate. A stage IV calcic soil occurs in the upper 0.75 m of the deposit which is mantled by Qsea. Thickness unknown but probably <5.0–7.0 m.

Qpo Older piedmont alluvium (Middle? to Upper Pleistocene) – Thin pebble-cobble and pebble-cobble-boulder gravel occurring as small remnants or capping low-gradient ridges emanating from the Rayo Hills. Clasts are 40–60% pebbles, 20–45% cobbles, and 10–20% boulders of Glorieta Sandstone and carbonate. Surface soils are commonly eroded. <2.4–3.0 m thick.

TERTIARY

Intrusive Units

Ti Intrusive monzonite (Lower Oligocene) – Medium to whitish or very light gray, weathering to medium or dark gray, non-vesicular, massive, aphanitic to phaneritic monzonite intruding weakly consolidated strata of the Torres Member of the Los Vallos Formation as dikes or sills. Spheroidal weathering is common. Where phaneritic, phenocrysts include 20–30% hornblende (medium to coarse, subhedral to euhedral prisms), 10–15% plagioclase (fine to medium, anhedral to subhedral), trace to 1% biotite (fine, subhedral), and trace quartz (fine to medium, anhedral). Bates et al. (1947) noted the presence of orthoclase, pyroxene, and magnetite in some samples. Hornblende and biotite are commonly altered to greenish or yellowish, powdery secondary minerals. Aphanitic margins contain trace to 1% very fine, equant phenocrysts inferred to be biotite based on their shape and luster, and feature occasional to common splotches of very pale green, grainy alteration minerals forming diffuse boundaries with the groundmass. Some dikes contain occasional xenoliths, up to 7 cm in diameter, of mafic material with subequal plagioclase and pyroxene phenocrysts and rare biotite. Whole-rock geochemistry indicates a monzonitic composition (55.2–55.7 wt% SiO2, 8.3–8.8% Na2O + K2O). Aldrich et al. (1986) obtained a K-Ar age of 30.2±2.0 Ma from a dike of similar composition in the Chupadera 7.5-minute quadrangle to the east. The size of three small exposures in section 4, T01S, R05E has been exaggerated in order to appear at map scale. Dikes may be up to 160 m wide but are more commonly 45–75 m in width.

PALEOZOIC

Psa San Andres Formation (Lower Permian) – Light to medium or brownish gray, thin- to thick-bedded, internally massive to horizontal-planar or ripple-laminated, featureless to vuggy, slightly fossiliferous, and/or bioturbated limestone, dolomitic or gypsiferous limestone, and dolostone. Fossils, (very fine crinoids and shell fragments), bioturbation (bedding plane-parallel burrows up to 4 cm in diameter), oncoids up to 22 cm long and 10 cm in diameter, and trace to occasional disseminated chert occur in the upper 10 m of exposure. Limestone may emit a slightly oily odor when struck. Wackestone, floatstone, and rudstone are recognized from the San Andres Formation (Brose et al., 2013). In the lower part, limestone and dolostone are interbedded with abundant gypsum and minor shale, mudstone, and sandstone. Two distinct gypsum/sandstone sequences are traceable across nearly all exposed outcrops in the southern half of the quadrangle. Gypsum is white to light or medium gray, poorly to moderately indurated, massive to vaguely medium- or thick-bedded, and internally massive to laminated. Abundant blades or nodules of dark-colored, secondary gypsum are observed in some intervals. Gypsum is present in beds or as fracture fill. Sandstones are similar to those of the upper Glorieta Sandstone. Mudstone is grayish purple to reddish brown, very poorly to moderately indurated, non- to strongly calcareous, internally massive, and silty to gypsiferous. The San Andres Formation caps mesas and plateaus with an upper erosional surface (Brose et al., 2013). 45 m thick near Chupadera Gap; Wilpolt et al. (1946) reported a thickness of 50 m from the southwest side of the Rayo Hills.

Pg Glorieta Sandstone (Lower Permian) – White to yellowish white or very pale pinkish, poorly to moderately indurated, strongly calcareous, massive or thin- to thick-bedded, tabular to lenticular, internally massive to horizontal-planar laminated to low-angle planar or tangential cross-stratified, moderately to well-sorted, subangular to rounded, quartzose, vfL-fU sandstone. Up to 5–10% feldspar and lithics (dark mafics and/or FeOx flakes) may be present in some sandstone bodies. Iron oxide stains and concretions up to 20 cm in diameter are occasionally observed in the upper 37 m of the unit. Rare siltstones are gray to dark greenish gray, slightly calcareous, lenticular, and massive. Sandstones are interbedded with thin siltstones and dark purplish gray, non-calcareous, massive to ripple-laminated mudstones in the lower 2 m of the unit, suggesting a gradational contact with the underlying Joyita Member of the Los Vallos Formation. Forms prominent cliffs and ledges below slopes of the lower San Andres Formation. 69 m thick near Chupadera Gap; Wilpolt et al. (1946) reported a thickness of 70 m from the southwest side of the Rayo Hills.

Pyv Los Vallos Formation of the Yeso Group (Lower Permian) – Interstratified limestone, dolostone, gypsum, mudstone, siltstone, and sandstone. The Joyita Member forms the upper approximately 12 m of the unit and consists of interstratified siltstone and sandstone with rare mudstone and neither gypsum nor carbonates present. Mudstones and siltstones are light reddish or reddish-yellow brown to maroon, poorly indurated, non- to slightly calcareous, massive or thin-bedded, internally massive to low-angle planar laminated (rare), and commonly gypsiferous. Sandstones are yellowish white to reddish brown, poorly to moderately well-indurated, non- to strongly calcareous, massive or thin- to thick-bedded, tabular, internally massive to low-angle planar cross-stratified, moderately well- to well-sorted, and subangular to rounded. Sand grains are vfL-fU and composed of 75–90% quartz, trace to 15% orange feldspar, and 3–7% lithics (dark mafics) with occasional reworked gypsum flakes. The Cañas Member forms an interval approximately 30–55 m thick below the Joyita Member and consists of whitish to grayish, poorly to moderately well-indurated, massive or wavy/thin- to medium-bedded, internally massive to nodular or laminated gypsum that is enterolithic in places. Mudstones and siltstones are as described above in the Joyita Member and commonly underlie covered slopes. A dolostone marker bed near the stratigraphic center of the Cañas Member is medium to dark gray, moderately indurated, wavy/thin-bedded, internally massive, and gypsiferous. The Torres Member forms the lower 168 m or more of the unit and consists of most of the lithologies described above. Carbonates in the Torres Member are medium to dark or brownish gray, moderately to well-indurated, very thin- to very thick-bedded, tabular to broadly lenticular, internally massive to horizontal-planar or ripple-laminated to brecciated dolomite or, rarely, dolomitic limestone. These are largely non-fossiliferous, slightly to very vuggy, and may emit a fetid or oily scent when struck. Wackestone, grainstone, and rudstone are recognized from the Torres Member, and four to six dolomite intervals may be traced over 100s of meters or more (Lucas et al., 2013). Torres Member gypsum is whitish to dark gray to mottled (red-yellow-gray), very poorly to well-indurated, massive or thin- to medium-bedded, internally massive or nodular to wavy laminated, and occasionally sandy with up to 5–7% grains of subangular to rounded, vfU-mL sand composed of at least 10% lithics (dark mafics) and feldspar. Mudstone and siltstone are light red or brownish red, very poorly to poorly indurated, non- to slightly calcareous, massive or thin-bedded, internally massive to vaguely ripple-laminated, and commonly gypsiferous. Sandstone in the Torres Member is yellowish, weakly calcareous, moderately well-sorted, and dominantly fine-grained with common gypsum flakes. The total thickness of the Los Vallos Formation in the quadrangle is uncertain due to poor exposure of the basal Torres Member and pervasive folding. However, a stratigraphic section and well logs suggest a thickness of approximately 235 m in the east-central part of the quadrangle.

Pym Meseta Blanca Formation of the Yeso Group (Lower Permian) – Whitish gray to buff or pinkish tan to occasionally green mottled, variably indurated to friable, thin- to medium-bedded, tabular, internally massive to low-angle planar or trough cross-stratified, moderately well- to well-sorted, subangular to rounded, vfL-mL sandstone composed of 80–95% quartz, 2–20% feldspar (plagioclase and minor potassium feldspar), and trace to 3% lithics (dark mafics and mica). Less common are intervals of reddish brown, moderately indurated, calcite-cemented, thin- to medium-bedded, tabular to lenticular, ripple cross-stratified (asymmetric), very well-sorted, arkosic vfL-vfU sandstone. Induration and texture impart a metaquartzite-like appearance to some intervals (Lucas et al, 2013). Siltstones containing halite pseudomorphs low in the unit are common elsewhere (Lucas et al., 2013) but not well-exposed in the map area. The lower contact with the Abo Formation is gradational and has not been strictly defined. We have mapped this contact at the approximate level where lighter red/orangish sandstones of the Meseta Blanca predominate over generally darker red sandstones and relatively thick, brick-red mudstones of the Abo Formation. In the north-central quadrangle, the unit is commonly mantled by 1–2 m of alluvial material that is not mapped due to its thin and discontinuous nature. Approximately 97 m thick in the west-central part of the quadrangle.

Pa Abo Formation (Lower Permian) – Interbedded dark reddish brown to pale red or dark purplish brown to maroon siltstone and very fine- to medium-grained sandstone. Sandstones are moderately indurated, non- to weakly calcareous, thin- to medium-bedded, internally massive or vaguely horizontal-planar to low-angle planar cross-laminated, well- to very well-sorted and arkosic. Contains trace to 2% subangular to subrounded, fL-cL sand grains composed of quartz, feldspar, dark mafics, and/or mica. Moderately well-exposed in the northwestern part of the quadrangle with a maximum thickness of approximately 235 m.

Pb Bursum Formation (Upper Pennsylvanian to Lower Permian) – Interstratified red to maroon and greenish gray mudstone and shale, reddish to yellowish brown sandstone, gray fossiliferous limestone, and minor intraformational (limestone-clast) conglomerate beds. Poorly exposed on this quadrangle. Approximately 76 m thick (from Scott et al., 2005; Allen et al., 2014).

IPa Atrasado Formation (Upper Pennsylvanian) – Cross section only. Gray, thin- to thick-bedded, fossiliferous limestone and intervening intervals dominated by greenish gray to reddish brown siliciclastic mudstone, siltstone, and calcareous shale. Cross-stratified to planar-laminated, silty sandstone to pebbly sandstone in thick, lenticular channel fills is common. 180–240 m thick (from Allen et al., 2014).

IPg Gray Mesa Formation (Middle Pennsylvanian) – Cross section only. Medium- to thick-bedded, fossiliferous, cherty limestone and siliciclastic deposits consisting of mudstone, shale, and sandstone. Approximately 120 m thick (from Allen et al., 2014).

IPs Sandia Formation (Middle Pennsylvanian) – Cross section only. Greenish-gray, reddish-brown, and yellowish mudstone to silty or sandy shale and calcareous shale, yellowish and reddish-brown, gray, and greenish-gray planar-laminated and cross-stratified sandstone to pebble conglomerate, and gray to brownish gray fossiliferous limestone and sandy limestone. Approximately 70 m to more than 100 m thick (from Allen et al., 2014).

PROTEROZOIC

Xu Paleoproterozoic rocks, undivided (Paleoproterozoic) – Cross section only. Chiefly the lower member of the Sevilleta Metarhyolite, described by Allen et al. (2014) as medium gray to black, dense, finely banded metarhyolite with minor white mica, oxides, epidote and biotite. Speckled with 1.0-2.5 mm white feldspar crystals that have been sericitized.