Geologic Map of the Tortugas Mountain7.5-Minute Quadrangle, Doña Ana County, New Mexico

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Scale 1:24,000

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Introduction

The Tortugas Mountain 7.5-minute quadrangle is located in south-central New Mexico and includes the east side of the city of Las Cruces. The quadrangle derives its name from a prominent landmark, Tortugas Mountain, which is a west-dipping block composed primarily of limestone that rises about 650 feet (≈200 m) above the surrounding desert floor. This mountain is a surface expression of a northerly trending buried horst block that is present between the Doña Ana Mountains to the north and Bishop Cap to the south. The horst separates the southern Jornada del Muerto Basin to the east from the Mesilla Basin to the west. Two outcrops of andesitic lava that are in the foothills of the Organ Mountains are located along the eastern edge of the quadrangle.

King and Kelley (1980) produced the first detailed geologic map of Tortugas Mountain and that mapping is also depicted on the Seager et al. (1987) map of the Las Cruces region. Prevalent faulting, fracturing, silicification, and fluorite mineralization of the carbonate rocks obscure both bedding and fossils. The age assignment of carbonates that comprise the mountain is based on poorly preserved fusilinid specimens (*Leptotriticites* and *Triticites*) identified by King and Kelley (1980). Older units on the northeast side of the mountain were assigned to the Pennsylvanian Bursum Formation and the younger upper part of the block was assigned to the Permian Hueco Limestone.

Tortugas Mountain is surrounded by fluvial and piedmont units assigned to the Pliocene to Pleistocene Camp Rice Formation. Younger inset deposits of Middle Pleistocene to Holocene age are found along arroyos and washes incised into the Camp Rice Formation. The depositional histories of the Camp Rice basin-fill and younger deposits are described in the following sections.

Plio–Pleistocene Camp Rice Formation

The Camp Rice Formation represents the upper Santa Fe Group, the late Cenozoic basin-fill of the Rio Grande rift (Spiegel and Baldwin, 1963; Hawley et al., 1969; Chapin and Cather, 1994). The Camp Rice Formation was named by Strain (1966) for poorly consolidated, stratigraphically high sediments in the Hueco Basin of west Texas and the name was carried into southern New Mexico by Hawley and others (1969), Hawley and Kottlowski (1969), and Seager and others (1971, 1987).

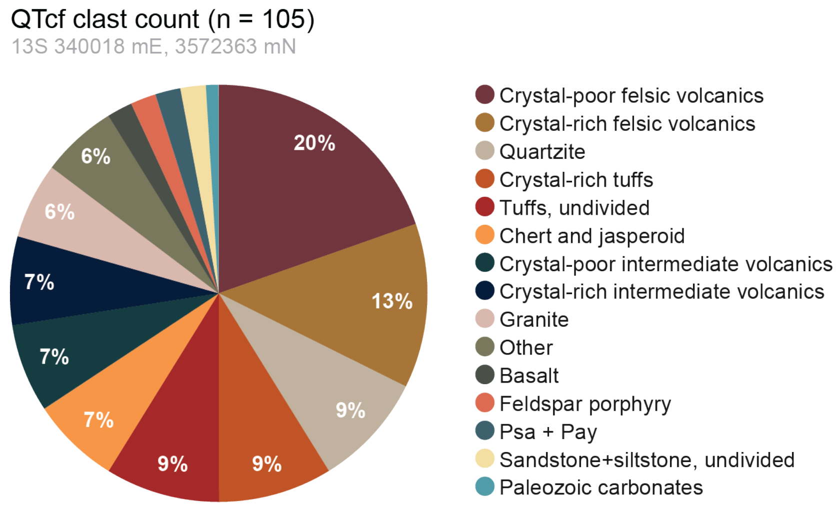
In the Tortugas Mountain quadrangle, the Camp Rice Formation consists of gravel, sand, silt, and mud deposited on coalesced fan complexes (*bajadas*) and by the ancestral Rio Grande in the Mesilla and Jornada del Muerto basins. These sediments were deposited during a time of rising base level and deposition on an expanding basin floor that was up to 40 miles (65 km) wide near El Paso to the south (Gile et al., 1981). Five member-rank stratigraphic units comprise the Camp Rice Formation in the map area.

Fluvial deposits of the ancestral Rio Grande (unit **QTcf**) dominate the surface outcrops on the west side of the quadrangle and gravelly fan deposits derived from the Organ Mountains (**Qcp**) dominate the outcrops to the east. A transitional unit separates and likely interfingers with the two facies (**Qct**). Other Camp Rice units include a stratigraphically high tongue of axial-fluvial sediment (**Qcf**) found below the Jornada I surface southeast of Fillmore Arroyo and older fanglomerate (**QTcc**) found along the eastern boundary of the quadrangle.

The ancestral Rio Grande arrived in southern New Mexico by 5 Ma (Mack et al., 1993, 1998; Koning et al., 2018), but axial-fluvial sediments of this age are not found in magnetostratigraphic sections in the Mesilla and Jornada del Muerto Basins. Mack and others (2006) suggest that the river was confined to a narrow belt until after 3.6 Ma, when it widened to occupy the entire Mesilla graben with an eastern floodplain limit that approximately coincided with the Tortugas Mountain horst block.

Stacked, grayish sands and imbricated pebble gravels in-unit **QTcf** are interpreted as channel deposits and are the most common ancestral Rio Grande facies found in the western quadrangle. Less common are brownish, cross-bedded, fine-grained sands and massive muddy deposits that indicate deposition in crevasse splays and low-energy overbank settings, respectively. Axial-fluvial facies are readily distinguished from piedmont or transitional facies of the Camp Rice Formation by sands containing abundant quartz grains (75–80%) and the presence of extra-basin clast rock types such as granite and quartzite.

FIGURE 1—*Pictured is a well-imbricated, sandy pebble gravel near the Sunset Parking Area at Tortugas Mountain, older axial-fluvial facies of the Camp Rice Formation (**QTcf**). Clast rock types visible in the photo include felsic to intermediate volcanics, limestone, chert, quartzite, and granite. The rock hammer is 25 cm long. 13S 339320 mE 3574638 mN.*



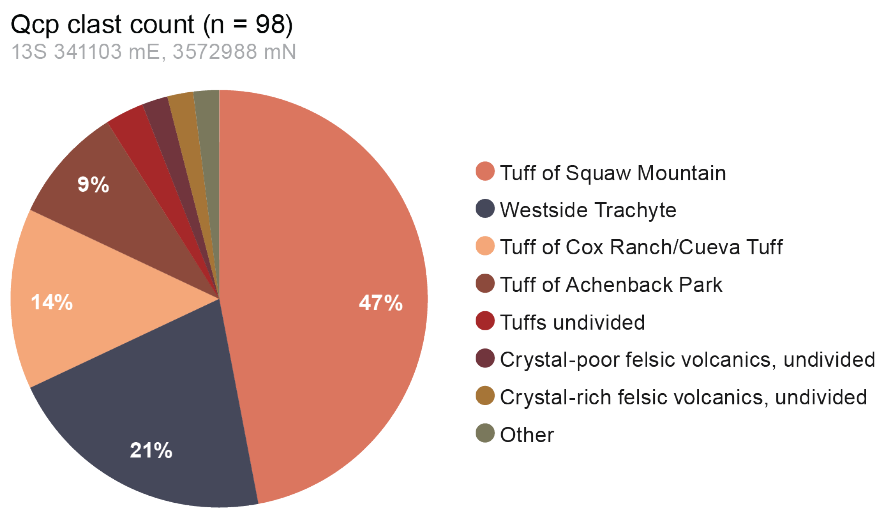


FIGURE 2*—Charts show clast counts in units* ***QTcf*** *and* ***Qcp****, illustrating the relative abundance of extra-basin clasts in axial-fluvial deposits. Refer to Seager (1981) for descriptions of volcanic rock types found in* ***Qcp****.*

Tributaries responded to the rising base level of the ancestral Rio Grande by depositing sediments on a broad piedmont slope separating the axial river valley from the Organ Mountains. As piedmont deposition progressed, alluvial fans extending from the mountain front coalesced into bajadas with small interfan areas confined to proximal positions. Grain size and rounding trends are indicative of proximity to the mountain front and/or deposition in channel versus interfluve positions in the landscape.

The matrix-supported, subangular conglomerate of unit QTcc is found along the eastern quadrangle boundary and was clearly deposited in a proximal fan position and is primarily comprised of debris flows or hyper-concentrated flows. Thin bodies of pebble gravel and massive silty sediment in unit Qcp east of Tortugas Mountain attest to deposition in fan channels and extra-channel settings (floodplains or interfluves), respectively, at medial or distal fan positions. Both units feature paleosols with stage III–IV carbonate morphology, suggesting long periods of stability in the landscape (Gile et al., 1981).

FIGURE 3—*Pictured is the coarse, subangular conglomerate near Sierra Vista Trail, older proximal piedmont facies of the Camp Rice Formation (QTcc). This sediment is interpreted as having been deposited by debris flows in a proximal alluvial fan setting. The walking stick is 1.5 m long. 13S 347191 mE 3576288 mN.*

A transitional facies (Qct) lies between axial-fluvial and piedmont deposits in the vicinity of Tortugas Mountain. This unit consists of loose, tan to pinkish silt-sand and mud that are massive to cross-laminated. These sediments are characteristic of deposition in alluvial flats or floodplain settings at the interface of distal fan toes and the floodplain of the ancestral Rio Grande (e.g., Jochems, 2018). The transitional facies likely interfingers with unit QTcf in the map area, although it is stratigraphically bound by QTcf and Qcp at Tortugas Mountain. This implies a locally progradational relationship of distal fan toes onto the ancestral Rio Grande floodplain. In turn, piedmont deposits prograded over Qct near the end of Camp Rice deposition, although the units may interfinger elsewhere.

FIGURE 4—*Pictured is the massive silt to vaguely low-angle cross-bedded silt and silt-sand in the transitional facies of the Camp Rice Formation (**Qct**). Gravels above consist entirely of carbonate clasts and are interpreted as Camp Rice piedmont deposits (**Qcp**) shed from Tortugas Mountain. The walking stick is 1.5 m long. 13 S 339746 mE 3573325 mN.*

Several lines of evidence indicate that the Camp Rice Formation exposed in the Tortugas Mountain quadrangle is mostly or entirely of upper Pleistocene age. First, magnetostratigraphic sections at Interstate 10 and Berino Tank (west and south of the quadrangle, respectively) place axial-fluvial deposits entirely in a reversed polarity interval (Mack et al., 1998, 2006). Interbedded pumice conglomerates, dated to 1.84 and 1.6 Ma ($^{40}Ar/^{39}Ar$), confirm that these sections occur in the 2.6–0.8 Ma Matuyama Chron (Mack et al., 1996). The base of the Camp Rice Formation is not exposed at these sections, which appear to correlate to the axial-fluvial deposits found in the quadrangle.

Second, the co-occurrence of three proboscidean genera in axial-fluvial deposits of the Camp Rice Formation at Tortugas Mountain constrains these sediments to the ≈1.9–0.25 Ma Irvingtonian North American land mammal age (Lucas et al., 1999). The presence of *Cuvieronius*, *Mammuthus*, and *Stegomastodon* fossils confirm an upper Pleistocene age for **QTcf** deposits at a former gravel pit on the northwest side of Tortugas Mountain because *Mammuthus* does not appear in the fossil record until after 2 Ma.

More recently, a *Stegomastodon* skull was found at the NMSU Golf Course near the lowest exposed axial-fluvial facies in the quadrangle (Houde and Peltier, 2018). Thus, this sediment is conceivably upper Pliocene in age as *Stegomastodon* appears in the fossil record during the Blancan North American land mammal age beginning 3.6 Ma.

Lastly, manganese in a travertine deposit interbedded with Camp Rice piedmont deposits on the north side of Tortugas Mountain yielded a $^{40}Ar/^{39}Ar$ age of 1.8 ± 0.19 Ma (Lueth and Peters, 2013). This deposit occurs ≈40 m below the local constructional top of the Camp Rice Formation.

Pleistocene to Holocene Geomorphology (post-Camp Rice Formation)

The post-Camp Rice geologic history of the Mesilla and southern Jornada del Muerto basins is thoroughly documented in the Desert Project. Sponsored by the U.S. Soil Conservation Service from the late 1950s to the early 1970s, the Desert Project was an ambitious study of soils and geomorphology in arid to semiarid environments of southern New Mexico (Gile et al., 1981). Among the numerous outstanding contributions of this project was the detailed mapping of geomorphic surfaces in the Las Cruces area, including those of the Tortugas Mountain quadrangle. This mapping is summarized in Sheet II of New Mexico Bureau of Mines and Mineral Resources Memoir 39 (Gile et al., 1981) and serves as a useful guide to the following discussion.

The weakly dissected piedmont slope in the eastern half of the quadrangle is capped by a complex of geomorphic surfaces formed after the end of Camp Rice deposition approximately 800 ka (Gile et al., 1981; Mack et al., 1993, 1998). The most prevalent of these is the Jornada I surface formed atop the piedmont facies of the Camp Rice Formation. The Jornada I surface comprises the original construction surface of the Camp Rice as well as erosional surfaces cut onto the piedmont basin-fill (Gile and Hawley, 1968). The Jornada I surface is typically associated with a state IV petrocalcic horizon where it is present as a constructional surface, such as in the southeast part of the map area.

FIGURE 5—*Pictured is a view to the east from the top of Tortugas Mountain, showing modestly dissected piedmont slope and geomorphic surfaces with the Organ Mountains on the skyline. Houses in center midground were built on the Jornada I surface. The Jornada I surface consists of both erosional and constructional geomorphic surfaces atop the piedmont facies of the Camp Rice Formation (Qcp). Dripping Springs Road descends from the Jornada I surface to the Picacho morphostratigraphic unit in the center to lower left of the photo.*

After 800 ka, the Rio Grande and it's tributary arroyos were incised into the broad valley floor as it integrated to the Gulf of Mexico (Gile et al., 1981; Mack et al., 1998). The Lava Creek B volcanic ash, dated at 0.63 Ma, is found in deposits graded to the Camp Rice constructional surface in Selden Canyon at the north end of the Mesilla Basin (Mack et al., 1993; Gile et al., 1995). Thus, local valley incision may not have begun in earnest until after 0.63 Ma.

Episodic entrenchment, driven by glacial cycles, formed inset tributary deposits at multiple elevations. These too, are associated with a series of geomorphic surfaces. The primary inset morphostratigraphic units in the map area are the Tortugas, Picacho, Fillmore, and Leasburg surfaces and their associated deposits and soils. Note that the "Fort Selden" morphostratigraphic unit encompasses both the Fillmore and Leasburg units where they are not readily distinguished.

The oldest of these units, the Tortugas surface, comprises a well-graded surface overlying up to 30 m of gravel and sand-silt in the eastern Robledo Mountains but is typically a ridge-summit erosional surface cut on the Camp Rice Formation in its type area east of Tortugas Mountain (Ruhe, 1962, 1967; Hawley and Kottlowski, 1969). The surface is not shown on the geologic map, but it occupies small erosional remnants intermediate in elevation between the Jornada I and Picacho surfaces. The Tortugas surface may overlie thin bodies of sediment (<3–10 m) capped by stage IV petrocalcic horizons in the upper reaches of some Fillmore Arroyo tributaries west of Soledad Canyon Road (Gile et al., 1995). However, these deposits are clearly subordinate to those of the Picacho morphostratigraphic unit in the vicinity.

The Picacho morphostratigraphic unit (**Qvop**) is the next oldest inset deposit and is extensive in the map area. The unit is typified by a reddish-brown to tan, massive to imbricated or cross-bedded pebble or pebble–cobble gravel underlying a stage III calcic horizon lying 18–24 m above modern grade. The Picacho alluvium attains a thickness of 15–21 m in terrace deposits near the mouths of tributary arroyos, signifying an interval of major, climate-modulated aggradation (Hawley and Kottlowski, 1969). It has long been recognized that the Picacho unit predates the Holocene Fillmore alluvium and that soil carbonates capping the deposit formed before ≈25 ka (Ruhe, 1967; Metcalf, 1969). A maximum age of ≈150 ka is typically assumed for the unit (Gile et al., 1981), corresponding to aggradation during late Marine Isotope Stage (MIS) 6 or early MIS 5.

Younger morphostratigraphic units in the quadrangle are found as low terraces along arroyos or as relatively undissected alluvial-fan deposits. Unit **Qvy** encompasses the Fillmore and Leasburg deposits at valley-border positions and the Organ and Isaacks' Ranch units, their piedmont slope counterparts, east of Tortugas Mountain. The latter are found in alluvial fans prograded onto the Jornada I surface (and upper Camp Rice piedmont deposits) in the northeast part of the quadrangle (unit **Qpyoi**).

The Fillmore and Leasburg deposits occur as yellowish-brown, massive or cross-stratified sand or sandy pebble gravel capped by cambic (Bw) and/or stage I calcic soils. These underlie surfaces graded to as high as 9 m above the modern Rio Grande valley. Organ and Isaack's Ranch deposits consist of thin (2–3 m) gravelly deposits in undissected fans, sheets, or lobes (Ruhe, 1964, 1967; Gile et al., 1981).

Charcoal and shell ^{14}C ages from the Fort Selden (Fillmore and Leasburg) morphostratigraphic unit span an interval from ≈9,400 to 1,100 cal yr BP, with soil development indicating a stable period ≈7,000 ka (Gile and Hawley, 1968; Metcalf, 1969; Gile et al., 1981). Radiocarbon ages of ≈6,400 to 1,100 cal yr BP for the Organ morphostratigraphic unit at Gardner Springs and Isaacks' Ranch north of the quadrangle are in good agreement with the Fort Selden ages (Gile and Hawley, 1968).

Arroyo and gully incision since the first local land survey in 1858 CE have produced sandy to gravelly valley-floor deposits that lack soils (units **Qvm** and **Qvh**). Flooding by the Rio Grande prior to the construction of Caballo and Elephant Butte dams upstream also resulted in historical sandy to clayey deposits found in the southwest corner of the quadrangle (unit **Qvmhr**; Gile et al., 1981). An oxbow and scroll bars are still visible in aerial imagery near Fort Fillmore Road (on San Miguel quad to the south); well logs indicate that underlying deposits are <15 m thick. Radiocarbon ages from logs in correlative deposits west of Las Cruces suggest an age of <1844 CE (Gile et al., 1981).

FIGURE 6—*Pictured are sandy to pebbly, modern to historical valley-floor deposits (**Qvm** and **Qvh**). Creosote and mesquite are growing on very low-lying terraces and bars of unit **Qvh**, deposited after ≈1,860 CE. The view is to the north-northeast with Tortugas Mountain in the center background and the Organ Mountains on the right skyline. 13S 339644 mE 3572262 mN*

Economic Resources

Tortugas Mountain is known for two important economic resources, fluorite and geothermal.

Fluorite

Fluorite mining on Tortugas Mountain started in 1919 and production ended in 1943, with a total production of 20,751 short tons of fluorite and 100 short tons of barite (McAnulty, 1978). The mining occurred along two main veins: the Tortugas vein in the center of the hill, which strikes N7°W and dips 70 to 80°NE at the surface and 60°W in the subsurface, and the Jones vein on the east side that strikes N50°W, is vertical and joins the other vein near its north end

(Johnston, 1928). The veins, on average, were 4 feet thick. By far, Johnston (1928) has the best description of the deposit. He notes that, in general, initial faulting formed gouge and breccia in the carbonate host rock, that fluorite replaced carbonate in the breccia, and that calcite deposition followed fluorite mineralization. In the Jones vein, in particular, the gouge contains cleavage pieces of fluorite, indicating post-mineralization movement along the fault, with final deposition of calcite and minor gypsum (Johnston, 1928). As of this writing the fluorite pits and adits on Tortugas Mountain were filled in or were in the process of being reclaimed.

Geothermal

King and Kelley (1980) were the first to describe fossil hot spring deposits on the northwest side of Tortugas Mountain. The travertine is in the Plio–Pleistocene Camp Rice Formation, and as mentioned earlier, manganese (cryptomelane) associated with the fossil geothermal system yielded a $^{40}Ar/^{39}Ar$ date of 1.8 ± 0.19 Ma (Lueth and Peters, 2013). This date fits well with proboscidean fossils found at the site (Lucas et al., 1999).

The modern geothermal system in the vicinity of Tortugas Mountain was originally found when the Clary and Ruther State 1 oil test produced steam and hot water in 1949 and when warm salty water in shallow wells was noted during the construction of the Las Alturas neighborhood (Witcher et al., 2002). New Mexico State University decided to develop the geothermal system during the mid-1970s to early 1980s to save on heating costs. A direct-use heating system was built in 1981–1982 to heat athletic buildings and other facilities on the east side of campus. Greenhouse and aquiculture business incubators were added to the system in 1985. This was one of the first attempts to use a geothermal resource to directly heat large facilities (e.g., the basketball ar ena) on a university campus. Because the use of this resource was ground-breaking, several mistakes in the initial design led to maintenance problems in later years (Millennium Energy, 2006). The system was taken offline in 2001.

Numerous geophysical surveys, shallow thermal gradient holes, two deep test wells, and four deep production wells were used to define the resource (Chaturvedi, 1979; 1981; Gross and Icerman, 1983; Icerman and Lohse, 1983). The resource is associated with a structural bench that is cut by a 3- to 4-mile-wide fault zone that generally steps down to the west across a series of faults. This structure forms the eastern boundary of the Mesilla Basin. All of the wells, except PG-4, are completed in the middle to lower Santa Fe Group. The lowest 12 m of PG-4 is in breccia in limestone that may represent a fault zone or a karst feature (Witcher et al., 2002).

New Observations from the Current Study

Pennsylvanian Panther Seep Formation

Outcrops on the northeast side of Tortugas Mountain include a 2-m-thick sandstone that, in most places, has been replaced by silica and is commonly brecciated along the top of the bed. Limestone with white and brown chert nodules lies below the silicified sandstone. We have correlated these beds to the Panther Seep Formation, which is consistent with the identification of the fusulinids from the northeast side of Tortugas Mountain by King and Kelley (1980).

FIGURE 7— *Close-up of the silicified Panther Seep Formation sandstone on the northeast side of Tortugas Mountain with breccia on top of the layer next to the rock hammer.*

Orientation and cross-cutting relations of silicified fractures

Fractures filled with white- to gray- to brown-weathering silica are dominant features on Tortugas Mountain. On the east side of the mountain, wide bands (up to 10 m) of silica-filled fracture networks with a pronounced northwest strike are common, as well as a generally higher fracture density. Detailed measurements of fracture orientations in the vicinity of two of the fluorite prospects highlight the northwest trend, as well as other orientations that vary between NE and N trends.

In all instances where cross-cutting relationships can be observed, the fluorite mineralization clearly cuts the silicified fractures.

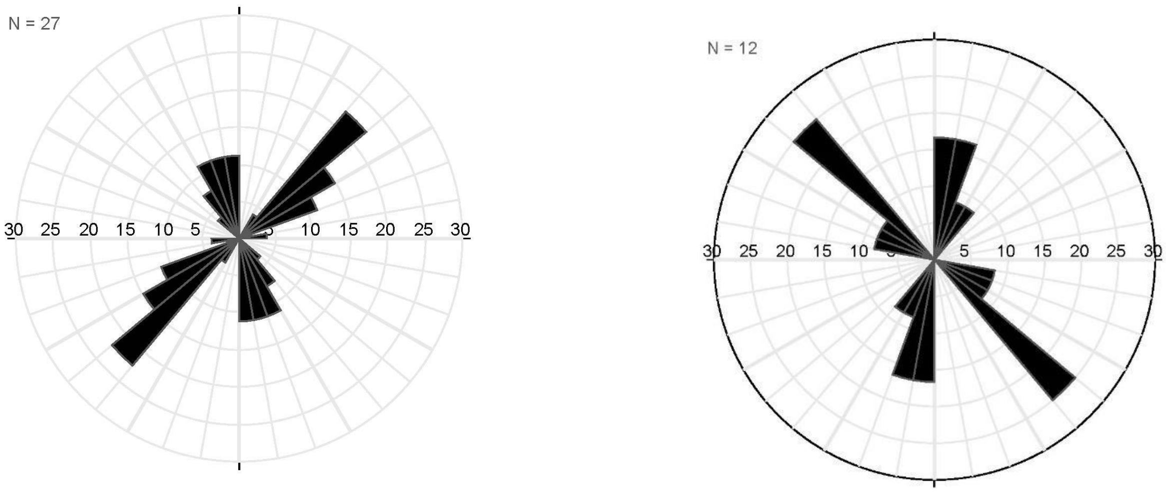


FIGURE 8—*Rose diagrams of the orientations of silica-filled fractures at two locations on Tortugas Mountain. The measurement on the left is at 13S 340292E 3573751N and the measurement on the right is at 13S 340264E 3573905N (UTM NAD 83). North is at the top of the diagrams. The NW-trending fractures are offset in a left-lateral sense or are truncated by the NE-striking fractures at the station on the left.*

FIGURE 9— *Fractures filled with white silica are truncated by fluorite at 13S 340289 3573893 in a long prospect trench covered by netting. A ball-point pen is shown for scale.*

DESCRIPTION OF MAP UNITS

QUATERNARY

Anthropogenic Units

daf **Disturbed land and anthropogenic fill (Modern to ≈50 years old)—**Dumped fill consisting of thick accumulations of sand, gravel, and clayey–silty sand. Mapped for thick road fill along Interstate 25, flood retention dams, and other areas affected by aggregate mining or urban development. The fill thickness is 1–10 m.

dac **Disturbed land and anthropogenic channelization (Modern to ≈50 years old)—** Mapped where existing channels have been modified due to flood control efforts.

ae **Anthropogenic excavated ground (Modern to ≈50 years old)—**Excavations associated with aggregate mining, landfills, and impoundments.

Eolian and Hillslope Units

Qes **Eolian sand and sheetwash, undivided (Historical)**—

Long—

Very fine to fine sand (<10-20% silt and medium- to coarse-grained sand) that is loosely consolidated and forms sheets that mantle high, relatively flat terrain or, less commonly, small coppice dunes. Colors range from reddish-brown (5YR 5/3–4) to brown (10YR 4–5/3); redder hues commonly result from the presence of argillic (Bt) horizons. The deposit is similar to unit **Qesc** but lacks gravelly sediment. On sand sheets, sparse to occasional pebbles weathered from underlying basin-fill may be scattered on the surface. Coppice dunes are vegetated (mostly mesquite, *Prosopis juliflora*) and largely formed 1885–1920 CE (Gile, 1966). The thickness is <2–3 m.

Short—

Mostly very fine- to fine-grained sand that is loosely consolidated and forms sheets or coppice dunes. Colors range from reddish-brown to brown (5–10YR); redder hues result from the presence of argillic (Bt) horizons. The deposit is similar to unit **Qesc** but lacks gravelly sediment. Coppice dunes are vegetated by mesquite (*Prosopis juliflora*) and largely formed 1885–1920 CE (Gile, 1966). The thickness is <2–3 m.

Qesc Eolian sand, sheetwash, and colluvium, undivided (Holocene)—

Long—

Silty sand and pebbly gravel that are loosely consolidated in massive to medium (15–30 cm), tabular to wedge-shaped beds and mantle footslopes and toeslopes. The sand is composed of yellowish-brown (10YR 5/4), weakly calcareous, internally massive to laminated or low-angle cross-stratified, very poorly to poorly sorted, angular to rounded grains up to cL in size with <15% silt. Grains consist of 70–80% quartz, 15–20% lithics (volcanics, ferromagnesian minerals), and 10–15% feldspar with trace brownish free-grain argillans. This sediment contains 5–15% floating subangular to rounded, fine to coarse pebbles with rare cobbles of volcanic lithologies and subordinate quartzite and chert. On steeper slopes, such gravel dominates the deposit and is clast- to matrix-supported; the deposit is massive or has vague to moderate slope-parallel fabric. The deposit commonly progrades over unit **Qvh** to a level 0.5–0.8 m above modern grade in larger drainages. Elsewhere, it grades laterally to unit **Qvy** deposits. It may be bioturbated by medium to very coarse roots and burrows. In places, **Qesc** may correspond to the Fillmore morphostratigraphic unit of Gile et al. (1981). The thickness is 0.75–2 m.

Short—

Silty sand and pebbly gravel that are loosely consolidated and mantle footslopes and toeslopes. Sand is yellowish-brown (10YR 5/4) and massive to laminated or low-angle cross-stratified, with 5–15% floating pebbles. On steeper slopes, gravel is clast- to matrix-supported and is massive or has vague to moderate slope-parallel fabric. The deposit may prograde over unit **Qvh** or grade laterally to unit **Qvy**. The thickness is 0.75–2 m.

Qc Colluvium (Holocene)—Pebble–cobble–boulder to cobble–boulder gravel that is loosely consolidated, poorly sorted, and angular to subrounded. The deposit forms aprons or mantles on the footslopes of Tortugas Mountain. The deposit may be clast- to matrix-supported, with open-framework in places, and is internally massive or may feature slope-parallel fabric. The thickness is <5 m.

Qls Landslide deposits (Holocene? to Late Pleistocene)—An approximately 10,000 m^2 slide is found on the northeast side of Tortugas Mountain, where it forms a prominent toe and consists of blocks of Hueco Formation carbonate up to 6.5 m across. The maximum thickness is approximately 15 m.

Qtc Talus and colluvium, undivided (Holocene? to Late Pleistocene)—Cobbly to boulder talus deposits that are angular to subangular and underly high slopes on the north side of Tortugas Mountain with subordinate to subequal proportions of colluvium (**Qc**). The deposit is open-framework in many places with internally massive or slope-parallel fabric. The thickness is <5–8 m.

Valley Fan Units

Qfm Modern fan alluvium (Modern to <80 years old)—Pebbly sand and sandy pebble gravel that are loosely consolidated and underly fan surfaces that gently grade to **Qvm** or **Qvmhr** deposits. Color, texture, and bar-and-swale topographic relief are similar to **Qvm** deposits with rare to occasional matrix-supported gravels. The thickness is <2 m.

Qfhm Historical and modern fan alluvium, undivided (Modern to ≈150 years old)—

Long–

Pebbly sand-silt and sandy pebble gravel that are loose to very weakly consolidated and underly fan surfaces graded at ≈2% slopes to **Qvm**, **Qvh**, or **Qvmhr** deposits. Pebble gravels are clast- or, less commonly, matrix-supported. Beds are tabular to broadly lenticular, and sedimentary textures range from massive to low-angle cross-stratified sand or weakly imbricated gravel. Color and grain/clast composition and texture are similar to **Qvm** and **Qvh** deposits found in Fillmore (San Miguel quadrangle) and Tortugas Arroyos. Typically non- or very weakly calcareous with little to no soil development. Tread height is <1 m above modern grade and inset up to 10 m below the Fillmore geomorphic surface of Ruhe (1962, 1964, 1967) and Gile et al. (1981) near the western boundary of the quadrangle. Surface possibly correlates to the Organ geomorphic surface of Gile et al. (1981), where the deposits are found in drainage ways on the piedmont slope. The thickness is <2 m in most places.

Short–

Sand–silt and pebble gravel that are loosely consolidated and gently grade to units **Qvm**, **Qvh**, or **Qvmhr**. The deposit is massive to imbricated or low-angle cross-stratified. Generally, non-calcareous with little or no soil development. Tread height is <1 m above modern grade and inset <10 m below the Fillmore geomorphic surface (Gile et al., 1981). The thickness is <2 m.

Qfy Younger fan alluvium (Holocene)—Pebbly sand and sandy pebble gravel that are loose to weakly consolidated and underly fan surfaces graded at 2–5% slopes to **Qvy**. Color, texture, and age correlations are similar to **Qvy** deposits; probably <3 ka in most places based on radiocarbon age from southeast Robledo Mountains (Gile et al., 1981). Stage I carbonate accumulation is common. The thickness is typically <2–4 m.

Valley-floor Units

Qvm Modern alluvium (Modern to ≈50 years old)—

Long—

Pebbly sand and sandy pebble or pebble–cobble gravel that are loosely consolidated. The deposit fills channels and forms longitudinal bars in ephemeral stream courses. Sand is composed of yellowish to light-yellowish-brown (10YR 5–6/4), horizontal-planar or low-angle cross-laminated, poorly to moderately sorted, subrounded to well-rounded, fL–cL grains. Grains consist of 65–75% quartz, 15–25% feldspar, and 10–20% lithics (volcanics, ferromagnesian minerals; granite and/or chert possible) with no clay. Gravels occur predominantly in bars and consist of clast-supported, poorly to moderately sorted, subangular to well-rounded pebbles (70–100%) and cobbles (0–30%) of mostly felsic volcanic lithologies with occasional granite, chert, and quartzite where stream courses drain QTcf exposures. The deposit features bar-and-swale topographic relief of 0.3–0.5 m. The thickness is <2–4.5 m (Gile et al., 1981).

Short—

Sand and gravel that are loosely consolidated. The deposit fills channels and forms longitudinal bars in ephemeral stream courses. Sand is yellowish to light-yellowish-brown (10YR) and horizontal-planar or low-angle cross-laminated. Gravels occur predominantly in bars and are clast-supported. The deposit features bar-and-swale topographic relief of 0.3–0.5 m. The thickness is <2–4.5 m (Gile et al., 1981).

Qvh Historical alluvium (≈50 to ≈150 years old)—

Long—

Sandy pebble gravel that is loosely consolidated in thin to thick(?) (7+ cm), tabular to lenticular beds that underly low terraces along stream courses. The deposit is internally massive to moderately well-imbricated with occasional low-angle cross-stratification. Gravel consist of clast- to matrix-supported, poorly sorted, subrounded to well-rounded pebbles (>80%) and cobbles (<20%) of mostly felsic volcanic lithologies with occasional exotic clasts reworked from various facies of the Camp Rice Formation. The matrix consists of brown to yellowish-brown (10YR 5/3–4), weakly to moderately calcareous, poorly sorted, subangular to rounded, fL–cU sand composed of 55–65% quartz, 20–25% lithics (volcanic, possible chert), and 15–20% feldspar with little or no clay. Occasional (<20%), thin- to medium-bedded (5–15 cm), massive to horizontal-planar-laminated or planar cross-stratified, pebbly sand similar to gravel matrix may be observed. The deposit lacks significant soil development. Surface features subdued bar-and-swale topographic relief of up to 0.25–0.3 m. Tread height is 0.2–0.8 m above modern grade; the deposit surface commonly onlaps older surfaces on the piedmont slope or is inset 3–10 m below the Fillmore geomorphic surface of Ruhe (1962, 1964, 1967) and Gile et al. (1981) near the western boundary of the quadrangle. Probably postdates the Fillmore morphostratigraphic unit of Gile et al. (1981), who note that the Fillmore surface was stable and occupied by prehistoric peoples by ≈1 ka (p. 45). The thickness is 0.5–4.5 m.

Short—

Sandy pebble gravel that is loosely consolidated and underlies low terraces. The deposit is massive to imbricated or low-angle cross-stratified. Sandy matrix is brown to yellowish-brown (10YR) and lacks clay. Subdued bar-and-swale topographic relief and no soil development. Tread commonly onlaps older piedmont slope surfaces or is inset 3–10 m below the Fillmore surface (Gile et al., 1981). The thickness is 0.5–4.5 m.

Qvmh **Modern and historical alluvium, undivided (Modern to ≈150 years old)—** Modern and subordinate historical alluvium, undivided. See descriptions for **Qvm** and **Qvh**.

Qvmhr **Modern and historical alluvium of the Rio Grande floodplain (Modern to ≈200 years old)—**

Long–

Sandy to clayey deposits that are grayish or light- to dark-brown (likely 10YR) with lesser pebble gravel underlying the Rio Grande floodplain in Mesilla Valley. Sand is fine- to coarse-grained. The deposit is frequently capped by loamy, organic-rich topsoil outside of modern and former channels. Portions of this unit mapped as **Rop1844** and **Rfp1844** indicate Rio Grande alluvium deposited before 1844 in a meander loop or floodplain (Ruhe, 1962). Radiocarbon ages from logs at depths of 5–7 m in correlative deposits west of Las Cruces suggest an age of <200 years old (Gile et al., 1981). Well logs indicate that the unit is less than 12–15 m thick in the southwest corner of the quadrangle (NMOSE, 2020).

Short–

Sand and clay that is gray to brown with lesser pebble gravel underlying the Rio Grande floodplain. The deposit is frequently capped by loamy topsoil. **Rop1844** and **Rfp1844** indicate portions deposited before 1844 (Ruhe, 1962). Ages from correlative deposits west of Las Cruces suggest an age of <200 yrs old (Gile et al., 1981). Well logs indicate that the unit is less than 12–15 m thick (NMOSE, 2020).

Qvy **Younger alluvium (Holocene to latest Pleistocene)—**

Long—

Pebbly sand or sandy pebble gravel that is loose to weakly consolidated and frequently fines upward to loamy sediment. Sand is dark-yellowish-brown (10YR 4/3–4) near Tortugas Mountain and is internally massive to trough or planar cross-stratified. Surface soils feature cambic (Bw) to weak calcic horizons featuring stage I carbonate accumulation; the former are associated with reddish-brown hues (5–7.5YR). At valley-border locations, the deposit underlies a surface graded to as much as 9 m below or above the modern Rio Grande valley. Charcoal and shell ^{14}C ages span an interval from ≈9,400 to 1,100 cal yr BP, with soil development indicating a stable period ≈7,000 cal yr BP (Gile and Hawley, 1968; Metcalf, 1969; Gile et al., 1981). This unit is correlative to the Fort Selden (Fillmore + Leasburg—valley border) and Organ and Isaacks' Ranch morphostratigraphic units (piedmont slope) of Ruhe (1962, 1964, 1967) and Gile et al.

(1981). The thickness ranges from 2–3 m on the piedmont slope up to 16 m along the Rio Grande valley border (modified from Gile et al. [1981]).

Short—

Pebbly sand or sandy pebble gravel that is loose to weakly consolidated and fines upward to loamy sediment. Sand is reddish-brown (5–7.5YR) where cambic soils have formed to yellowish-brown (10YR), and is massive to trough or planar cross-stratified. Surface soils feature cambic (Bw) to stage I calcic horizons. The thickness is 2–16 m (modified from Gile et al. [1981]).

Qvyg **Gray younger alluvium (Holocene to latest Pleistocene)**—Occupies the same elevation position in the landscape as Qvy, but has a grayish-white hue in aerial imagery.

Qva **Valley-floor alluvium, undivided (Holocene to latest Pleistocene)**—Varying proportions of modern (Qvm), historical (Qvh), and younger (Qvy) alluvium filling valley-floors and underlying modern channels. See detailed descriptions of each unit.

Qvaes **Valley-floor alluvium, undivided, with eolian sand and sheetwash component (Holocene to latest Pleistocene)**—Varying proportions of modern (Qvm), historical (Qvh), and younger (Qvy) alluvium filling valley-floors and underlying modern channels. This unit includes a substantial component of eolian sand and sheetwash (Qes), mostly as a thin mantle on alluvial sediment. See detailed descriptions of each unit.

Older Alluvial Units

Qvop **Picacho Alluvium (Late Pleistocene)—**

Long—

Sandy pebble to pebble-cobble gravel that is weakly to moderately consolidated in massive or medium to very thick, tabular to broadly lenticular beds. The deposit is internally massive to moderately-well imbricated or locally cross-stratified. Gravel are mostly clast-supported, very poorly to poorly sorted, subangular to well-rounded, and consist of clasts of rhyolite and rhyolitic tuff to the south and felsic extrusives plus monzonite to the north. The matrix consists of moderately calcareous, poorly sorted, subangular to rounded, fine- to coarse-grained sand. Colors mostly range from reddish-brown to brown (5–7.5YR). A stage III calcic horizon commonly caps the deposit; rarely, a thin argillic (Bt) horizon is preserved above this. Tread height is 18–24 m above modern grade. The thickness is <15–21 m (modified from Ruhe [1967] and Gile et al. [1981]).

Short—

Sandy pebble to pebble-cobble gravel that is weakly to moderately consolidated and is massive to imbricated or locally cross-stratified. Clasts consist of rhyolite and rhyolitic tuff to the south and felsic extrusives plus monzonite to the north. A stage III calcic horizon commonly caps the deposit. Tread height is 18–24 m above modern grade. The thickness is <15–21 m (modified from Ruhe [1967] and Gile et al. [1981]).

Alluvial Fan and Piedmont Units

Qpy Younger fan-piedmont alluvium (Historical to latest Pleistocene)—Similar to unit **Qvy** but underlying discontinuous areas of incision and common gully-mouth fans. The deposits are slightly thicker near axial channels and thinner where they underlie wide, sheet-like landforms. The unit is confined to the upper piedmont slope. The thickness is <2–3 m (modified from Gile et al. [1981]).

Qpyoi Younger fan-piedmont alluvium, Organ to Isaacks' Ranch morphostratigraphic unit (Holocene to latest Pleistocene)—Similar to units **Qvy** and **Qpy** but occurring in mostly undissected fans, sheets, and lobes readily correlated to the Organ or Issacks' Ranch geomorphic surfaces of Ruhe (1964, 1967) and Gile et al. (1981). The thickness is 2–3 m.

Qpo Older fan-piedmont alluvium (Late to Middle? Pleistocene)—

Long—

Pebble–cobble to pebble–boulder gravel that is loose to moderately consolidated in medium- to very thick (25–60+ cm), tabular to wedge-shaped beds. Gravel are mostly matrix-supported, internally massive to vaguely imbricated, very poorly to poorly sorted, angular to subrounded pebbles (50–70%), cobbles (30–50%), and boulders (<20%). The matrix consists of reddish-brown (5–7.5YR) or pale- to yellowish-brown (10YR, less common), strongly calcareous, very poorly sorted, angular to subrounded, silty, vfL–cU sand. A stage II+ calcic soil horizon is observed in the upper 0.8–1.3 m of the deposit. Moderate to strong varnish is observed on 10–15% of surface clasts. The deposit likely correlates to the Picacho surface of Ruhe (1967) and Gile et al. (1981). The thickness is 2–10 m.

Short—

Gravel that is loose to moderately consolidated and massive to vaguely imbricated. The matrix sand is reddish-brown (5–7.5YR) or pale- to yellowish-brown (10YR, less common). The deposit is capped by a stage II+ calcic soil. Moderate to strong varnish on 10–15% of surface clasts. Likely correlative to the Picacho surface (Ruhe, 1967; Gile et al., 1981). The thickness is 2–10 m.

Qpa Fan-piedmont alluvium, undivided (Historical to Middle? Pleistocene)—Varying proportions of younger (**Qpy, Qpyoi**) and older (**Qpo**) fan-piedmont alluvium. See detailed descriptions of each unit.

QUATERNARY–TERTIARY

Basin-fill Units

Qcf Younger axial-fluvial facies of the Camp Rice Formation (early Pleistocene)—Sandy deposits underlying the Jornada I surface in the southern part of the quadrangle. Lithologically similar to unit QTcf. The thickness is <12–15 m.

Qcp Younger piedmont facies of the Camp Rice Formation (early Pleistocene)—

Long—

Pebble–cobble to pebble–boulder gravel that is weakly consolidated to carbonate-cemented in massive or in medium to thick (25–80 cm), tabular beds. Gravel clasts are matrix-supported (lesser clast-supported) and internally massive or with slope-parallel fabric. Clasts consist of very poorly sorted, angular to subrounded pebbles (40–70%), cobbles (30–45%), and boulders (0–30%). South and west of Tortugas Mountain, all clasts are Lower Permian carbonates, whereas clast lithologies are dominated (70–75%) by felsic volcanics (especially the Tuff of Squaw Mountain) to the east. White to pinkish-gray or pink colors (10YR 8/1; 7.5YR 7/2–3) result from carbonate cement; reddish-brown to brownish colors (5–7.5YR) are common in its absence. Occasionally, beds of tabular sand-silt similar to unit Qct are encountered. Gile et al. (1981) note that these facies may grade to loam or silt with gravel interbeds at distal piedmont positions, may contain buried soils, and that the unit is frequently capped by a laminar, petrocalcic horizon (stage IV carbonate accumulation). Well logs indicate a maximum thickness of 30–40 m.

Short—

Gravel that is weakly consolidated to carbonate-cemented, commonly matrix-supported, and massive or with slope-parallel fabric. The unit may grade to loam or silt with gravel interbeds at distal piedmont positions, may contain buried soils, and is frequently capped by a laminar, petrocalcic (stage IV) horizon (Gile et al., 1981). The maximum thickness is 30–40 m.

Qct Transitional facies of the Camp Rice Formation (early Pleistocene)—

Long—

Silt–sand that is loose to very weakly consolidated in massive or thin to medium, tabular beds. The deposit consists of light-brown to pink (7.5YR 6/4–7/3), moderately to strongly calcareous, internally massive to vaguely low-angle cross-laminated, poorly to moderately sorted, subangular to rounded, silt to mL sand composed of 60–70% quartz, 20–30% lithics (volcanic, ferromagnesian minerals, possible chert), and 10–20% feldspar with little clay. Silt-sand is strong brown (7.5YR 4–5/6) east of Tortugas Mountain. Muddy beds of a similar color may also be present and are generally tabular and massive. The unit contains occasional buried cambic (Bw) to argillic or calcic (Bt, Btk/stage II) soil horizons with abundant small carbonate masses or medium to large nodules. Locally, Bw or Bt horizons are eroded, leaving only the calcic horizons. These paleosol packages are typically 20–80 cm thick. The maximum thickness is about 25 m.

Short—

Silt–sand and mud that is loose to very weakly consolidated and massive to cross-laminated. The deposit is light-brown to pink or strong brown (7.5YR 6/4–7/3; 4–5/6). The unit contains occasional buried cambic (Bw) to argillic or calcic (Bt, Btk/stage II) soil horizons; locally, Bw or Bt horizons are eroded. Paleosol packages are typically 20–80 cm thick. The maximum thickness is about 25 m.

QTcf Older axial-fluvial facies of the Camp Rice Formation (early Pleistocene to Pliocene)—

Long—

Pebble gravel and sand that is loose to moderately consolidated and calcite-cemented. Gravel is clast-supported, thin- to medium-bedded (7–40+ cm), broadly lenticular, and well-imbricated to trough or planar cross-stratified (foresets 20–40 cm tall). Clasts consist of poorly sorted, subrounded to well-rounded pebbles (75–100%) and cobbles (0–25%) of mostly felsic volcanics with subordinate amounts (2–10% each) of intermediate volcanics, basalt, quartzite, granite, chert, and sedimentary lithologies. The matrix consists of white to very pale-brown (10YR 8/1–2) where calcite-cemented, or brown to light-brownish-gray or pale-brown (10YR 5/3, 6/2–3), strongly calcareous, very poorly to poorly sorted, subangular to well-rounded, fL–cL sand composed of 75–80% quartz, 10–15% lithics (volcanic, ferromagnesian minerals, granite, chert) with no clay. Gravel underlies weakly to moderately calcareous, massive to thick-bedded (55+ cm), lenticular (occasionally tabular), internally massive to planar cross-stratified (foresets up to 35–40 cm tall), poorly to moderately sorted, subrounded to well-rounded, vfL–mL sand. Color and sand composition are similar to gravel matrix. Sand is mostly massive in the upper 2–4 m of the deposit. Massive clayey to loamy beds are locally present. Fossils of the proboscideans *Cuvieronius*, *Mammuthus*, and *Stegomastodon* have been recovered from this unit locally (Lucas et al., 1999; Houde and Peltier, 2018). Soils are generally not observed. Well logs indicate a thickness of 100–215 m.

Short—

Pebble gravel, and sand that is loose to moderately consolidated and calcite-cemented. Gravel are well-imbricated to cross-stratified and contain common exotic clasts (quartzite, granite, and chert). These deposits underlie internally massive to planar cross-stratified sand that is brownish (10YR) in color. Soils are generally not observed. The maximum thickness is 215 m.

QTcc Older proximal piedmont facies of the Camp Rice Formation (earliest Pleistocene? to Pliocene)—

Long—

Pebble–boulder gravel/conglomerate that is weakly consolidated to carbonate-cemented in thin to medium (5–55+ cm), tabular (rarely lenticular) beds. The unit is mostly matrix-supported and internally massive with rare open-framework beds. Clasts consist of very poorly to poorly sorted, angular to subrounded pebbles (55–100%), cobbles (0–30%), and boulders (0–15%) of felsic volcanics derived from the western Organ Mountains. Monzonite clasts may be present to the north. The matrix consists of dark-reddish-brown (e.g., 5YR 3/4), very weakly calcareous, very poorly sorted, angular to subrounded, fU–vcL sand composed of 80–85% lithics (volcanic) and 15–20% quartz + feldspar with up to 20–25% reddish clay films. The unit contains 10–15% thin, tabular beds of pebbly sand similar to gravel matrix. Stage III–IV calcic horizons observed in the upper 1–2 m. The thickness is from 0 to perhaps 90 m.

Short—

Gravel/conglomerate that is weakly consolidated to carbonate-cemented. The unit is matrix-supported and massive or rarely open-framework. Clasts are felsic volcanics and monzonite derived from the western Organ Mountains. The matrix sand is dark-reddish-brown (5YR) with <25% reddish clay films. The unit contains 10–15% thin beds of pebbly sand. Stage III–IV calcic horizons observed in the upper 2 m. The thickness is 0–90 m.

Qcru **Camp Rice Formation, undivided (Pleistocene)**—Cross section only. Correlates to the upper Santa Fe (USF) unit of Hawley et al. (2020).

TERTIARY

Tsf **Santa Fe Group, undivided (Miocene to Pleistocene)**—Cross section only. Includes the Middle Santa Fe and Lower Santa Fe facies of Hawley et al. (2020).

Tv **Undifferentiated volcanic rocks (Eocene to early Oligocene)—**Cross section only. Lavas and ash-flow tuffs derived mainly from calderas in the Organ Mountains or Doña Ana Mountains.

Twt **West-side trachyte flows (Eocene)**—

Long—

Porphyritic trachyte lavas that are dark- or purplish-gray weathering, reddish-brown, and massive to flow-banded. Phenocrysts are altered but include 10–20% crystals that are mostly fine to coarse plagioclase (<6 mm; subhedral to euhedral laths) with minor biotite and hornblende (Seager et al., 1981). Two K-Ar ages of ≈33.7 Ma were obtained for nearby flows (Seager, 1981; Seager et al., 1981), but more recent $^{40}Ar/^{39}Ar$ dating of the west side lavas by Zimmerer and McIntosh (2013) yield dates of 35.68 ± 0.09 Ma to 36.28 ± 0.23 Ma. Individual flows are up to 30 m thick; the overall thickness is up to 300 m (Seager, 1981).

Short—

Porphyritic trachyte lavas that are dark- or purplish-gray and massive to flow-banded,. Phenocrysts are altered but include 10–20% crystals that are mostly plagioclase with minor biotite and hornblende. Recent $^{40}Ar/^{39}Ar$ dating by Zimmerer and McIntosh (2013) yield dates of 35.68 ± 0.09 Ma to 36.28 ± 0.23 Ma. Individual flows are up to 30 m thick; the overall thickness is up to 300 m (Seager, 1981).

Ts **Tuff of Squaw Mountain (Eocene**)—Cross section only. Densely welded tuff derived from the Organ Caldera (Seager, 1981). U-Pb date is 36.215 ± 0.016 Ma and $^{40}Ar/^{39}Ar$ date is 36.03 ± 0.16 Ma (Rioux et al. 2016; Zimmerer and McIntosh, 2013).

To **Orejon Andesite (Eocene)**—Cross section only. Gray andesite to dacite lava flows and debris flows reported in geothermal well Chaffee 55-25 south of Tortugas Mountain (Seager et al., 1987). U-Pb dates are 43–44 Ma (Creitz et al., 2018).

PALEOZOIC

Phlu **Upper part of the lower Hueco Formation (early Permian)—** Fossil-poor limestone that is tan to yellow-orange, cream, or light-gray and thin- to medium-bedded. It is found on the west side of Tortugas Mountain. Contact with underlying unit **Phll** is not well-exposed and may be gradational over a few meters. The exposed thickness is >5 m.

Phll **Lower part of the lower Hueco Formation (early Permian)—**

Long—

Limestone, dolomite, and dolomitic limestone that are light- to medium-gray (less commonly dark-gray), mostly massive or medium- to very thick-bedded (>20 cm), internally massive or with rare light-colored wavy laminae, and fossil-poor to fossiliferous. Recrystallization is common. Some beds contain occasional to abundant fusulinids that may be disseminated or clustered; these are <1.5–5 mm long. Gastropods, bivalves, horn corals, crinoid stems, and burrows are less common; crinoids are commonly silicified where preserved. A microchonchid tubeworm observed in the lower part of the unit may be *Helicoconchus elongatus* (C. Dunn, pers. comm., 2018). At least one white chert bed is observed near the presumed base of the unit on the east side of Tortugas Mountain. Otherwise, chert occurs as sparse to pervasive lace or, less commonly, as nodules and lenses that are white or sometimes gray. Extensive silicification and local barite/fluorite mineralization may be encountered along fracture zones. The minimum thickness is 305 m.

Short—

Limestone, dolomite, and dolomitic limestone that are light- to medium-gray and massive to wavy laminated. Fossils include fusulinids and a few gastropods, bivalves, horn corals, and crinoid stems, and tubeworms; these are commonly silicified. Chert occurs as lace or nodules. Extensive silicification and local barite/fluorite mineralization may be encountered along fracture zones. The minimum thickness is 305 m.

IPps **Panther Seep Formation (Late Pennsylvanian)—**

Long—

Sandstone, limestone, and breccia that are poorly exposed. Breccia consists of mostly white (rare gray), angular, pebble- to cobble-sized chert fragments in a reddish-yellow, clayey matrix. Sandstone is up to 2 m thick and consists of massive to horizontal-planar or perhaps cross-laminated, very fine siliceous grains. Below the sandstone is dark-gray limestone containing lenses, nodules, and beds of brown (minor white) chert. Seager et al. (1987) note that this unit includes shale and siltstone elsewhere. The exposed thickness is <45 m.

Short—

Sandstone, limestone, and breccia that are poorly exposed. Breccia consists of white, angular, pebble- to cobble-sized chert fragments in a reddish-yellow, clayey matrix. Sandstone is up to 2 m thick and consists of massive to laminated, very fine siliceous grains. Below sandstone is dark-gray limestone containing lenses, nodules, and beds of brown (minor white) chert. The exposed thickness is <45 m.

IPlc **Lead Camp Limestone (Late Pennsylvanian)**—Cross section only. Limestone and dolomite are intercalated with shale and minor sandstone and conglomerate in the lower third of the unit (Seager et al., 1987). The thickness is about 200 m in the Organ Mountains (Seager, 1981).

CM **Undifferentiated Cambrian to Mississippian sedimentary rocks (Cambrian to Mississippian)**—Cross section only. Dolomite, limestone, shale, and subordinate sandstone.

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