Geologic Map of the Paraje Well 7.5-Minute Quadrangle, Socorro County, New Mexico

By

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Open-file Digital Geologic Map OF-GM 286

Scale 1:24,000

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Executive Summary

The Paraje Well quadrangle is located 190–200 km (≈120 mi) south of Albuquerque in the southeastern San Marcial basin of the southern Rio Grande rift. This basin lies between the east-tilted, southern Socorro basin to the northeast and the east-tilted Engle basin to the south. The Rio Grande flows southwest through the center of the quadrangle, whose 1–3 km wide floodplain is periodically inundated by Elephant Butte Lake when the reservoir is filled to near-capacity. On the west side of the floodplain lies mesas dissected by canyons 15–30 m (50–100 ft) deep. To the east lies a low geomorphic bench, mostly covered by a basalt of the Jornada del Muerto volcanic field, followed by a gentle, sandy slopes ascending to a higher basalt-capped surface.

Although the area once hosted 1,300–2,200 people between 1880 and 1920 (Marshall and Walt, 1984), today the San Marcial basin is home to <70 people. The establishment of Elephant Butte Reservoir, whose upper end extends into the quadrangle, in addition to major floods along the Rio Grande in 1929 and 1936 are the main reasons for the drastic drop of population. What was once farmlands and fields has been transformed into a riparian woodland dominated by tamarisks.

Surficial sediment overlies most of the quadrangle with mostly eolian and sheetflood sediment to the east of the Rio Grande and various alluvial allostratigraphic units to the west of the Rio Grande. Eolian sediment (primarily late Holocene in age) consists of sand sheets with variable amounts of low dunes. Dune forms are mostly 0.2–2 m tall and include coppice, irregular, or longitudinal forms. Longitudinal dunes typically trend 060–070°. In the Holocene, the eolian sediment has commonly been reworked into sheetflood deposits, which are characterized by massive, very fine- to medium-grained sand and silty–clayey sand with minor, scattered, coarser sand grains and pebbles. This sheetflood sediment commonly hosts weakly developed, cumulic, buried soils with Stage I carbonate morphology.

Alluvial allostratigraphic units to the west of the Rio Grande floodplain post-date 800 ka (minimum age of the Santa Fe Group) and occupy valley-floor positions, valley-margin alluvial fan deposits, and several terrace and piedmont allostratigraphic units. Valley-floor deposits and valley-margin alluvial fan deposits can be differentiated into younger alluvium, historic alluvium, and modern alluvium. The younger alluvium is assigned to a low-level terrace deposit whose tread stands 0.5–4 m above the modern drainage. The associated geomorphic surface is relatively smooth, lacks bar-and-swale topography, and features a weak desert pavement. The topsoil of the younger alluvium is characterized by calcic horizon(s) with visually detectable Stage I to I(+) carbonate morphologies (clast surfaces are partially to wholly covered by $CaCO_3$ coats but the matrix is not whitened; Gile et al., 1966). The historic and modern alluvium differ from the younger alluvium allostratigraphic unit in several aspects: (1) they have less sand beds, and the sand beds that are present commonly feature internal laminations; (2) their geomorphic surfaces exhibit bar-and-swale topography; and (3) these deposits lack notable topsoil development, with no visible calcium carbonate coats on clast surfaces. The historic alluvium underlies treads that are mostly 1–1.5 m above the modern alluvium, the deposit is 1–2 m thick (thickening to 3 m towards the Rio Grande floodplain), and the unit is inferred to be 10–100 years old. The modern alluvium is relatively sparsely vegetated, sports steep-walled channels, exhibits 0.1–0.6 m of bar-and-swale topography, and is inferred to have been active within the past 10 years.

Two middle Pleistocene piedmont deposits comprise extensive allostratigraphic units above Holocene-age valley-floor units. Both become finer-grained eastwards (down-gradient), and near the Rio Grande both exhibit coarsening-upward trends. Their surfaces exhibit petrocalcic horizons with Stage III to IV carbonate morphologies. The higher of these piedmont deposits is 1–12 m thick (thickening eastwards) and underlies an extensive, high-level geomorphic surface associated with the Nogal Canyon fan. Its tread and base are 3–6 m above those of the lower piedmont deposits.

The lower piedmont deposit is informally referred to as the San Marcial formation, which thickens eastward from 2–6 m to 25 m. The San Marcial formation consists of a cobble-rich, reddish sandy gravel that laterally grades eastward, and extends over, a brownish sand and pebbly sand. The sand–pebbly sand unit interfingers eastward with a fine-grained, marginal basin-floor deposit, which in turn interfingers eastward into an axial-fluvial sand. The axial fluvial sand overlies an extensive sandy gravel that contains exotic gravel and an obsidian correlated to the 1.44 Ma Rabbit Mountain obsidian in the Jemez Mountains. The top (tread) of the San Marcial Formation is 12–30 m (40–100 ft) above modern grade and its base always lies above modern grade.

Inset into the San Marcial formation are four terrace levels. All of them are a sandy gravel with minor pebbly sand or sand. The middle two are termed the “middle-level terrace suite,” which are roughly midway up between the Holocene valley-floor and the tread of the San Marcial formation. Topsoil development is Stage II to II(+) on relatively stable surfaces. The middle-level terrace suite appears to project eastward to a 11–12 m-thick, axial-river fill terrace capped by a of 78.1± 3.2 ka basalt (age from Sion et al., 2020). Thus, we infer that the middle-level terrace suite shortly predates 78 ka. The sandy gravel of the lowest terrace level is 1–5 m thick and commonly browner and less consolidated than higher terraces. Its tread height is 2–7 m above the valley floor and topsoil development is characterized by a Stage I(+) to II calcic horizons. We infer an age of the latest Pleistocene for the lower terrace.

These previously mentioned alluvial deposits are inset into or unconformably overlie the Santa Fe Group. The Santa Fe Group represents clastic deposits associated with the Rio Grande rift, prior to regional incision that occurred ca. 830 Ma (Sion et al., 2020). Exposed Santa Fe Group on the Paraje Well quadrangle consists of the Palomas Formation. Three interfingering lithofacies assemblages were mapped in the Palomas Formation (listed east to west): axial-fluvial, basin-floor marginal facies, and distal piedmont. Extending from the eastern quadrangle boundary to 2.5 km west of the modern floodplain is the axial-fluvial lithofacies. This deposit is weakly to moderately consolidated, light-colored, and generally lacks fine-grained intervals. The deposit is composed of light-brownish-gray to white sand with <25% pebbly beds and <10% mud (clay–silt) beds. The sand is horizontal-planar-laminated to cross-laminated, mainly fine- to coarse-grained, and composed of quartz, minor vitreous feldspar (plagioclase and sanidine), 10–25% orangish grains (mostly composed of chert and potassium feldspar with lesser granite), 1025% gray to dark-colored lithic grains, and 1–3% mafic grains. The sand is "clean," having <0.5% clay in the matrix. Pebbly sand (comparably minor sandy pebbles beds) occur as very thin to medium (lesser thick), lenticular beds or are cross-stratified. Gravel composition is as follows: ≈50–60% felsic volcanic rocks, 1–10% intermediate volcanic rocks (mostly light-gray and hornblende- or pyroxene-phyric), 1–15% chert, 1–20% orange granite, 0.5–5% quartzite, 1% quartz, <25% sedimentary clasts (sandstone, siltstone, and limestone), trace to 0.5% Pedernal Chert, and <1% foliated metamorphic clasts (gneiss, schist, and amphibolite). Clast diversity, particularly the proportion of exotic clasts, increases up-section.

West of the axial-fluvial lithofacies assemblage lies redder sediment containing 1–15% gravelly bodies whose clasts are wholly volcanic. The distal piedmont lithofacies assemblage is characterized by tabular-bedded, very fine- to fine-grained sand and silty–clayey very fine to fine sand. The fine sand is in thick beds that are internally massive (locally horizontal-planar-laminated). These fine sand beds commonly contain minor (0.5–15%), scattered, medium to very coarse grains of out-sized sand and trace to 15% scattered very fine to coarse volcanic pebbles. The internally massive beds and out-size sand grains are consistent with deposition by hyper-concentrated flows. Between the axial-fluvial lithofacies and piedmont lithofacies assemblages lies a fine-grained, transitional unit. This transitional unit contains ≤1% volcanic-pebble beds and consists of very fine- to fine-grained sand, silty fine sand, silt, and clay. The strata are in very thin to very thick, tabular beds that are internally massive (minor horizontal-planar-laminated).

Hard rocks on the Paraje Well quadrangle include Upper Cretaceous strata and Upper Pleistocene basalt flows. The Cretaceous rocks are probably syn-Laramide (Lucas et al., 2019) and consist of >40 m of well-cemented sandstone with minor pebbly sandstone beds and minor fine-grained beds. Much-younger, olivine-phyric basalt flows were mapped east of the Rio Grande, whose source was the Jornada del Muerto volcano. The lower flow is the more extensive of the two. It flowed down the low-sloping escarpment east of the river in small paleovalleys inset into the axial-fluvial facies of the Palomas Formation, and then spread out onto the top of the thick axial fill terrace immediately east of the modern Rio Grande floodplain—providing age control for the middle-level terrace suite. This lower flow returned three $^{40}Ar/^{39}Ar$ ages: 0.0781± .0032 Ma (Sion et al., 2020) together with 0.072.0±.0003 Ma and 0.139±0.015 Ma (Matt Heizler of the NM Bureau of Geology and Mineral Resources, pers. comm., Dec. 11, 2020).

Noteworthy structural elements on the Paraje Well quadrangle include two fault zones. Low scarps or slope changes on the San Marcial formation tread, in addition to three fault exposures of the Palomas Formation, are used to map a northwest-trending graben in the western part of the quadrangle. Normal to left-lateral, oblique-normal faults associated with this graben have vertically offset (by >5 m) lower Pleistocene strata of the Palomas Formation (piedmont lithofacies assemblage). Less than 2 m of vertical displacement occurred on some fault strands after the formation of the ca. 200(?) ka San Marcial geomorphic surface. The aforementioned escarpment east of the river approximately coincides with a notable west-down gravity gradient, which we attribute to a west-down fault called the Paraje Well fault. This fault may possibly have moved as much as 15 m since 1.44 Ma.

Description of Map Units

QUATERNARY

Anthropogenic Units

afd Disturbed land and anthropogenic fill

Recent (<100 years old)

Long—

The unit represents altered ground and thick accumulations of sediment (primarily sand, minor gravel, clay, and silt) used as fill for levees and berms. The deposit is 1–6 m thick.

Short—

The unit represents altered ground and thick accumulations of sediment (primarily sand, minor gravel, clay, and silt) used as fill for levees and berms. The deposit is 1–6 m thick.

ae Excavated ground

Recent (<100 years old)

Long—

The unit represents excavations associated with stock tank impoundments and borrow pits.

Short—

The unit represents excavations associated with stock tank impoundments and borrow pits.

Eolian and Sheetflood Units Outside of Valley Floors

Locally, underlying map units are noted using a backslash (i.e., Qes/underlying unit).

Qe Eolian sand

Late Holocene to recent (historic + modern)

Long—

Loosely consolidated, fine- to medium-grained sand that forms dunes, sheets, or ramps (the latter along the margins of basalt flows). The dune forms are mostly 0.3–2 m tall and include coppice, irregular, or longitudinal forms; longitudinal dunes typically trend 060–070°. The available exposures lack cross-stratification. The sand is light-brown (7.5YR 6/4), well-sorted, subangular to rounded (mostly subrounded), fine-upper- to medium-upper-grained (fU–mU), and <10% coarse-lower-grained (cL), which is composed of quartz, 15–25% feldspar, and 5–18% lithics (e.g., mafics). Surface clast coverage is typically no more than 5% over a 30-m2 area. The deposit is 0.3–2 m thick.

Short—

Loosely consolidated, light-brown (7.5YR 6/4) sand that forms 0.3–2 m tall dunes, sheets, or ramps (the latter along the margins of basalt flows). The dunes are mostly internally massive and include coppice, irregular, or longitudinal forms. The sand consists of well-sorted, mostly subrounded, and is fine- to medium-grained. Surface clast coverage is typically no more than 5%. The deposit is 0.3–2 m thick.

Qeb Eolian sand with subordinate outcrops of basalt

Late Pleistocene to recent (historic + modern)

Long—

Mapped where small (not mappable at 1:24,000) basalt outcrops occur within predominately eolian sand sheets or dunes. See individual descriptions for units Qe and Qb.

Short—

Mapped where small (not mappable at 1:24,000) basalt outcrops occur within predominately eolian sand sheets or dunes. See individual descriptions for units Qe and Qb.

Qes Eolian sand and minor sheetflood deposits

Middle to Late Holocene

Long—

Loosely consolidated sand that underlies eolian sheets, coppice dunes, irregular dune forms, and small blowouts (<0.75 m deep). The sand is grayish-brown to brown (10YR 5/2–3) in the western quadrangle but brown to light-brown to strong-brown (7.5YR 5–6/4, 5/6) in the eastern quadrangle, non-calcareous, massive to low-angle planar cross-stratified or laminated, moderately to moderately well-sorted, subangular to well-rounded, and very fine- to medium-grained (mostly fine to medium). The grains are composed of 75–80% quartz, 10–15% lithics (volcanic and ferromagnesian minerals), and 10–25% feldspar with no clay. Occasional to common (3–30%), fine- to very coarse-grained pebbles at the surface are weathered from the underlying basin-fill units. Topsoil development is weak to non-existent. In the eastern half of the quadrangle, this unit is mapped where dune forms are present and the sand exhibits an orangish color. The dunes commonly overlie burrowed and massive, fine- to medium-grained, orangish sand exhibiting pedogenesis (subangular blocky ped development, faint and sparse illuviated clay on ped faces, and Stage I carbonate morphology). There is no more than 5% surficial pebble coverage over a 30-m2 area. The deposit is generally less than 2–2.5 m thick.

Short—

Loosely consolidated sand that underlies eolian sheets, coppice dunes, irregular dune forms, and small blowouts. The sand is fine- to medium-grained and is grayish-brown to brown (10YR 5/2–

3) in the west and light- to strong-brown (7.5YR 5–6/4, 5/6) in the east. There are occasional to common (3–30%) pebbles at surface. The topsoil development is weak to non-existent, but in the eastern quadrangle, deeper sand is pedogenically altered. The deposit is <2–2.5 m thick.

Qesc Eolian sand, sheetflood, and colluvium, undivided

Holocene

Long—

Loosely consolidated sand with subordinate pebble or pebble to cobble gravel found on the lee sides of ridges or terraces. The sand is similar in color and texture to unit Qes and massive to cross-stratified or laminated. The gravel is poorly sorted and mostly subangular to subrounded. The deposit is commonly vegetated with little or no soil development. The deposit is 3–4 m thick, maximum.

Short—

Loosely consolidated sand with subordinate pebble or pebble to cobble gravel found on the lee sides of ridges or terraces. The sand is similar in color and texture to unit Qes and massive to cross-stratified or laminated. The gravel is poorly sorted and mostly subangular to subrounded. The deposit is commonly vegetated with little or no soil development. The deposit is 3–4 m thick, maximum.

Qsy Younger sheetflood deposits

Holocene

Long—

Massive, very fine- to medium-grained sand (mostly very fine- to fine-grained) and clayey to silty sand with minor, scattered coarser sand and 1–15% pebbles (mostly very fine- to coarse-grained); silt to clay content is <20%. The sand is brown (7.5YR 5/4) to light-reddish-brown (5YR 6/3) and poorly to moderately sorted. Very thin to thin, lenticular beds (0.5–3%) of sandy pebbles (pebbles are mostly very fine- to coarse-grained). Cumulic buried soils are common and manifested by ped development (medium- to coarse-grained, subangular blocky, and hard), faint clay illuviation features, bioturbation, and Stage I calcic soils. The deposit is locally overlain by 1–20 cm of well-stratified, non-pedogenically modified, pebbly sand or sand inferred to be <100 years old. These beds are very thin and tabular to lenticular and the sediment consists of fine- to very coarse-grained, subrounded to subangular, poorly sorted sand that is dominated by volcanic grains. The deposit is 1–3 m thick.

Short—

Massive, very fine- to medium-grained sand and clayey to silty sand with minor, scattered coarser sand and 1–15% pebbles; clay to silt content is <20%. Very thin to thin, lenticular beds (0.5–3%) of sandy pebbles. Buried soils are common (Stage I calcic horizons and local clay illuviation). Locally overlain by 1–20 cm of well-stratified sand and pebbly sand with no topsoil development. The deposit is 1–3 m thick.

Qse Sheetflood deposits with minor eolian sand

Holocene

Long—

Moderately consolidated sheetflood deposits inferred to have reworked a notable proportion of eolian sand; the unit is mapped east of the Rio Grande and includes surficial eolian sand sheets. Eolian deposits are typically in sheets rather than dune forms; see detailed descriptions of units Qe and Qes. Sheetflood deposits consist of pink (7.5YR 7/3–4) to strong- or light-brown (7.5YR 4–5/6, 6/4), massive, very fine- to medium-grained sand and clayey to silty sand; clay to silt content may be up to 15%. Sheetflood deposits are typically pedogenically modified and characterized by burrowing; strong to moderately developed, medium- to coarse-grained, subangular peds; faint illuviated clay films on ped faces; and Stage I carbonate morphology. The surficial gravel coverage (mainly pebbles) is 0–15%. The deposit likely averages 2–3 m thick.

Short—

Moderately consolidated sheetflood deposits with reworked eolian sand; the unit is mapped east of the Rio Grande and includes surficial eolian sand sheets. Sheetflood deposits consist of pink (7.5YR 7/3–4) to strong- or light-brown (7.5YR 4–5/6, 6/4), massive, very fine- to medium-grained sand and clayey to silty sand (up to 15% clay to silt) that may be pedogenically modified with Stage I carbonate morphology. The deposit likely averages 2–3 m thick.

Qsaey Younger sheetflood and alluvial deposits reworking eolian sand, undivided

Holocene

Long—

Similar to unit Qasy and composed mainly of fine- to coarse-grained sand. The sand is interpreted to be predominately reworked eolian sand via sheetflooding and alluvial processes. The eolian sand was sourced from the inner Rio Grande valley. See description for unit Qasy. The deposit is possibly up to 5–7 m thick.

Short—

Similar to unit Qasy and composed mainly of fine- to coarse-grained sand. The sand is interpreted to be predominately reworked eolian sand via sheetflooding and alluvial processes. The eolian sand was sourced from the inner Rio Grande valley. See description for unit Qasy. The deposit is possibly up to 5–7 m thick.

Rio Grande Valley-floor Units

The following units were mapped primarily using 2014 aerial imagery from the National Agriculture Imagery Program (NAIP). Features likely postdate ≈1990, when Elephant Butte Reservoir was last filled to capacity. All units are underlain by historic/younger alluvium (Qah/Qay).

Rw14 Water

Modern

Long—

Flowing or standing water apparent in 2014 digital aerial imagery.

Short—

Flowing or standing water apparent in 2014 digital aerial imagery.

Rcb Rio Grande bar deposits

Modern

Long—

Unvegetated, longitudinal bars of sand and perhaps minor gravel that is apparent in 2014 digital aerial imagery.

Short—

Unvegetated, longitudinal bars of sand and perhaps minor gravel that is apparent in 2014 digital aerial imagery.

Rch Rio Grande channel deposits

≈40 years old to modern

Long—

Areas of the Rio Grande floodplain with banded surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. These textures mostly parallel the axis of the modern floodplain. The unit is laterally gradational with unit Rcs (modified from Cikoski [2018]).

Short—

Areas of the Rio Grande floodplain with banded surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. These textures mostly parallel the axis of the modern floodplain. The unit is laterally gradational with unit Rcs (modified from Cikoski [2018]).

Rcs Rio Grande channel-splay deposits

≈40 years old to modern

Long—

Areas of the floodplain with fanning/distributary surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. Commonly, distributary textures can be traced back to current or former locations of the Rio Grande channel, including one splay that breached a conveyance channel after 1978. The unit is laterally gradational with unit Rch (modified from Cikoski [2018]).

Short—

Areas of the floodplain with fanning/distributary surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. Commonly, distributary textures can be traced back to current or former locations of the Rio Grande channel, including one splay that breached a conveyance channel after 1978. The unit is laterally gradational with unit Rch (modified from Cikoski [2018]).

Rsb Rio Grande scroll-bar deposits

≈40 years old to modern

Long—

Areas of the floodplain with scrolled surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. These textures are composed of tightly parallel, arcuate shapes formed by migration of the river channel. The unit mostly predates units Rch and Rcs, although a few scrolls have formed between 2005 and 2014.

Short—

Areas of the floodplain with scrolled surface textures (such as vegetation trends) that are apparent in 2014 digital aerial imagery. These textures are composed of tightly parallel, arcuate shapes formed by migration of the river channel. The unit mostly predates units Rch and Rcs, although a few scrolls have formed between 2005 and 2014.

Rau Rio Grande undifferentiated deposits, primarily floodplain alluvium

≈40 years old to modern

Long—

Areas of the floodplain with non-distinct surface textures. This includes areas of the floodplain that have been artificially disturbed by land management or former agricultural activities such that primary surface textures are unrecognizable (modified from Cikoski [2018]).

Short—

Areas of the floodplain with non-distinct surface textures. This includes areas of the floodplain that have been artificially disturbed by land management or former agricultural activities such that primary surface textures are unrecognizable (modified from Cikoski [2018]).

Rlls Lakeshore deposits

≈40 years old

Long—

Loosely consolidated gravelly sand associated with the highstands of Elephant Butte Reservoir. The sediments are principally reworked from the underlying deposits and tributary alluvium. The unit is only mapped where it is particularly thick or extensive or where it masks underlying geologic relationships. The deposit is <4 m thick (modified from Cikoski [2018]).

Short—

Loosely consolidated gravelly sand associated with the highstands of Elephant Butte Reservoir. The sediments are principally reworked from the underlying deposits and tributary alluvium. The unit is only mapped where it is particularly thick or extensive or where it masks underlying geologic relationships. The deposit is <4 m thick (modified from Cikoski [2018]).

Valley-floor Units

Many of the valley-floor map units reflect combinations of deposits, such as combined younger alluvium and modern alluvium (Qaym). In these combined units, the unit with the largest exposed area is shown first, followed by the unit with the lesser area of exposure. Where modern and historic deposits are subequal (±20%) the resulting map unit is called recent and abbreviated as Qar.

Qam Modern alluvium

Modern

Long—

Loosely consolidated gravelly sand and gravel that forms bars which underlie channels in ephemeral drainages, inferred to be <10 years old and likely to be fluvially active after high-intensity storm events. The gravel consists of pebbles, minor cobbles, and 1–10% boulders. The gravel is clast-supported, subrounded (mostly) to subangular, poorly (minor moderately) sorted, and composed of felsic-rich volcanic rocks with <5% intermediate volcanic rocks that include feldspar-phyric varieties. The sand is brown to grayish-brown (10YR 7/2–6/3–5/2; 6/1–6/2; 7.5YR 5/4), subrounded (mostly) to subangular, and poorly sorted. The sand grain sizes range from fine-upper- to very coarse-upper-grained (fU–vcU) with mostly medium-upper- to very coarse-upper-grained (mU–vcU) and ≤10% very fine-lower to fine-lower-grained (vfL–fL) sand. West of the Rio

Grande, the sand is composed of volcanic grains with subordinate feldspar and quartz. East of the Rio Grande, the sand composition is dominated by quartz and feldspar grains (minor mafic-lithic). There is very little to no interstitial clay. The bar forms are mostly longitudinal and underlain by well-graded pebbles through coarse cobbles. No topsoil is present. The vegetation density is sparse to moderate. Bar-and-swale topography and occasional to common steep-walled channels characterize the surface, exhibiting up 0.1–0.6 m of relief. The deposit is 1–4(?) m thick.

Short—

Loosely consolidated gravelly sand and gravel that underlie active channels in ephemeral drainages, very likely <10 years old. The gravel consists of pebbles, minor cobbles, and 1–10% boulders. The sand is brown to grayish-brown (7.5–10YR) with most grain sizes in the mU–vcU range. Bar-and-swale topography and steep-walled channels characterize the surface, exhibiting up to 0.1–0.6 m of relief. The deposit is 1–4(?) m thick.

Qah Historic alluvium

Historic (10 to ≈150 years old)

Long—

Well-stratified, very thin- to thin-bedded, sandy gravel and pebbly sand (with minor non-gravelly sand) that underlies low terraces in valley bottoms. The unit lacks notable topsoil development and bar-and-swale topography is evident in the gravelly sediment. The unit typically overlies Qay across a sharp contact. The sediment forms very thin to thin (lesser medium-bedded) tabular to lenticular beds (internally massive to horizontal-planar-laminated with very minor ripple marks) and has very minor cross-stratification. The gravel consists of clast-supported pebbles with 1–20% cobbles, which are subrounded (mostly) to subangular and poorly (locally moderately) sorted within a bed. West of the Rio Grande, the clasts are composed of felsic volcanic clasts with <5% intermediate volcanic clasts. The sand is brown (7.5YR 5/3–4) to strong-brown (7.5YR 5/6) to light-brown (7.5YR 6/4), fine- to very coarse-grained, subrounded to subangular, poorly sorted, and composed mostly of volcanic lithics with subordinate quartz and feldspar. The deposit lacks interstitial clay; however, locally, the sand may have 1–10% silt. The deposit may feature <10% lenses of massive to vaguely low-angle cross-stratified sand similar to the gravel matrix. Locally, there is a 5–10 cm thick cap of light-brown to light-yellowish-brown (7.5–10YR 6/4), very fine- to fine-grained sand and silty sand, variably mixed with minor pebbles and medium-lower to very coarse-upper-grained (mL–vcU) sand. Loose to weakly consolidated. The unit lacks notable topsoil development, in particular it lacks moderate to strong ped development and typically lacks visual evidence for CaCO3 accumulation; however, locally, there may be 1–15% clast coverage by very thin coats (<0.1 mm) of CaCO3; weak to no effervescence in HCl. The surface lacks a desert pavement (20–98% surface-clast density, no Av peds, and no clast varnish). There is a higher variety of shrubs compared to Qay. Bar-and-swale topography has 1–20 cm of relief with minor erosional gullies up to 60 cm in depth. The tread height is typically 1–1.5 m. The deposit is 0.1–2 m thick.

Short—

Well-stratified sandy gravel, pebbly sand, and sand that underlies low terraces (1–1.5 m tread height) in valley bottoms. Very thin- to medium-bedded, tabular to lenticular beds (internally massive to horizontal-planar-laminated; very minor ripple marks). The unit lacks notable topsoil development and bar-and-swale topography is evident in gravelly sediment; it often overlies Qay across a sharp contact. The deposit is 0.1–2 m thick.

Qamh Modern and historic alluvium, undivided

Modern (<10 yrs old) and Historic (10 to ≈150 years old)

Long—

The unit is composed of modern alluvium (Qam) and subordinate historic alluvium (Qah). See detailed descriptions of each respective unit. The deposit is 0.5–2 m thick.

Short—

The unit is composed of modern alluvium (Qam) and subordinate historic alluvium (Qah). See detailed descriptions of each respective unit. The deposit is 0.5–2 m thick.

Qahm Historic and modern alluvium, undivided

Modern (<10 yrs old) and Historic (10 to ≈150 years old)

Long—

The unit is composed of historic alluvium (Qah) and subordinate modern alluvium (Qam). See detailed descriptions of each respective unit. The deposit is 0.5–2 m thick.

Short—

The unit is composed of historic alluvium (Qah) and subordinate modern alluvium (Qam). See detailed descriptions of each respective unit. The deposit is 0.5–2 m thick.

Qar Recent (historic + modern) alluvium

Recent (historic + modern)

Long—

The unit is composed of historic alluvium (Qah) and modern alluvium (Qam) in subequal (±20%) proportions. See descriptions of units Qam and Qah. It is weakly consolidated and 0.5–3 m thick.

Short—

The unit is composed of historic alluvium (Qah) and modern alluvium (Qam) in subequal (±20%) proportions. See descriptions of units Qam and Qah. It is weakly consolidated and 0.5–3 m thick.

Qary Recent (historic + modern) alluvium and younger alluvium, undivided

Recent (historic + modern) and Early to Late Holocene, respectively

Long—

The unit is composed of recent alluvium (Qar) and subordinate younger alluvium (Qay). See detailed descriptions of Qam, Qah, and Qay. The deposit is 0.5–4 m thick.

Short—

The unit is composed of recent alluvium (Qar) and subordinate younger alluvium (Qay). See detailed descriptions of Qam, Qah, and Qay. The deposit is 0.5–4 m thick.

Qahy Historic and younger alluvium, undivided

Historic and Early to Late Holocene, respectively

Long—

The unit is composed of historic alluvium (Qah) and subordinate younger alluvium (Qay). See detailed descriptions of each respective unit. The deposit is 0.5–4 m thick.

Short—

The unit is composed of historic alluvium (Qah) and subordinate younger alluvium (Qay). See detailed descriptions of each respective unit. The deposit is 0.5–4 m thick.

Qay Younger alluvium west of the Rio Grande

Early to Late Holocene

Long—

Brownish sand, pebbly sand, slightly clayey to silty fine sand, and sandy gravel underlying valley-bottom terraces whose heights are 0.5–2.5 m above modern grade. The sediment features weakly developed, buried soils and the geomorphic surface is weakly to very weakly varnished, relatively smooth (except for local subtle relief by cobbly bars), and has calcic horizons with Stage I to I(+) carbonate morphologies. The sand and pebbly sand beds are typically medium- to thick-bedded, relatively tabular, and internally massive (rarely horizontal-planar-laminated). The sandy gravel beds are very thin- to medium-bedded and lenticular to tabular (internally horizontal-planar-laminated to massive). The gravel consists of pebbles (very fine- to very coarse-grained) with 0–20% cobbles and 0–3% boulders that are subrounded to subangular and moderately to poorly sorted (mostly subrounded and poorly sorted), and clast-supported. The gravel is composed predominately of felsic volcanic rocks with minor feldspar porphyries and minor intermediate volcanic rocks. The matrix of the sandy gravel consists of brown (7.5YR 5/4) to gray to pinkish-gray (7.5YR 6/1–2), fine- to very coarse-grained, subrounded to subangular (mostly subrounded), poorly sorted sand dominated by volcanic grains with minor feldspar and quartz. The pebbly sand and sand beds, including slightly clayey to silty (1-15% fines dominated by silt) fine sand beds, are light-brown (7.5YR 6/3–4) to brown to yellowish-brown (7.5–10YR 4–5/4); very fine- to medium-grained; subrounded to subangular; and have minor (mostly 1–20%), scattered, coarse to very coarse sand grains with trace to 15% scattered pebbles. These sandy beds typically contain 1–25% interbeds composed of sandy pebbles or pebbly sand (lenticular, very thin- to thin-bedded, and less commonly medium-bedded). Buried soils exhibit subangular blocky, hard ped development, Stage I calcic horizons, and faint to no clay illuviation (as 1–10% bridges or 1–25% clay films on ped faces). The topsoil is 20–60 cm thick and has calcic horizons (Bk), which are characterized by $CaCO_3$ coats around >15% of clast surfaces and weak to moderate, fine- to coarse-grained, subangular blocky, and slightly hard ped development. On older and stable surfaces, there are illuviated clay horizons (Btk horizons) in the upper part of the soil with faint films on ped faces, pores, or clast coatings. The topsoil calcic horizons exhibit Stage I to I(+) morphology and very rarely Stage II. The geomorphic surface sports a very weakly developed desert pavement (80–100% clast density, weak Av peds, weak to no clast varnish) and typically lacks bar-and-swale relief, although cobbly bars may still have a subdued (up to 0.1 m) surficial expression and erosion may produce local channels up to 30 cm deep. The tread height is 0.5–2.5 m above the active channel and the riser with adjoining Qah is commonly 0.5–1 m tall. The unit is weakly to moderately consolidated and typically effervesces in HCl. The deposit is 1–5(?) m thick.

Short—

Brownish sand, pebbly sand, slightly clayey to silty fine sand, and sandy gravel underlying valley-bottom terraces whose treads are 0.5–2.5 m above modern grade; weakly developed, buried soils with Stage I carbonate morphologies. The surface has a very weak desert pavement, is relatively smooth with local subtle relief by cobbly bars, and has Stage I to I(+) calcic horizons. The deposit is 1–5(?) m thick.

Qaym Younger and modern alluvium west of the Rio Grande, undivided

Early to Late Holocene and modern, respectively

Long—

The unit is composed of younger alluvium (Qay) and subordinate modern alluvium (Qam). See detailed descriptions of each unit. The deposit is 1–4 m thick.

Short—

The unit is composed of younger alluvium (Qay) and subordinate modern alluvium (Qam). See detailed descriptions of each unit. The deposit is 1–4 m thick.

Qayh Younger and historic alluvium west of the Rio Grande, undivided

Early Holocene to historic

Long—

The unit is composed of younger alluvium (Qay) and subordinate historic alluvium (Qah). See detailed descriptions of each unit.

Short—

The unit is composed of younger alluvium (Qay) and subordinate historic alluvium (Qah). See detailed descriptions of each unit.

Qayr Younger and recent (historic + modern) alluvium west of the Rio Grande, undivided

Early Holocene to modern

Long—

The unit is composed of younger alluvium (Qay) and subordinate recent alluvium (Qar). See detailed descriptions of each unit. The deposit is 1–4 m thick.

Short—

The unit is composed of younger alluvium (Qay) and subordinate recent alluvium (Qar). See detailed descriptions of each unit. The deposit is 1–4 m thick.

Qayax Younger alluvium deposited by the axial river (Rio Grande)

Early to Middle Holocene

Long—

Former terrace deposit consisting of axial sand and very minor pebbles. Similar to unit Qtax; however, it contains less gravel. Tread was 5–6 m above the floodplain before creation of Elephant Butte Reservoir (U.S. Bureau of Reclamation topographic map dated 1908; map no. 24-PT-503-14). Now, the tread is about the same elevation as the modern Rio Grande floodplain. Qayax possibly correlates with unit Qayo. The deposit is 2–6(?) m thick.

Short—

Former terrace deposit consisting of axial sand and very minor pebbles. Similar to unit Qtax; however, it contains less gravel. Tread was 5–6 m above the floodplain before creation of Elephant Butte Reservoir (U.S. Bureau of Reclamation topographic map dated 1908; map no. 24-PT-503-

14). Now, the tread is about the same elevation as the modern Rio Grande floodplain. Qayax possibly correlates with unit Qayo. The deposit is 2–6(?) m thick.

Qayo Older subunit of the younger alluvium west of Rio Grande

Early to Middle Holocene

Long—

Loosely consolidated, brownish sand, gravel, and pebbly sand with likely interbeds of sand and clayey to silty fine sand. Similar to unit Qay; however, it appears to contain slightly more gravel. The gravel is composed of subrounded, light-gray, felsic-dominated volcanic clasts with trace speckled-rhyolite porphyry clasts, 3–5% intermediate volcanic clasts, and 0–10% reworked axial gravel; depending on location. The unit underlies valley-bottom terraces whose heights are 2.5–4 m above modern grade. The tread of Qayo lies 2–2.5 m above the general tread level of Qay. The geomorphic surface is very weakly varnished and relatively smooth. Local exposure of topsoil indicates a 20 cm-thick calcic horizon (Bk) with Stage I(+) carbonate morphology, which is locally overlain by a ≈20 cm thick, reddish-brown, illuviated clay horizon (Bt). The sediment appears to be less cobbly than that of the terrace deposits, but lack of exposure makes this inference uncertain. Qayo may possibly correlate to the lowest terrace units (e.g. Qtl, Qtsi1). The deposit is 2–4(?) m thick.

Short—

Brownish sand, gravel, and pebbly sand with likely interbeds of sand and clayey to silty fine sand. Similar to unit Qay; however, it appears to contain slightly more gravel. The sediment appears less cobbly than the lowest terrace deposits (e.g., Qtl, Qtsi1). Tread heights are 2.5–4 m. The geomorphic surface is very weakly varnished and relatively smooth. The topsoil has a Stage I(+) calcic horizon (Bk) locally overlain by illuviated clay horizon (Bt). The deposit is 2–4(?) m thick.

Qaye Younger alluvium east of the Rio Grande

Early to Late Holocene

Long—

Brownish, weakly consolidated, massive sand with 5–15% scattered pebbles. The sand is interbedded with 0.5–10% very thin to thin, lenticular beds of pebbles reworked from the axial-fluvial facies of the Palomas Formation. The sand is light-brown to pale-brown to light-yellowish-brown (10–7.5YR 6/3–4) to pink (7.5YR 7/3), poorly to well-sorted, subangular to subrounded, fine- to coarse-grained (mostly medium-grained with ≤10% very fine-grained sand.) The sand contains 0–10% clay to silt (mostly silt) and 3–12% scattered very coarse grains, which are composed of quartz, minor feldspar, and 15–25% lithic grains. The sand in pebbly beds is mostly medium- to very coarse-grained. The pebbles are poorly to moderately sorted, mostly subrounded, very fine- to coarse-grained (with sparse amounts of very coarse grains), and consist of lithologies that have been reworked from QTpa. The sand and pebbly beds are commonly overprinted by paleosols exhibiting Stage I to II calcium carbonate accumulations in addition to weak to moderate, fine- to very coarse-grained, subangular blocky ped development and very weak to no illuviated clay (sparse, faint clay films as bridges, on ped faces, or lining pores); strong effervescence in hydrochloric acid. The deposit likely averages 2–3 m thick.

Short—

Brownish, massive sand with 5–15% scattered pebbles and 0.5–10% very thin to thin, lenticular beds of pebbles eroded from QTpa. Sand is mostly medium-grained and has 0–10% clay to silt content with 3–12% scattered very coarse grains. Common pedogenesis characterized by ped development, very weak to no illuviated clay, and Stage I to II calcic horizons. The deposit likely averages 2–3 m thick.

Qayre Younger and recent (historic + modern) alluvium, undivided

Early Holocene to modern

Long—

The unit is composed of younger alluvium (Qay) and very minor recent alluvium (Qah + Qam) east of the Rio Grande. See detailed descriptions of each unit.

Short—

The unit is composed of younger alluvium (Qay) and very minor recent alluvium (Qah + Qam) east of the Rio Grande. See detailed descriptions of each unit.

Qayrf Fine-grained younger and recent (historic + modern) alluvium, undivided

Early Holocene to modern

Long—

Very fine- to fine-grained sand, clayey to silty fine sand, and clay to silt deposited on very low gradients or closed topographic depressions east of the Rio Grande (commonly due to blockage of ephemeral streams by dunes). The sediment is brown to light-brown (7.5YR 5–6/4; 5/2–3, 6/3), massive (may be laminated in the upper 1–2 cm), and weakly to moderately consolidated with an overall estimate of 1–25% fines. The deposit is likely 1–3 m thick.

Short—

Very fine- to fine-grained sand, clayey to silty fine sand, and clay to silt deposited on very low gradients or closed topographic depressions east of the Rio Grande (commonly due to blockage of ephemeral streams by dunes). The sediment is brown to light-brown, massive (may be laminated in upper 1–2 cm), and weakly to moderately consolidated with an overall estimate of 1–25% fines. The deposit is likely 1–3 m thick.

Qasy Younger alluvium and sheetflood deposits, undivided

Holocene

Long—

Sandy deposits that consist of interfingering or gradational relationships between younger alluvium (Qay) and sheetflood deposits (Qsy). The unit is commonly strong-brown, reddish-yellow, or light-brown; massive; pedogenically modified; and typically has Stage I carbonate morphology. See detailed descriptions of each unit.

Short—

Sandy deposits that consist of interfingering or gradational relationships between younger alluvium (Qay) and sheetflood deposits (Qsy). The unit is commonly strong-brown, reddish-yellow, or light-brown; massive; pedogenically modified; and typically has Stage I carbonate morphology. See detailed descriptions of each unit.

Alluvial Fan Units

Many of the alluvial fan map units reflect combinations of deposits, such as combined younger alluvium and historic alluvium (Qfyh). In these combined units, the unit with the largest exposed area is shown first, followed by the unit with the lesser area of exposure. Where modern and historic deposits are subequal (±20%), then the resulting map unit is called recent and abbreviated as Qfr.

Qfm Modern fan alluvium

Modern

Long—

Loosely consolidated gravelly sand and sandy gravel that underlie fan channels, bars, and levees. The sand is brown to yellowish-brown (10YR 5/3–4) and consists of very weakly to non-calcareous, very poorly to poorly sorted, angular to rounded, fine- to very coarse grains composed of volcanics, minor quartz, and minor feldspar with no clay. The gravel includes sandy pebble to cobble and pebble to cobble to boulder deposits. Clast proportions include 55–90% pebbles, 10–45% cobbles, and 0–10% small boulders of mostly felsic lithologies reworked from Palomas Formation basin-fill and terrace gravels. Soils are not observed. Bar-and-swale topography characterizes the surface and exhibits up to 0.4–0.5 m of relief. The deposit is <2–3 m thick in most places.

Short—

Loosely consolidated sand and gravel that underlie fan channels, bars, and levees. The sand is brown to yellowish-brown (10YR 5/3–4) and consists of fine to very coarse grains composed of volcanics, minor quartz, and minor feldspar with no clay. Bar-and-swale topography characterizes the surface and exhibits up to 0.4–0.5 m of relief. The deposit is <2–3 m thick in most places.

Qfh Historic fan alluvium

Historic (10 to ≈150 years old)

Long—

Weakly consolidated, well-bedded sandy pebbles and pebbly sand. The unit lacks a notable topsoil and has 3–30 cm tall bar-and-swale topography. The strata are in very thin to thin (minor medium), tabular to lenticular to wedge-shaped beds. The gravel consists of pebbles with 1–30% cobbles that are clast- to sand-supported, poorly to moderately imbricated, subrounded to subangular, poorly sorted within a bed, and composed primarily of felsic volcanic rocks. The sand is brown to dark-brown (7.5YR 3–5/4), fine- to very coarse-grained, subrounded to subangular, poorly sorted, and a volcanic litharenite. The sand matrix has little to no (<7%) clay, is very weakly calcareous, and is weakly consolidated. The surface has a bar-and-swale relief of 3–40 cm, no notable topsoil, clast coverage by CaCO3 is <15% in upper few decimeters, no desert pavement, and no clast varnishing. The deposit is 0.1–3 m thick.

Short—

Weakly consolidated, well-bedded sandy pebbles and pebbly sand; the unit lacks a notable topsoil and has 3–30 cm tall bar-and-swale topography. Strata are in very thin- to thin-bedded (minor medium), tabular to lenticular to wedge-shaped beds. The gravel consists of pebbles with 1–30% cobbles. The sand is dark-brown to brown (7.5YR), fine- to very coarse-grained, and lacks clay (very locally up to 7%). The deposit is 0.1–3 m thick.

Qfmh Modern and historic fan alluvium, undivided

Modern (<10 yrs old) and Historic (10 to ≈150 years old)

Long—

The unit is composed of modern fan alluvium (Qfm) and subordinate historic fan alluvium (Qfh). Qfmh is similar to unit Qamh but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qam and Qah. The unit is weakly consolidated and 1–3 m thick.

Short—

The unit is composed of modern fan alluvium (Qfm) and subordinate historic fan alluvium (Qfh). Qfmh is similar to unit Qamh but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qam and Qah. The unit is weakly consolidated and 1–3 m thick.

Qfhm Historic and modern fan alluvium, undivided

Modern (<10 yrs old) and Historic (10 to ≈150 years old)

Long—

The unit is composed of historic fan alluvium (Qfh) and subordinate modern fan alluvium (Qfm). Qfhm is similar to unit Qahm but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of units Qah and Qam. The unit is weakly consolidated and 1–3 m thick.

Short—

The unit is composed of historic fan alluvium (Qfh) and subordinate modern fan alluvium (Qfm). Qfhm is similar to unit Qahm but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of units Qah and Qam. The unit is weakly consolidated and 1–3 m thick.

Qfr Recent (historic + modern) fan alluvium

Recent (historic + modern)

Long—

The unit is similar to unit Qar but it forms an alluvial fan at the mouths of tributary drainages. See description of units Qah and Qam. The unit is weakly consolidated and 1–3 m thick.

Short—

The unit is similar to unit Qar but it forms an alluvial fan at the mouths of tributary drainages. See description of units Qah and Qam. The unit is weakly consolidated and 1–3 m thick.

Qfhy Younger alluvial fans and slopewash deposits, undivided

Early Holocene to historic

Long—

The unit is similar to historic fan alluvium (Qfh) and subordinate younger fan alluvium (Qfy). Ofhy is similar to unit Qahy but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of units Qah and Qay. The unit is weakly consolidated and 1–4 m thick.

Short—

The unit is similar to historic fan alluvium (Qfh) and subordinate younger fan alluvium (Qfy). Ofhy is similar to unit Qahy but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of units Qah and Qay. The unit is weakly consolidated and 1–4 m thick.

Qfry Recent (historic + modern) and younger fan alluvium, undivided

Early Holocene to modern

Long—

The unit is composed of recent fan alluvium (Qfr) and subordinate younger fan alluvium (Qfy). Qfry is similar to unit Qary but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qah, Qam, and Qay. The unit is weakly consolidated and 1–4(?) m thick.

Short—

The unit is composed of recent fan alluvium (Qfr) and subordinate younger fan alluvium (Qfy). Qfry is similar to unit Qary but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qah, Qam, and Qay. The unit is weakly consolidated and 1–4(?) m thick.

Qfy Younger fan alluvium

Early to Late Holocene

Long—

Weakly consolidated pebble to cobble gravel in thin to thick (25–80 cm), tabular to lenticular to wedge-shaped beds. The gravel is clast- to sand-supported and internally massive to crudely imbricated. The clasts consist of subangular to rounded (mostly subrounded), poorly sorted pebbles (60–90%) and cobbles (10–40%) of >95% felsic volcanic lithologies. The gravel matrix consists of brown (7.5YR 4/2–4 or 5/4), moderately to strongly calcareous, poorly sorted, subangular to rounded, silty, fine- to very coarse-grained sand composed of 70–80% lithic (volcanic), 15–20% quartz, and 10–15% feldspar grains with up to 10% brownish clay films. The topsoil has ped development with typically weak and slightly hard, subangular blocky peds. A Stage I calcic horizon which is locally overlain by an illuviated clay (Btk) horizon is observed in the upper 20–40 cm. There is a weak desert pavement with varnish on no more than 10% of surface clasts, 90–95% surface-clast density, and no Av peds. The bar-and-swale topographic relief is up to 10–20 cm. The tread height is 1–2.5 m above modern grade (minimum thickness).

Short—

Weakly consolidated pebble to cobble gravel in thin to thick, tabular to lenticular to wedge-shaped beds. The gravel is clast- to sand-supported. The matrix is brown (7.5YR), fine- to very coarse-grained sand. The topsoil has a Stage I calcic horizon. The surface has a weak varnish on

<10% of surface clasts and bar-and-swale topographic relief is up to 0.2 m. The tread height is 1–2.5 m above modern grade (minimum thickness).

Qfye Younger fan alluvium east of the Rio Grande

Early to Late Holocene

Long—

Fan deposits in the eastern part of the quadrangle. The sand and minor pebbles are reworked from the axial-fluvial facies of the Palomas Formation (QTpa). The deposit is 1–3 m thick.

Short—

Fan deposits in the eastern part of the quadrangle. The sand and minor pebbles are reworked from the axial-fluvial facies of the Palomas Formation (QTpa). The deposit is 1–3 m thick.

Qfyh Younger and historic fan alluvium, undivided

Early Holocene to ≈10 years ago

Long—

The unit is composed of younger (Qfy) and subordinate historic (Qfh) fan alluvium. See detailed descriptions of each unit. The unit is weakly to moderately consolidated and 1–4(?) m thick.

Short—

The unit is composed of younger (Qfy) and subordinate historic (Qfh) fan alluvium. See detailed descriptions of each unit. The unit is weakly to moderately consolidated and 1–4(?) m thick.

Qfyr Younger and recent (historic + modern) fan alluvium, undivided

Early Holocene to modern

Long—

The unit is similar to unit Qary but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qay, Qah, and Qam. The unit is weakly to moderately consolidated and 1–4(?) m thick.

Short—

The unit is similar to unit Qary but it forms an alluvial fan at the mouths of tributary drainages. See descriptions of Qay, Qah, and Qam. The unit is weakly to moderately consolidated and 1–4(?) m thick.

Qfyfc Younger fan alluvium derived from the north end of the Fra Cristobal Mountains

Early to Middle Holocene

Long—

Sand and minor gravel derived from south of the quadrangle (granitic terrain of the northern Fra Cristobal Mountains). The sand is brown (7.5YR 5/4), poorly to moderately sorted, angular to subangular, and very fine- to very coarse-grained. The coarser sand is composed wholly of granite fragments. The pebbles are very fine- to very coarse-grained and composed of angular to subangular granite. The fan surface generally lacks bar-and-swale topography. The deposit is several m thick.

Short—

Sand and minor gravel derived from granite found south of the quadrangle. The sand is brown (7.5YR 5/4), poorly to moderately sorted, angular to subangular, and very fine- to very coarse-grained. The coarser sand is composed wholly of granite fragments. The pebbles are very fine to very coarse and composed of angular to subangular granite. The fan surface generally lacks bar-and-swale topography. The deposit is several m thick.

Qfo Older fan deposits

Late Pleistocene to Early Holocene

Long—

Loosely consolidated pebble and pebble to cobble gravel in thick to very thick (75–160 cm), tabular to wedge-shaped beds. The gravel is clast- to occasionally matrix-supported and internally massive to moderately imbricated. The clasts consist of very poorly to poorly sorted, subangular to rounded pebbles (55–95%), cobbles (5–45%), and boulders (0–5%) of >95% felsic volcanic lithologies. The gravel matrix consists of brown to strong-brown (7.5YR 4/4–6), moderately calcareous, poorly to moderately sorted, angular to rounded, fU–cU sand composed of 50–55% lithics (volcanic and ferromagnesian minerals), 35–40% quartz, and 5–15% feldspar grains with no clay. A Stage I calcic horizon is observed in the upper 40 cm. There is a weak varnish on 25–40% of surface clasts. The tread height is 2.1–3.2 m above modern grade. The deposit is <3–4 m thick.

Short—

Loosely consolidated gravel in thick to very thick, tabular to wedge-shaped beds. Clast- to matrix-supported and internally massive to imbricated. The matrix is brown to strong-brown (7.5YR), fine to coarse sand with no clay. A Stage I calcic horizon is observed and there is a weak varnish on 25–40% of surface clasts. The tread height is 2.1–3.2 m above modern grade. The deposit is <3–4 m thick.

Terrace Deposits that Flank Modern Canyons

Qt Terrace deposits, undivided

Late Pleistocene

Long—

Loosely to moderately consolidated, sandy gravel, and gravelly sand in very thin to thick, tabular to lenticular beds that underlie terraces in modern canyons. The gravel is clast-supported and well-imbricated to locally trough or planar cross-stratified. The clasts consist of very poorly to poorly sorted, subangular to well-rounded pebbles, cobbles (10–40%), and boulders (1–3%). Clast lithologies are mostly or entirely fine-grained felsic volcanics with trace to a few percent each of feldspar porphyry, chert, and/or intermediate volcanics (visual estimate). The gravel matrix consists of very poorly to moderately sorted, subangular to rounded, fU–vcU sand composed of 80–90% lithics (volcanic) and 10–20% quartz and feldspar. The gravel may be intercalated with minor lenses of thin, tabular beds of silty, very fine- to fine-grained sand or pebbly sand (very fine- to very coarse-grained) that are horizontal-planar- or cross-laminated to trough cross-stratified. Soils and surface characteristics generally vary with age. Moderate to strong calcic horizons with Stage II–II(+) carbonate accumulation, illuviated clay (Bt, Btk horizons where not eroded), and various degrees of desert pavement development and clast varnishing may be observed at the surface. The deposit lacks bar-and-swale topography and buried soils. The deposit is 0.3 to 1 m thick.

Short—

Loosely to moderately consolidated, sandy gravel, and gravelly sand in very thin to thick, tabular to lenticular beds underlying terraces in modern canyons. The clasts consist of pebbles, cobbles (10–40%), and boulders (1–3%). The sand is mostly medium- to very coarse-grained. Stage II–III(+) calcic horizons, desert pavement, and clast varnishing are observed at the surface. The deposit is 0.3 to 1 m thick.

Qtl Lower terrace deposits in low-order canyons

Latest Pleistocene

Long—

Sandy gravel with 15–40% cobbles and 1–10% boulders. The deposit commonly features illuviated clay (Bt) horizon in topsoil. There is a weak varnish on 20–30% of surface clasts. The tread generally lies 1.5–3 m above valley floors. The deposit is 0.3–1 m thick.

Short—

Sandy gravel with 15–40% cobbles and 1–10% boulders. The deposit commonly features illuviated clay (Bt) horizon in topsoil. There is a weak varnish on 20–30% of surface clasts. The tread generally lies 1.5–3 m above valley floors. The deposit is 0.3–1 m thick.

Qtax Terrace deposit underlain by axial sand of the Rio Grande

Late Pleistocene

Long—

Loosely consolidated sand and minor interbedded gravel immediately east of the Rio Grande in the northeastern corner of the quadrangle. The deposit correlates to the general #2 terrace level in Simon and Sheep Canyons (Qtsi2 and Qtsh2) and is overlain by 2–3 m of vesicular basalt (Qb). The sand is pinkish-gray (7.5YR 7/2), medium- to coarse-grained, subangular to rounded (mostly subrounded), well- to moderately sorted, and composed of quartz, 15% orange-colored grains (orange-stained quartz, granite, and chert), and 15–20(?)% feldspar. The gravel composes roughly 1–10% of the strata and consists of subrounded to rounded, moderately to poorly sorted pebbles with 5–10% cobbles. The estimated clast composition is as follows: roughly subequal distribution of felsic volcanic rocks, intermediate volcanic rocks, quartzite, and chert; ≈10% Paleozoic limestone; and <5% sandstones. The deposit is up to 11–12 m thick, but the base is not exposed.

Short—

Loosely consolidated medium- to coarse-grained sand immediately east of the Rio Grande. The deposit is overlain by 2–3 m of vesicular basalt (Qb). The gravel comprises 1–10% of the strata and consists of subrounded to rounded, moderately to poorly sorted pebbles with 5–10% cobbles. The gravel is composed mainly of felsic volcanic rocks, intermediate volcanic rocks, quartzite, and chert; other compositions are present but minor. The deposit is up to 11–12 m thick.

Terrace Deposits along Milligan Gulch

Qtmi1 Lowest terrace deposits

Late Pleistocene

Long—

Sandy gravel in medium, lenticular to tabular beds. The gravel consists of very fine to very coarse pebbles with 30–40% cobbles and up to 7% boulders, which are clast-supported, subrounded, poorly to very poorly sorted, and composed wholly mainly of felsic volcanic clasts (30–35% of these clasts are moderately porphyritic) and 0.5–2% intermediate volcanic clasts. The sandy gravel matrix is fine- to very coarse-grained, subrounded to subangular, poorly sorted, and composed of volcanic detritus, minor feldspar, and minor quartz. Sandy gravel may be overlain by pebbly sand, which itself is overlain by very fine- to fine-grained, massive sand and silty fine-grained sand with 5% scattered, medium- to very coarse-grained sand and 1–5% scattered pebbles. The deposit has weak to strongly developed desert pavement. The topsoil has a 30–50 cm thick calcic horizon with Stage I(+) to II carbonate morphology, but locally there is a 40–50 cm thick, Stage III calcic horizon buried by ≈1 m of the capping unit (Qsy). The tread height is 3–4 m and the strath height is 2–3 m. The deposit is mostly 1–3 m thick.

Short—

Sandy gravel in medium, lenticular to tabular beds. The gravel consists of pebbles with 30–40% cobbles and ≤7% boulders. The sandy gravel matrix is fine- to very coarse-grained. The topsoil has a 30–50 cm thick, calcic horizon with Stage I(+) to II carbonate morphology, however, locally, a Stage III calcic horizon is preserved beneath 1 m of the capping unit (Qsy). The tread height is 3–4 m and the strath height is 2–3 m. The deposit is mostly 1–3 m thick.

Qtmi2 Lower-middle terrace deposits

Late Pleistocene

Long—

Sandy gravel in thin to medium, tabular to lenticular beds. The gravel is sand- to clast-supported and composed of very fine to very coarse pebbles, 40% fine to coarse cobbles, and 2–3% boulders. The gravel is subrounded, poorly sorted, and composed of felsic volcanic rocks (25–35% of which are notably porphyritic) with 0.5% dark intermediate volcanic rocks. The matrix sand is light-brown (7.5YR 6/3), medium- to very coarse-grained (<10% very fine- to fine-grained) that is subrounded to subangular, poorly sorted, and composed of volcanic detritus with minor feldspar and quartz. There is a weak desert pavement. The topsoil has a Stage I(+) to II carbonate morphology. The tread height is 4–8 m and the strath height is 3–5 m, both increasing to the west. The deposit is ≈4 m thick.

Short—

Sandy gravel in thin to medium, tabular to lenticular beds. The gravel is sand- to clast-supported and composed of pebbles, 40% cobbles and 2–3% boulders. The matrix sand is brownish and medium- to very coarse-grained. There is a weak desert pavement. The topsoil has a Stage I(+) to II carbonate morphology. The tread height is 4–8 m and the strath height is 3–5 m, both increasing to the west. The deposit is ≈4 m thick.

Terrace Deposits of Simon Canyon

Qtsi1 Lower terrace deposits

Late Pleistocene

Long—

Sandy gravel with abundant cobbles (25–50%) and 1% boulders. The tread lies 3–5 m above modern grade and 2 m above the tread of Qay. There is a weak desert pavement (80–90% clast density, weak varnish, and weak Av peds). The geomorphic surface lacks bar-and-swale topography. Topsoil development is not observed. There is a high chance of miscorrelation with unit Qayo, but it was distinguished from the latter based on the presence of weak clast varnish and cobble-rich texture. The deposit is ≈1 m thick.

Short—

Sandy gravel with abundant cobbles (25–50%) and 1% boulders. The tread lies 3–5 m above modern grade and 2 m above the tread of Qay. There is a weak desert pavement. The geomorphic surface lacks bar-and-swale topography. Topsoil development is not observed. There is a high chance of miscorrelation with unit Qayo, but it was distinguished from the latter based on the presence of weak clast varnish and cobble-rich texture. The deposit is ≈1 m thick.

Qtsi2 Middle terrace deposits

Late Pleistocene

Long—

Weakly consolidated sandy gravel with subordinate pebbly sand and sand. The gravel is mostly clast-supported and in medium to thick, lenticular beds and 10% U-shaped channel fills 30–50 cm deep. The gravel is composed of very fine to very coarse pebbles with 5–25% cobbles and 1–2% boulders, which are subrounded, poorly sorted, and composed of felsic clasts with 1% intermediate gravel. The sand in the gravel matrix is reddish-brown to yellowish-red (5YR 5/4–4/6; coarse sand grains are light-gray), fine- to very coarse-grained (mostly medium- to very coarse-grained), subrounded to subangular, poorly sorted, and mostly composed of volcanic detritus and 0.5–1% clay chips. The pebbly sand and sand are horizontal-planar-laminated (minor very thin to medium beds). The sand is brown to light-brown (7.5YR 5–6/4) and mostly very fine- to medium-grained. The topsoil manifests a Stage II to II(+) carbonate morphology on relatively stable surfaces. The tread is ≈7 m above modern grade near the western quadrangle boundary (6–7 m below the tread of Qsmpg), and ≈12 m near the Rio Grande floodplain (≈18 m below Qsmg tread). Unit QTsi2 correlates with unit Qtas. The deposit is 1–4 m thick.

Short—

Weakly consolidated sandy gravel with subordinate pebbly sand and sand. The gravel is composed of pebbles with 5–25% cobbles and 1–2% boulders; matrix sand is fine to very coarse. The pebbly sand and sand are horizontal-planar-laminated. The sand is brownish and mostly very fine- to medium-grained. The topsoil manifests a Stage II to II(+) carbonate morphology. The tread is ≈7 m above modern grade. The deposit is 1–4 m thick.

Qtsi3 Upper terrace deposits

Late(?) Pleistocene

Long—

Sandy gravel composed predominately of volcanics. The tread lies ≈15 m above the valley floor and 10 m below the tread of Qsmpg. The deposit is 1–2 m thick.

Short—

Sandy gravel composed predominately of volcanics. The tread lies ≈15 m above the valley floor and 10 m below the tread of Qsmpg. The deposit is 1–2 m thick.

Terrace Deposits of Sheep Canyon

Qtsh1 Lower terrace deposits

Latest Pleistocene

Long—

Weakly to moderately consolidated sandy gravel with 10–20% pebbly sand. The beds are thin to medium and tabular to lenticular with local cross-stratification (very thin to thin foresets up to 40 cm tall). The gravel is clast- to sand-supported and composed of very fine to very coarse pebbles with 5–20% cobbles (locally up to 50%) and 1% boulders, which are subrounded (minor subangular), poorly to very poorly sorted and composed of felsic-dominated volcanics with 0.5–2% speckled-rhyolite porphyry marker clasts and 1–3% feldspar-phyric intermediate clasts. The gravel matrix is pinkish-gray to strong-brown 7.5YR 6/2–5/6 (mostly brown to strong-brown, 7.5YR 5/4–4/6), fine- to very coarse-grained (mostly medium- to very coarse-grained) sand that is subrounded to subangular, poorly to moderately sorted, and mainly composed of volcanic grains with lesser feldspar and quartz; <1% fines and no clay chips or coats. The pebbly sand is brown (7.5YR 4/4) and in very thin, tabular beds. The topsoil is characterized by a 30 cm-thick illuviated clay (Bt) soil horizon underlain by a 30–50 cm thick Stage II calcic horizon that has a diffuse base. Both horizons have weakly consolidated, fine-grained, subangular blocky, slightly hard peds. The basal contact is a scour with up to 1 m of relief. The tread height is 3–5 m. The deposit is 3–5 m thick.

Short—

Weakly-moderately consolidated sandy gravel with 10–20% pebbly sand. The beds are thin to medium and tabular to lenticular with local cross-stratification. The gravel is composed of pebbles with 5–50% cobbles and 1% boulders. The sand is fine to very coarse. The topsoil is characterized by a 30 cm-thick illuviated clay (Bt) soil horizon underlain by a 30–50 cm thick Stage II calcic horizon. The tread height is 3–5 m. The deposit is 3–5 m thick.

Qtsh2 Middle(?) terrace deposits

Late Pleistocene

Long—

Poorly exposed sandy gravel at 13S 304875mE 3719580mN and 305745mE 3718910mN NAD83. The terrace tread lies 8–11 m above modern grade and 17–20 m below the tread of Qsmpg. The unit may correlate with Qtsh3 if the tread has a steeper gradient than the tread of Qsmpg. The deposit is likely a few meters thick.

Short—

Poorly exposed sandy gravel at 13S 304875mE 3719580mN and 305745mE 3718910mN NAD83. The terrace tread lies 8–11 m above modern grade and 17–20 m below the tread of Qsmpg. The unit may correlate with Qtsh3 if the tread has a steeper gradient than the tread of Qsmpg. The deposit is likely a few meters thick.

Qtsh3 Upper terrace deposits

Late Pleistocene

Long—

Well- to moderately consolidated sandy gravel with 20% pebbly sand. The tread lies midway or higher between the valley floor and the tread of unit Qsmpg. The strata are in thin to medium, tabular to lenticular beds. Very thin, lenticular beds are also present (especially for pebbly sand) with 1–3% cross-stratification characterized by low-angle cross-laminations to very thin cross-beds; foresets are typically planar and about 10 cm tall. The gravel is mostly clast-supported and composed of pebbles with 25–50% cobbles (cobbles are mostly in medium, lenticular beds) and 1% boulders. The gravel is subrounded, poorly sorted, and composed of felsic volcanic rocks (mostly fine-grained and includes 20% clasts of Vicks Peak Tuff) with 3% intermediate volcanic clasts (feldspar-phyric or megacrystic) and 0.5–1% of the speckled-rhyolite porphyry clasts. The sand is reddish-brown to yellowish-red (5YR 5/4–6), medium- to very coarse-grained, subrounded (mostly) to subangular, poorly sorted, and has <1% clay (no distinct clay chips or coats). Depending on location, the terrace tread is 8–10 m above the valley floor and 8–10 m below the tread of Qsmpg. The strath lies 3–6(?) m above the valley floor. The deposit is 3–5 m thick.

Short—

Reddish sandy gravel with 20% pebbly sand. The strata are in thin to medium, tabular to lenticular beds. Very thin, lenticular beds are also present (especially for pebbly sand) with 1–3% cross-stratification. The gravel is composed of pebbles with 25–50% cobbles and 1% boulders. The terrace tread is 8–10 m above the valley floor and 8–10 m below the tread of Qsmpg. The strath lies 3–6(?) m above the valley floor. The deposit is 3–5 m thick.

Terrace Deposits of Crawford Hollow

Qtc1 Lower terrace deposits

Latest Pleistocene

Long—

Moderately consolidated, sandy gravel in vague, thin to thick, tabular to lenticular beds. Very weakly clay-cemented. The gravel consists of clast-supported, imbricated, poorly sorted, subangular to subrounded pebbles with subordinate cobbles (more abundant near the base). The tread lies 2–7 m above the valley floor. The unit may locally be subdivided into two subunits (not mapped) whose treads differ about 1 m in height. It is not known if these represent separate depositional events or if the lower is a fill-cut terrace. The deposit is 0.3–1 m thick.

Short—

Sandy gravel in vague, thin to thick, tabular to lenticular beds. The gravel consists of clast-supported pebbles with minor cobbles. The tread lies 2–7 m above the valley floor. The unit may locally be subdivided into two subunits (not mapped) whose treads differ about 1 m in height. It is not known if these represent separate depositional events or if the lower is a fill-cut terrace. The deposit is 0.3–1 m thick.

Qtc2 Lower-middle terrace deposits

Late Pleistocene

Long—

Terrace sediment that coarsens-upwards from a pebbly sand to a clast-supported sandy gravel with 30% cobbles that overlies the axial sand of QTpa. The gravel is in thin to thick beds. The sand is fine- to very coarse-grained, subrounded to subangular, poorly sorted, and composed of volcanic-dominated sand with 10–15% clay fragments. The clay imparts a strong-brown to yellowish-red color (7.5–5YR 4/6). The tread is ≈9 m above Qah. The deposit is 2–3 m thick.

Short—

Terrace sediment that coarsens-upwards from a pebbly sand to a clast-supported sandy gravel with 30% cobbles that overlies the axial sand of QTpa. The gravel is in thin to thick beds. The sand is fine- to very coarse-grained, subrounded to subangular, poorly sorted, and composed of volcanic-dominated sand with 10 – 15% clay fragments. The clay imparts a strong-brown to yellowish-red color (7.5 – 5YR 4/6). The tread is ≈9 m above Qah. The deposit is 2 – 3 m thick.

Terrace Deposits of Silver Canyon

Qts Undivided terrace deposits

Late Pleistocene

Long—

Loose to weakly consolidated sandy gravel and silt to sand in thick (50–80 cm), tabular to broadly lenticular beds underlying terraces along Silver Canyon. The gravel is clast-supported and moderately well-imbricated. The clasts consist of poorly sorted, subrounded to rounded pebbles (50–100%) and cobbles (0–50%) dominated by felsic volcanics. The gravel matrix consists of brown (7.5YR 4–6/4), strongly calcareous, very poorly to poorly sorted, subrounded to rounded, vfU–cU sand composed of 80–85% lithics (volcanic) and 15–20% quartz and feldspar with <5% brownish free-grain argillans. The deposit features up to 15% lenses of strong-brown (e.g., 7.5YR 5/6), mostly tabular-bedded, internally massive to low-angle cross-stratified or laminated, slightly pebbly silt to fL or mU sand. The strongest soil development observed is Stage I(+) calcic soil in the upper 30 cm of deposit. There is a weak to moderate varnish on 5–30% of surface clasts. The deposit lacks bar-and-swale topography. The tread lies 2 m above valley floors. The deposit is 6–7 m thick.

Short—

Weakly consolidated pebble to cobble gravel and brownish (7.5YR) sand. The gravel is commonly imbricated with occasional lenses of massive to cross-stratified silt to sand. The strongest soil development observed is Stage I(+) calcic soil in the upper 30 cm of deposit. There is a weak to moderate varnish on 5–30% of surface clasts. The tread lies approximately 2 m above valley floors. The deposit is 6–7 m thick.

Erosional Surfaces

Qx High-level erosional surface

Middle Pleistocene

Long—

An erosional surface locally developed on top of the San Marcial formation (unit Qsmpg).

Short—

An erosional surface locally developed on top of the San Marcial formation (unit Qsmpg).

Geomorphically High-level Piedmont and Terrace Deposits

San Marcial formation (informal)

We apply the informal, newly proposed name of San Marcial formation to a laterally extensive, several meter thick, sand and gravel deposit that underlies most of the area west of the Rio Grande and is inset into older Santa Fe Group deposits. A prominent, widespread geomorphic surface developed on top of the deposit primarily represents the culmination of this noteworthy Middle Pleistocene aggradational event, although post-aggradation erosion has locally resulted in fill-cut geomorphic surfaces. A useful clast to recognize the San Marcial formation, in addition to younger inset terrace gravels, is a speckled, slightly greenish porphyry that contains 15–20% phenocrysts of 0.3–1 mm-long, relatively equant mafics (pyroxene?) and trace amounts of 0.5–1.5 mm long quartz phenocrysts. In the following descriptions, we call this the "speckled-rhyolite porphyry marker clast." This formation is subdivided according to provenance (piedmont vs. axial) and texture (gravel vs. sand and pebbly sand vs. clay, silt, and fine sand). Inferred to correlate with the Tortugas sand near Las Cruces, which is capped by a ≈200 ka basalt (age from Leavy, 1987), and so the San Marcial formation is probably ≈200–300 ka (John Hawley, written communication, May 7, 2020).

Qsm San Marcial formation, undivided

Middle Pleistocene

Long—

Cross section only. Sandy gravel that grades laterally eastward into pebbly sand and then into floodplain and axial sand deposits. The unit coarsens-upwards and the facies prograded eastward with time. The lower strata fill the paleotopography. See detailed descriptions of units Qsmag, Qsmas, Qsmf, Qsmps, Qsmpg. The deposit is up to 13 m thick.

Short—

Cross section only. Sandy gravel that grades laterally eastward into pebbly sand and then into floodplain and axial sand deposits. The unit coarsens-upwards and the facies prograded eastward with time. The lower strata fill the paleotopography. See detailed descriptions of units Qsmag, Qsmas, Qsmf, Qsmps, Qsmpg. The deposit is up to 13 m thick.

Qsmag San Marcial formation, axial sediment dominated by sandy gravel and gravelly sand

Middle Pleistocene

Long—

Loose to weakly consolidated sandy gravel and gravelly sand in very thin to thin, lenticular to tabular beds. The unit lies below the eastern part of unit Qsmas and lies in an inset relation against older QTpa. The gravel is predominately pebbles with trace to 10% fine cobbles. The gravel is moderately to well-sorted and subrounded to rounded (minor subangular). The gravel composition (from two clast counts and visual estimates) is: 15–20% felsic volcanic rocks, 10–15% intermediate volcanic rocks, 10–20% quartzite, 7–15% granite, 10–20% chert, 2–5% felsic plutonic rocks (non-granitic), 1% intermediate plutonic rocks, 5% quartz, 0–3% vesicular basalt, 1–2% reddish siltstone to very fine sandstone (likely Permian), 1–3% non-Permian sandstones, 1–3% limestone, 0–4% meta-sandstones to siltstones, 0–1% diorite-gabbro, 0–0.5% gneiss-schist, trace to no Pillar Phyllite, trace to 2% Pedernal Chert, and 0.5% petrified wood. The sand is light-brownish-gray to pale-brown to light-gray (10YR 6/2–3; 7/1), fine-upper- to coarse-upper-grained (fU—cU) including up to 20% very coarse sand that is subangular to subrounded, moderately to poorly sorted, and composed of quartz and vitreous feldspar, 5–12% orange-colored grains (potassium feldspar, granite fragments, and minor chert), and 10–15% dark mafic-lithic grains. The deposit is 1–3 m thick.

Short—

Loose to weakly consolidated sandy gravel and gravelly sand in very thin to thin, lenticular to tabular beds. The unit immediately underlies Qsmas and is inset into QTpa. The gravel consists of pebbles with trace to 10% fine cobbles, which are subrounded to rounded, and have a more diverse composition than QTpa pebbles. The sand is light-brownish-gray to pale-brown to light-gray (10YR) and fine- to coarse-grained. The deposit is 1–3 m thick.

Qsmagl Lower allostratigraphic unit, lithologically similar to Qsmag

Middle Pleistocene

Long—

The unit is located ≈6 m below Qsmag and is 1–3 m thick. Stratigraphic relations are ambiguous, and it is possible that this is a much younger, Late Pleistocene terrace deposit.

Short—

The unit is located ≈6 m below Qsmag and is 1–3 m thick. Stratigraphic relations are ambiguous, and it is possible that this is a much younger, Late Pleistocene terrace deposit.

Qsmagh Higher allostratigraphic unit, lithologically similar to Qsmag

Middle Pleistocene

Long—

The unit is located 3–6 m above Qsmag and is 1–3 m thick. Local outcrops indicate this unit is a distinctive allostratigraphic unit representing an older paleo-terrace deposit; younger Qsmag and Qsmps were inset into this paleo-terrace. This unit may be part of the post-Qsmag aggradational package (generally correlative to unit Qsmps) in other places.

Short—

The unit is located 3–6 m above Qsmag and is 1–3 m thick. Local outcrops indicate this unit is a distinctive allostratigraphic unit representing an older paleo-terrace deposit; younger Qsmag and Qsmps were inset into this paleo-terrace. This unit may be part of the post-Qsmag aggradational package (generally correlative to unit Qsmps) in other places.

Qsmas San Marcial Formation, axial sediment dominated by sand

Middle Pleistocene

Long—

Loose to weakly consolidated, fining-upward sand with minor pebbly sand that conformably overlies units Qsmag and underlies Qsmaf. The lower sand is mostly medium- to coarse-grained, whereas the upper sand is mostly fine- to very fine-grained. The bedding is relatively vague, horizontal to low-angle cross-laminated or massive. The sand is light-gray to pale-brown (10YR 7/1–6/3), subrounded to subangular, poorly to well-sorted, and composed of quartz, vitreous feldspar, 5–15% orange-colored grains (potassium feldspar, granite fragments, and minor chert), and 7–15% dark lithic-mafic grains. The lack of cementation and vaguer bedding distinguishes this unit from the sandstone of QTpa. The deposit is 1–6 m thick.

Short—

Loose to weakly consolidated, fining-upward sand that conformably overlies units Qsmag and underlies Qsmaf. The lower sand is mostly medium- to coarse-grained (with local pebbles); the uppermost sand is mostly fine- to very fine-grained. Massive or horizontal- to low-angle cross-laminated. The sand is light-gray to pale-brown (10YR 7/1–6/3). The lack of cementation and vaguer bedding distinguishes this unit from QTpa sand. The deposit is 1–6 m thick.

Qsmf San Marcial Formation, fine-grained strata

Middle Pleistocene

Long—

Coarsening-upward succession. The lower part consists of thin to thick, tabular beds of silty or clayey very fine- to fine-grained sand, very fine- to fine-grained sand, clay, and silt. There are minor nodules of calcium carbonate in the clayey beds. The sand is pink to light-reddish-brown (5YR 6–7/3) or light-yellowish-brown to light-brown (10–7.5YR 6/4; 7.5YR 6/3) or yellowish-brown to pale-brown (10YR 5/4–6/3). The clay is reddish-brown (5YR 5/4) to brown to dark-brown (7.5YR 4/3–3–5/4), and the silt is light-yellowish-brown to light-brown to brown (10–7.5YR 6/4; 7.5YR 5/4). The fine sand and silt may be laminated (ripple-marked or low-angle foresets up to 3 cm tall), but otherwise bedding is internally massive. Local wavy beds are present due to soft-sediment deformation. The upper part of the succession consists of fine- to coarse-grained sand, locally with scattered 1–5% very coarse sand or pebbles, and is overprinted by weakly developed paleosols. The sand is light-brown to strong-brown (7.5YR 6/4 to 4–5/6), subrounded to subangular, poorly sorted, relatively massive, and consists of quartz and feldspar, 3–10% orange-colored grains (granite, chert, or potassium feldspar), and ≈15% felsic volcanic grains. The paleosols are characterized by Bk or Btk horizons that have medium- to coarse-grained, subangular blocky, hard peds; very few to no faint clay films on ped faces; and weak to strong effervescence in HCl, up to 15% CaCO3 filaments, and trace CaCO3 nodules. Local, non-mappable, gravelly tongues of unit Qsmps are included, especially to the west, and the unit grades laterally westward into unit Qsmps. Typically overlies unit Qsmag but is mostly unmappable at 1:24,000 scale. The deposit is 2–10 m thick.

Short—

Fine-grained sediment that coarsens upwards to sand. The lower part consists of interbedded clay, silt, and very fine- to fine-grained sand in thin to thick, tabular beds. The upper part is light-brown to strong-brown, poorly sorted, fine- to coarse-grained sand overprinted by calcic and weakly illuviated clay horizons. The unit typically overlies unit Qsmag and grades laterally westward into unit Qsmps. The deposit is 2–10 m thick.

Qsmps San Marcial Formation, piedmont sediment dominated by sand and pebbly sand

Middle Pleistocene

Long—

Weakly to moderately consolidated, light-brown to strong-brown to brown (7.5YR 5–6/4; 5/6), locally reddish-yellow (7.5YR 6/6) or pink (7.5YR 7/4), very fine- to medium-grained sand and silty fine sand. The lower to middle part of the unit is inset into unit QTpa or QTpf. The uppermost strata may partly interfinger westwards with Qsmpg, but most commonly Qsmpg overlies this unit over a sharp and scoured contact. The proportion of finer-grained strata (very fine- to fine-grained sand, clayey to silty [1-10% fines], and minor silt) become more abundant to the east near the lateral gradation of this unit with Qsmaf. West of this gradation, the sand is coarser (vfL–mL) and contains 1–15%, scattered, out-sized grains of coarser sand and trace to 15% scattered very fine to coarse pebbles with the proportion of pebbles increasing westwards. The sandy strata are in thin to very thick, tabular beds that are internally massive. These strata are interbedded with sandy gravel to pebbly sand beds that are minor (1–35%) very thin to thin, and lenticular or thicker gravelly intervals that are tabular, lenticular, or in U-shaped channel-fills (up to 1 m thick). Within the >10 cm-thick gravelly intervals, the beds are thin to medium (minor thick) and lenticular. The gravel consists of subrounded (minor subangular), moderately to poorly sorted pebbles with 2–20% cobbles that are clast- to sand-supported and composed of felsic volcanic rocks with <5% intermediate volcanic rocks, dominated by feldspar-bearing porphyries, and 0.5% of the speckled-rhyolite porphyry marker clast. The sandy matrix of the gravel is light-brown to strong-brown (7.5YR 6/4–5/6) to yellowish-red (5YR 4/6), fine- to very coarse-grained (mostly coarse- to very coarse-grained), subrounded to subangular, poorly to moderately sorted. The matrix is composed predominately of volcanic grains with lesser quartz and feldspar, and typically <1% clay filling pores or as coats on clasts, but locally as much as 15%. The sands outside of gravels are subrounded to subangular and well- to poorly sorted. The sands are commonly overprinted by paleosols with weakly to strongly developed, fine- to coarse-grained, subangular blocky, slightly hard to very hard peds. The paleosols also feature Stage I calcic horizons and local faint clay illuviation features. Locally, near the base of the unit, there are relatively thin (<1 m thick) intervals of well-sorted, cross-laminated, fine- to coarse-grained axial sand. Near the western buttress margin, this unit contains notable reworked sand from QTpa that forms a relatively massive or vaguely bedded, weakly consolidated, brownish (7.5YR 5–6/4; 5/6; 10YR 6/3), pebbly sand deposit. The reworked sand is typically fine- to medium-grained (<20% coarser sand), poorly sorted, and resembles the sand in QTpa. The unit is more calcareous than units QTpf or QTppd, with weak to strong effervescence in HCl. The unit is non-cemented and erodes readily where it is finer-grained at its eastern end. The deposit is 3–13 m thick.

Short—

Weakly to moderately consolidated, brownish (7.5YR), very fine- to medium-grained sand and silty fine-grained sand inset into the Santa Fe Group. The unit coarsens westwards, where it contains 1–15%, scattered, out-sized coarser sand and trace to 15% pebbles. The sand is interbedded with 1–35% sandy gravel to pebbly sand. Near the western buttress this unit contains abundant reworked sand from QTpa. The unit is non-cemented and more calcareous than units QTpf or QTppd. The deposit is 3–13 m thick.

Qsmpf San Marcial Formation, piedmont and fine-grained sediment, undivided

Middle Pleistocene

Long—

Coarsening-upward package consisting of (from bottom to top): Qsmpaf, Qsmps, and Qsmpg. See descriptions of those individual units. The deposit is 5–7 m thick.

Short—

Coarsening-upward package consisting of (from bottom to top): Qsmpaf, Qsmps, and Qsmpg. See descriptions of those individual units. The deposit is 5–7 m thick.

Qsmpg San Marcial Formation, piedmont sediment dominated by sandy gravel

Middle Pleistocene

Long—

Well-consolidated, sandy gravel, subordinate pebbly sand, and 1–20% sand that is reddish, and contains sparse calcic paleosols. The strata are in very thin to medium (mostly thin to medium), lenticular to tabular beds. Cobble-bearing beds tend to be medium and lenticular; and 5–20% U-shaped channel fills (up to ≈1 m deep) that are commonly cross-stratified, with locally abundant cross-stratification outside of these narrow channels; foresets are very thin to medium-bedded, planar, and up to 0.2–2 m tall. The gravel is composed of very fine to very coarse pebbles, 1–40% cobbles, and trace to 3% boulders. The gravel is mostly clast-supported (minor sand-supported), subrounded, poorly sorted (minor moderate within a bed), and composed of felsic volcanic rocks with <5% intermediate rocks (mostly composed of feldspar porphyries) and trace to 3% speckled-rhyolite porphyry clasts. In the gravel assemblage, the Vicks Peak Tuff is the most common regional ignimbrite, with much less South Canyon Tuff (1–5%) and even lesser Datil Well-Hells Mesa Tuffs, with the South Canyon Tuff increasing in abundance northwards. The gravel matrix consists of fine to very coarse-grained sand (mostly medium to very coarse) that is subrounded to subangular, poorly to moderately sorted, and composed predominately of volcanic detritus and 0.5–15% (mostly 0.5–5%) clay filling interstitial pores or as clast coats. This clay imparts a reddish-brown to light-reddish-brown (5YR 5–6/4) to yellowish-red (5YR 4–5/6) color, but non-clayey sand is light-gray to pinkish-gray (5YR hue). The sand and pebbly sand form minor (up to 25%) thin to thick, tabular to wedge-shaped beds that are internally massive and light-brown to strong-brown (5–7.5YR 6/4–5/6) and locally clayey to silty (5-10% fines). The sand is mostly very fine- to medium-grained, with minor (<15%) coarse to very coarse sand and 1–5% scattered pebbles (subrounded and volcanic). The sand beds may be overprinted by paleosols with coarse- to very coarse-grained, angular blocky peds with moderate coverage by distinct to faint clay films on ped faces. The topsoil exhibits a Stage III to IV K horizon 30 to ≈80 cm thick. In topographic lows, this petrocalcic horizon is overlain by younger pebbly sediment overprinted by Btk horizons (illuviated clay features and Stage I carbonate morphology); this younger pebbly sand and associated soil is lumped with Qsmpg. The surface (tread) exhibits variable desert pavement development. The lower contact is a scoured surface with meter-scale relief. Weakly cemented by clay, and 2–11 m thick, thinning eastward to 1–4 m where it overlies units Qsmps, Qsmpf, and Qsmas.

Short—

Well-consolidated, sandy gravel, subordinate pebbly sand, and 1–20% sand that is reddish-brown, and contains sparse calcic paleosols. The strata form very thin to medium, lenticular to tabular beds and 5–20% U-shaped channel-fills. The gravel is composed of pebbles, 1–40% cobbles, and 1–3% boulders. The sand is mostly medium- to very coarse-grained and contains 0.5–5% clay. The deposit is 2–11 m thick, thinning eastward to 1–4 m thick.

Older Piedmont Deposits

Qpgo Older piedmont gravels

Middle Pleistocene

Long—

Weakly to well-consolidated, orangish sandy gravel and subordinate pebbly sand whose tread and strath are 2–3 meters above adjoining unit Qsmpg. The sandy gravel form very thin to thick (mostly very thin to medium), tabular to lenticular beds. The gravel is composed of pebbles with 5–40% cobbles and 0–5% boulders that are clast- to sand-supported. The gravel are subrounded (mostly) to subangular, moderately to poorly sorted within a bed, and composed of felsic volcanic rocks with 0.5–4% feldspar-phyric intermediate(?) volcanic rocks (trace mega-phyric with 2–4 mm long phenocrysts) and 0–0.5% speckled-rhyolite porphyry clasts. The gravel matrix is yellowish-red to strong-brown (5–7.5YR 5/6) or brown (7.5YR 5/4) sand that is fine- to very coarse-grained (mostly coarse to very coarse), subrounded to subangular, poorly sorted, and composed of volcanic grains with minor feldspar and quartz. Weakly cemented by 1% clay (as coats or disseminated within matrix). Locally, near the base, there are thick, internally massive beds of sand with 1–10% scattered pebbles; the sand is light-brown to reddish-yellow (7.5YR 6/4–6) and has 1–10% silt. Weakly cemented by clays with weak to no HCl effervescence. The topsoil consists of a 0.5–1 m thick calcic horizon with a Stage III to III(+) carbonate morphology. Moderately to strongly developed desert pavement. The deposit is 1–7 m thick.

Short—

Orangish sandy gravel and subordinate pebbly sand whose tread and strath are 2–3 meters above those of adjoining unit Qsmpg. The sandy gravel form mostly very thin to medium, tabular to lenticular beds. Locally, there are thick, internally massive beds of sand with 1–10% pebbles. Weakly cemented by clays and weak to no HCl effervescence. The topsoil consists of a 0.5–1 m thick, Stage III to III(+) calcic horizon. The deposit is 1–7 m thick.

Qpng Gravelly piedmont sediment of Nogal Canyon fan

Middle Pleistocene

Long—

Weakly to moderately consolidated, sandy gravel, pebbly sand, and sparse sand in thin to thick (45–120 cm), tabular to broadly lenticular beds; locally trough cross-stratified. Overlies the sandier facies of Qpns. The gravel is clast-supported and consists of very poorly to poorly sorted, subrounded to well-rounded pebbles (55–95%), cobbles (5–45%), and boulders (usually <5%). Clast lithologies are mostly or entirely felsic volcanics with trace to a few percent each of feldspar porphyry and/or intermediate volcanics (visual estimate). The gravel matrix consists of reddish-brown (5YR 5/3–4) to strong-brown (7.5YR 5/6), very fine- to very coarse-grained sand. The sand is subrounded to rounded, poorly sorted, composed of 85–90% lithics (volcanic) and 10–15% quartz and feldspar with 10–20% reddish to brownish clay bridges and films. The gravel may be intercalated with rare lenses of sand similar to the gravel matrix. The underlying strata may be scoured up to 0.6 m. Soils and surface characteristics generally vary with age. Moderate to strong calcic horizons (Stage II–IV carbonate accumulation), illuviated clay horizons (where not eroded), and various degrees of desert pavement development and clast varnishing may be observed at the surface. The unit may correlate to unit Qpgo to the north. The deposit is 2–7 m thick.

Short—

Sandy gravel, pebbly sand, and sparse sand in thin to thick, tabular to broadly lenticular beds; locally trough cross stratified. The gravel is composed of pebbles with 5–45% cobbles and <5% boulders. The clasts are composed of felsic volcanics with trace to 3% each of feldspar porphyry and/or intermediate volcanics. The matrix sand is reddish-brown to strong-brown. The topsoil has Stage II to IV calcic horizons. The deposit is 2–7 m thick.

Qpns Sandy piedmont sediment of Nogal Canyon fan

Middle Pleistocene

Long—

Gravelly sand with subordinate sandy gravel that grades eastward to a coarsening-upward package; the latter consists of sand and pebbly sand that overlies 2–4 m of muddy very fine- to fine-grained sand (with minor scattered coarser sand) that, in turn, overlies 1–2 m of light-brown to reddish-brown clay to silt. To the north, there is a locally a 1.2 m-thick, weak-red (2.5YR 4/2), argillic paleosol that is disconformably overlain by pinkish-gray (7.5YR 6/2), medium- to coarse-grained sand composed of volcanic lithics, feldspar, and quartz. Just above the basal contact, this sand is cemented by gypsum and there are pure gypsum crystals in the upper 10 cm of the paleosol below the contact. To the west, the basal contact is a pronounced scour with up to 6 m of paleotopographic relief. The deposit is 5–12 m thick.

Short—

Gravelly sand with subordinate sandy gravel that grades eastward to a coarsening-upward package consisting of: fine- to very coarse-grained sand and pebbly sand overlying 2–4 m of muddy sand that, in turn, overlies 1–2 m of light-brown to reddish-brown clay to silt. To the north, there is a locally a 1.2 m-thick, argillic paleosol. The basal contact exhibits 6 m of paleotopographic relief. The deposit is 5–12 m thick.

Quaternary Volcanic Units

Qb Basalt

Late Pleistocene

Long—

Black to very dark-gray (N2.5/ to 3/), highly vesicular basalt with trace to 1% olivine phenocrysts 0.5–3 mm long (mostly 1–2 mm long). The groundmass is relatively fine-grained but has plagioclase laths up to 1 mm long and locally exhibiting trachytic texture. The Late Pleistocene age is based on unpublished 40Ar/39Ar data (M. Zimmerer, pers. comm., 2019). The deposit is 1–8 m thick.

Short—

Black to very dark-gray (N2.5/ to 3/), highly vesicular basalt with trace to 1% olivine phenocrysts 0.5–3 mm long (mostly 1–2 mm long). The groundmass is relatively fine-grained but has plagioclase laths up to 1 mm long and locally exhibiting trachytic texture. The Late Pleistocene age is based on unpublished 40Ar/39Ar data (M. Zimmerer, pers. comm., 2019). The deposit is 1–8 m thick.

Qbu Basalt, upper flow lobe

Late Pleistocene

Long—

Black (N2.5\), vesicular basalt with 0.5% olivine phenocrysts 1–2 mm long. The groundmass is relatively fine-grained, but plagioclase microlaths are observed that are mostly 0.1–0.4 mm (1–5%

of plagioclase are up to 1 mm long). Locally overlies unit Qb along the eastern quadrangle boundary, where it exhibits steep margins that are 8 m thick.

Short—

Black (N2.5\), vesicular basalt with 0.5% olivine phenocrysts 1–2 mm long. The groundmass is relatively fine-grained, but plagioclase microlaths are observed that are mostly 0.1–0.4 mm (1–5% of plagioclase are up to 1 mm long). Locally overlies unit Qb along the eastern quadrangle boundary, where it exhibits steep margins that are 8 m thick.

Qbe Basalt outcrops surrounded by subordinate eolian sand

Late Pleistocene to Late Holocene

Long—

Mapped where subordinate proportions of eolian sand bury basalt exposures in the eastern half of the quadrangle. See individual descriptions for units Qb and Qe.

Short—

Mapped where subordinate proportions of eolian sand bury basalt exposures in the eastern half of the quadrangle. See individual descriptions for units Qb and Qe.

QUATERNARY–TERTIARY

Basin-fill Units

Basin-fill units collectively belong to the Santa Fe Group. The upper Santa Fe Group is called the Palomas Formation, consistent with nomenclature used in the Engle and Palomas Basins to the south. To the south and west of the quadrangle, STATEMAP work is using the age-equivalent term Sierra Ladrones Formation for these strata. The Palomas Formation is relatively non-cemented and little deformed (tilted <3°). Underlying Santa Fe Group strata are not exposed on this quadrangle, but based on other exposures in the Rio Grande rift, these strata exhibit more cementation and deformation than the Palomas Formation.

Santa Fe Group

Palomas Formation

QTppd Distal piedmont facies of the Palomas Formation

Early Pliocene to Early Pleistocene

Long—

Well-consolidated (minor moderately consolidated), pink to tan to orange, tabular-bedded, very fine- to fine-grained sand and clayey to silty very fine to fine sand; minor sandy silt or clay and 1–15% gravelly bodies; non-calcareous. The fine sand is in medium to very thick (mostly thick), tabular beds that are internally massive (locally horizontal-planar-laminated). Colors are various shades of orange to tan, centering on pink to light-brown to light-reddish-brown (5–7.5 YR 7/3–

4; 6/4), but also reddish-yellow (7.5YR 6/6) to yellowish-red (5YR 4–5/6), pinkish-white (7.5YR 8/2) to pink (5–7.5YR 7/3–4), or strong-brown (7.5YYR 5/6). The clays are brown to light-brown to light-reddish-brown (7.5–5YR 6/3–4; 5/4) to reddish-yellow or yellowish-red (7.5YR 6/6; 5YR 4–5/6) to reddish-brown (5YR 5/4). The unit contains up to 25% silt and 1–25% clay (combined is rarely more than 30%, and, overall, silt is more abundant than clay) and commonly contains minor (0.5–15%), scattered, medium to very coarse grains of out-sized sand and trace to 15% scattered very fine to coarse volcanic pebbles. The silt beds (1–10%) are commonly tannish to pink to light-brown (e.g., 7.5YR 8/1–3; 7/2; 6–7/3–4) and internally massive or laminated (horizontal-planar- or low-angle cross-laminated). Gravelly bodies are 0.05 to 5 m thick (mostly 0.1–2 m), lenticular- to tabular in geometry (laterally extending up to ≈100 m in outcrop) and occur as paleochannel fills or paleochannel-mouth fan lobes. Typical bedding within the gravel bodies is lenticular to tabular and up to 30 cm thick. The paleochannel fills are locally cross-stratified, scoured, and the basal contact has 10s of cm of relief. The paleochannel-mouth fan lobes commonly exhibit a convex-up upper contact and the gravelly beds interfinger laterally with sand. The gravel bodies typically form very thin to medium, lenticular to tabular beds. The gravel consists of very fine to very coarse pebbles with 0–15% cobbles (mostly fine) that are subrounded (mostly) to subangular, poorly (mostly) to moderately sorted, and mostly clast-supported. The gravel is composed of felsic volcanic rocks (mostly fine-grained) with 1–3% feldspar-phyric intermediate volcanic rocks (includes trace to 0.5% porphyries with particularly large feldspar phenocrysts [3–10 mm]), and trace to no speckled-rhyolite porphyry marker clasts that are proportionally lower than in the San Marcial formation. The proportion of gravel bodies decreases to the east as the proportion of sandy clay to silt beds increases. The sandy matrix of the gravel is reddish-brown to light-reddish-brown (5YR 5–6/4) to yellowish-red (5YR 5/6–8) to pinkish-gray (7.5YR 6–7/2) to light-brown (7.5YR 6/3–4) to brown to strong-brown (7.5YR 5/4–6), fine- to very coarse-grained (mostly medium to very coarse), subrounded to subangular, and poorly sorted. The matrix is composed of volcanic (mainly felsic) sand with 5–30% quartz and feldspar and 0–3% clay (as coats, chips, or disseminated). Gravelly bodies have scoured bases and typically have abrupt tops (gradational over 1–3 cm, the latter consistent with avulsion processes). Paleosols (1–7%) are mostly 15–25 cm thick and characterized by reddening, ped development (moderately to strongly developed, fine to very coarse-grained, angular to subangular blocky to prismatic and hard to very hard), and clay illuviation (faint to distinct and on ped faces). Paleosls are commonly yellowish-red, reddish-brown, light–reddish-brown, (5YR 5/6; 5–6/4). Calcic horizons are very rare with 1–15% root pores that are typically <3 mm wide, such paleosols often serve to demarcate beds. Very weak to no HCl effervescence. The deposit is 50–100(?) m thick.

Short—

Well-consolidated, orange to tan, very fine to fine sand and clayey to silty fine sand; minor sandy clay to silt and 1–15% gravelly bodies. The finer strata are mostly in thick, tabular beds (internally massive, locally laminated); gravelly bodies are lenticular to tabular and up to 5 m thick. Trace to no speckled-rhyolite porphyry clasts. Paleosols (1–7%) have very rare calcic horizons. Very weak to no HCl effervescence. The deposit is 50–100(?) m thick.

QTpf Fine-grained, basin-floor margin facies of the Palomas Formation

Early Pliocene to Early Pleistocene

Long—

Reddish or orangish to pale-colored, fine-grained strata consisting of very fine- to fine-grained sand, clayey to silty fine sand, silt, and clay that are interpreted mainly as floodplain deposits with ≤1% pebble beds that are mostly very thin- to thin-bedded and lenticular (minor medium to thick beds that are tabular). The strata are in very thin to very thick, tabular beds that are internally massive (minor horizontal-planar-laminated). The silt and very fine- to fine-grained sand beds are pink to light-brown (7.5YR 6–7/3–4), with silts also being pinkish-gray to white to pinkish-white (7.5YR 7–8/1–2). The clays are brown to reddish-brown (5–7.5YR 4–5/4; 5YR 5/3). Mixed clay to silt or muddy very fine to fine sand are light-reddish-brown to pink to reddish-brown (5YR 5–7/4) to yellowish-red (5YR 4–5/6) to light-brown (7.5YR 6/4). The sand is very fine- to fine-grained and may contain grains in the mL range. Minor interbedded axial sand similar to unit QTpa. Local calcium carbonate precipitation is present as nodules, root and paleo-burrow casts, or tabular beds (10–30 cm thick and ≈1% of strata; locally porous and tufa-like). An example of the latter is a probable ciénega (marsh) deposit found between Silver Canyon and Crawford Hollow. Minor beds of light-reddish-brown (5YR 6/4) to yellowish-red (5YR 5/6), fine- to medium-grained sand with scattered, minor (1–25%), coarse to very coarse sand grains and up to 10% very fine to medium pebbles composed of subrounded to subangular volcanic rocks. The very sparse pebble beds are composed of very fine to very coarse-grained, subrounded, volcanic pebbles in a pink to light-brown (7.5YR 6/3–4) sand matrix that is very fine- to very coarse-grained (mostly fine- to medium-grained), subangular to subrounded, poorly sorted, and mostly composed of detritus derived from volcanic terrain. Minor weak paleosols manifest ped development (very fine- to coarse-grained, subangular blocky peds, locally prismatic), reddening, local clay illuviation (1–50%, faint films on ped faces), and minor root traces (≤1 mm diameters). There are very sparse calcic horizons that are up to 60 cm thick (Stage I to II morphology). The unit is laterally gradational with the distal piedmont facies of unit QTppd. Along the eastern quadrangle boundary, several meters of this unit overlies QTpa. There, it consists of pink to light-brown (7.5YR 6–7/4), less commonly yellowish-red (5YR 4–5/6), very fine- to fine-grained sand and silty fine sand; pink (7.5YR 7/3) silt; and minor reddish-brown to light-reddish-brown (5YR 5–6/4) clay to silt and muddy very fine- to fine-grained sand. A laterally extensive, ≈10-cm-thick tufa bed (light-gray, with 1–5% pores and very sparse root tubules) is also mapped as a key bed in the eastern quadrangle. Moderately to well-consolidated and mostly non- to weakly cemented. The deposit is 3–20 m, or more, thick.

Short—

Very fine- to fine-grained sand, clayey to silty fine sand, silt, and clay that are interpreted mainly as floodplain deposits with ≤1% pebble beds. Minor beds of fine- to medium-grained sand with 1–25% coarser sand and <10% volcanic pebbles. The Strata is in very thin to very thick, tabular beds (internally massive, minor horizontal-planar-laminated). The unit contains local tufa beds, mapped as a key bed, and paleosols. The deposit is 3–20 m, or more, thick.

Guaje Pumice Bed

1.6 Ma

Long—

Pumice gravel in a matrix of coarse to very coarse pumice sand grains mixed with about 5–7% silt that coarsens upwards. Poorly sorted in the lower half of bed, where cU–vcU sand is mixed with very fine to coarse pebbles. Cobbles and fine boulders are found in the upper half. The bed is ≈30 cm thick.

Short—

Pumice gravel in a matrix of coarse to very coarse pumice sand grains mixed with about 5–7% silt that coarsens upwards. Poorly sorted in the lower half of bed, where cU–vcU sand is mixed with very fine to coarse pebbles. Cobbles and fine boulders are found in the upper half. The bed is ≈30 cm thick.

QTpa Axial-fluvial facies of the Palomas Formation

Early Pliocene to Early Pleistocene

Long—

Light-brownish-gray to white, laminated sand with <25% pebbly beds containing up to 20% exotic clasts (e.g., quartzite and chert) and <10% mud beds; unit intertongues westward, and locally, is overlain by unit QTpf. The sand is horizontal-planar-laminated to cross-laminated. The pebbly sand (lesser sandy pebbles forms very thin to medium (lesser thick) lenticular beds or are cross-stratified (local trough forms, foresets are <30 cm tall). Basal scouring by gravelly beds form up to 0.6 m of relief along contacts with underlying sediment. The pebbles are very fine to very coarse, subrounded to well-rounded, and moderately to poorly sorted. The pebbles are composed of felsic volcanic rocks, 1–10% intermediate volcanic rocks (mostly light-gray and hornblende- or pyroxene-phyric), 1–15% chert, 1–20% orange granite, 0.5–5% quartzite, 1% quartz, and <25% sedimentary clasts (sandstone, siltstone, and limestone), trace to 0.5% Pedernal Chert, and <1% foliated metamorphic clasts (gneiss, schist, and amphibolite). Felsic volcanic cobbles are locally found at base of the unit (includes the Hells Mesa Tuff). The sand is light-brownish-gray to white (10YR 6–7/2, 8/1; minor 10YR 6/3–4 and 7/3), predominately fU–cL with <7% cU–vcU grain sizes, subangular to subrounded, and well- to moderately sorted. The sand is composed of quartz, minor vitreous feldspar (plagioclase and sanidine), 10–25% orangish grains (mostly composed of chert and potassium feldspar with lesser granite), 10–25% gray to dark-colored lithic grains, 1–3% mafic grains, and <0.5% clay in the matrix. Mud rip-up clasts up to 25 cm across are locally found in basal parts of the sandy beds, particularly where scoured into mud. The sparse mud beds in this unit are pale to very pale-brown (2.5Y–10YR 8/2 and 2.5Y 7/3), yellowish-red to reddish-brown (5YR 4–5/4–6), or brown. The mud beds are weakly to moderately consolidated, non-calcareous, and massive to horizontal-planar-laminated. The mud beds contain whitish gypsum crusts, blades, and masses, particularly in and near Silver Canyon. The upper 1 to 2 m of the unit is a gradational zone into the overlying unit (QTpf). It consists of a fining-upward sequence of fine-grained sand transitioning upwards to very fine-grained sand to silt. These strata are locally rich in rhizoliths and are horizontal-planar-laminated to ripple marked to wavy laminated to massive. Buried soils do not occur in the gravels or sands but illuviated clay (Bt) horizons are observed in muddy intervals in a few places and are indicated by mottling and prismatic peds. Fragments of fossil vertebrates are occasionally found in the muds and sands. A partial vertebra of the glyptodont Glyptotherium texanum recovered approximately 1 km north of Silver Canyon in the Black Hill 7.5-minute quadrangle suggests that the uppermost axial-fluvial strata are younger than 2.7 Ma (D. Gillette and G. Morgan, pers. comm., 2019). The unit is locally well-cemented, but mostly non-cemented and loosely to weakly consolidated. The main body is >30 m thick, but near its eastern intertonguing contact with QTpf the unit occurs as 1–5 m thick tongues.

Short—

Light-brownish-gray to white sand with <25% pebbly beds. The sand is typically well-laminated (cross-stratified to horizontal-planar) and composed of quartz, minor vitreous feldspar, 10–25% orangish grains (potassium feldspar, granite, and chert), 15–25% dark lithics, and <0.5% clay in the matrix. Pebbles contain up to 20% exotic clasts such as quartzite and chert. Locally well-cemented but generally loosely consolidated. The deposit is >30 m thick.

QTpau Upper tongue of the axial-fluvial facies of the Palomas Formation

Early Pleistocene

Long—

Axial sand, as described in unit QTpa, that contains in its gravel assemblage either Rabbit Mountain obsidian (1.47 Ma) or pumice inferred to be derived from the Bandelier Tuff (both found in the Jemez Mountains of north-central New Mexico). The unit projects to or above the Guaje Pumice bed mapped north of Simon Canyon. 1.2–1.6 Ma in age. The deposit is 2–4 m thick.

Short—

Axial sand, as described in unit QTpa, that contains in its gravel assemblage either Rabbit Mountain obsidian (1.47 Ma) or pumice inferred to be derived from the Bandelier Tuff (both found in the Jemez Mountains of north-central New Mexico). The unit projects to or above the Guaje Pumice bed mapped north of Simon Canyon. 1.2–1.6 Ma in age. The deposit is 2–4 m thick.

Lower Santa Fe Group

Tsf Undifferentiated Santa Fe Group underlying the Palomas Formation

Late Oligocene through Late Miocene

Long—

Cross section only. Clastic, basin-fill sediment consisting of well-consolidated and variably cemented sand, silt, and clay. Possible conglomeratic tongues may be present to the west. The sand and conglomerates consist of volcanic detritus from the San Mateo Mountains. A 500–700 m thickness has been inferred for the cross section but this is highly uncertain; a thinner wedge of <50(?) m may be present immediately east of the Paraje Well fault.

Short—

Cross section only. Clastic, basin-fill sediment consisting of well-consolidated and variably cemented sand, silt, and clay. Possible conglomeratic tongues may be present to the west. The sand and conglomerates consist of volcanic detritus from the San Mateo Mountains. A 500–700 m thickness has been inferred for the cross section but this is highly uncertain; a thinner wedge of <50(?) m may be present immediately east of the Paraje Well fault.

Tertiary Volcanic Units

Tm Mogollon Group

Early to Late Oligocene

Long—

Cross section only. Felsic ignimbrites probably interbedded with volcaniclastic sediment, the latter likely being sandstone, muddy sandstone, and conglomerate. The ignimbrites include the Vicks Peak Tuff, which is a gray to light-gray, welded, crystal-poor tuff observed 6 km west of this quadrangle. Phenocrysts contain trace to 3% sanidine, trace to 1% mafic grains, and trace quartz (Jochems and Koning, 2019). The underlying La Jencia Tuff may also be present. The unit is 50–100(?) m thick.

Short—

Cross section only. Ignimbrites likely interbedded with minor volcaniclastic sandstone, muddy sandstone, and conglomerate. The ignimbrites include the Vicks Peak Tuff: a gray to light-gray, welded, crystal-poor tuff observed 6 km to west. Phenocrysts contain trace to 3% sanidine, trace to 1% mafic grains, and trace quartz (Jochems and Koning, 2019). The underlying La Jencia Tuff may also be present. The unit is 50–100(?) m thick.

Td Datil Group

Late Eocene to earliest Oligocene

Long—

Cross section only. Ignimbrites, intermediate lavas, and likely volcaniclastic sandstone, muddy sandstone, and conglomerate. The unit underlies the Hells Mesa Tuff, although the latter may not be present in this area. In the adjoining Black Hill quadrangle to the west (Jochems and Koning, 2019), ignimbrites include the tuff of Rocque Ramos Canyon (a likely correlative of the Datil Well Tuff, per William McIntosh [written communication, November 14, 2019]), which is up to 100 m thick and has 15–40% phenocrysts composed of sanidine, subordinate plagioclase, and trace to 7% biotite. The lowest volcanic unit in the Black Hill quadrangle is a purplish-brown (weathering to dark-reddish- or grayish-brown), aphanitic, trachyandesite lava, it has up to 3% phenocrysts dominated by plagioclase and pyroxene. The unit is 100–150(?) m thick.

Short—

Cross section only. Ignimbrites, intermediate lavas, and likely volcaniclastic sandstone, muddy sandstone, and conglomerate. The ignimbrites include the Tuff of Rocque Ramos Canyon, which has 15–40% phenocrysts composed of sanidine, subordinate plagioclase and ≤7% biotite. The lowest unit to the west is a trachyandesite lava with 3% phenocrysts dominated by plagioclase and pyroxene (Jochems and Koning, 2019). The unit is 100–150(?) m thick.

CRETACEOUS

Kmrs Sandstone of the McRae Group

Late Campanian to Maastrichtian

Long—

Sandstone with minor pebbly beds and fine-grained beds (the latter is inferred in non-exposed intervals) mapped near the southern edge of the quadrangle at the north end of the Fra Cristobal Mountains. The sandstone bodies are 1–4 m thick and broadly lenticular to tabular. They contain 1% very thin to medium, lenticular beds of pebbly sandstone to pebble-conglomerate. The pebbles are angular to subrounded, very fine- to coarse-grained, and mainly composed of silicified argillite (probably intra-formational) with trace to 20% granite, trace limestone, and trace quartzite. The sandstone is cross-laminated within a given story (mostly low-angle foresets up to 20 cm tall). The sand is moderately sorted, subangular, mostly fL–cL (1–10% cU–vcU sand is associated with pebbly beds), and is composed of ≈60% quartz, 5–25% feldspar, and 10% lithic grains. The sandstone is well-cemented and varnishes to a dark-reddish-brown. This deposit is correlated to the Double Canyon Formation of the McRae Group by Lucas et al. (2019), although we feel that this sandstone may be older than that unit. Furthermore, the apparent lack of volcanic detritus in the sandstone suggests that correlation to the McRae Group is inappropriate. The presence of granite clasts strongly suggests deposition during Laramide tectonism (Lucas et al., 2019). The unit is >40 m thick.

Short—

Well-cemented sandstone with minor pebbly and fine-grained beds (the latter is inferred in non-exposed intervals) mapped near the southern edge of the quadrangle at the north end of the Fra Cristobal Mountains. The sandstone bodies are 1–4 m thick and broadly lenticular to tabular, cross-stratified in a given story, and fine- to coarse-grained. The pebbles are composed of silicified argillite (probably intra-formational), trace to 20% granite, trace limestone, and trace quartzite. The unit is >40 m thick.

Kfa Ash Canyon and Fence Lake Formations, undivided

Turonian to Campanian

Long—

Cross section only. Coarsening-upward sequence deposited in a fluvial (minor swamp) environment. The lower part is a gray- to olive-colored package of mudstone, siltstone, and very fine- to fine-grained sandstone with minor yellowish, coarser sandstone channel-fills and <3% coals. In the upper part of the unit, the sandstone strata dominate and finer strata are subordinate. The nomenclature is from Lucas et al. (2019). The unit is ≈300 m thick.

Short—

Cross section only. Coarsening-upward sequence deposited in a fluvial (minor swamp) environment. The lower part is a gray- to olive-colored package of mudstone, siltstone, and very fine- to fine-grained sandstone with minor yellowish, coarser sandstone channel-fills and <3% coals. In the upper part of the unit, the sandstone strata dominate and finer strata are subordinate. The nomenclature is from Lucas et al. (2019). The unit is ≈300 m thick.

Kg Gallup Sandstone

Late Turonian

Long—

Cross section only. White to yellow, quartz-rich, fine- to medium-grained sandstone intercalated with subordinate grayish mudstone. The sandstones are cross-stratified, horizontal-planar, or massive. The unit was mostly deposited in a nearshore marine environment where one or more shallowing-upward cycles are apparent (e.g., Koning et al., 2011; Seager and Mack, 2003). The unit is ≈30 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

Short—

Cross section only. White to yellow, quartz-rich, fine- to medium-grained sandstone intercalated with subordinate grayish mudstone. The sandstones are cross-stratified, horizontal-planar, or massive. The unit was mostly deposited in a nearshore marine environment where one or more shallowing-upward cycles are apparent (e.g., Koning et al., 2011; Seager and Mack, 2003). The unit is ≈30 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

Kmd D-Cross Tongue of the Mancos Shale

Middle to late Turonian

Long—

Cross section only. Noncalcareous, gray to greenish-gray clay shale (lower part) coarsening upwards to a silty shale interbedded with thin siltstones and very fine sandstones in its upper part. Local septarian concretions are up to 1 m across. Minor calcarenite beds are present near the base. Conformably underlies the Gallup Sandstone. The unit is 58 m thick in the Victorio wells to the southeast (Lucas et al., 2019; Hook et al., in prep).

Short—

Cross section only. Noncalcareous, gray to greenish-gray clay shale (lower part) coarsening upwards to a silty shale interbedded with thin siltstones and very fine sandstones in its upper part. Local septarian concretions are up to 1 m across. Minor calcarenite beds are present near the base. Conformably underlies the Gallup Sandstone. The unit is 58 m thick in the Victorio wells to the southeast (Lucas et al., 2019; Hook et al., in prep).

Kth Tres Hermanos Formation

Middle Turonian

Long—

Cross section only. Contains these ascending members: the Atarque Sandstone (planar- to cross-bedded, coarsening-upward, very fine- to fine-grained sandstone), the Carthage Member (mudstone and siltstone with minor sandstone), and the Fite Ranch Sandstone (planar- to cross-bedded, very fine- to fine-grained sandstone and minor intercalated shale). The unit is 63 m thick (Lucas et al., 2019; Hook, et al., 1983; nomenclature from Hook et al., 1983).

Short—

Cross section only. Contains these ascending members: the Atarque Sandstone (planar- to cross-bedded, coarsening-upward, very fine- to fine-grained sandstone), the Carthage Member (mudstone and siltstone with minor sandstone), and the Fite Ranch Sandstone (planar- to cross-bedded, very fine- to fine-grained sandstone and minor intercalated shale). The unit is 63 m thick (Lucas et al., 2019; Hook, et al., 1983; nomenclature from Hook et al., 1983).

Kmt Tokay Tongue of the Mancos Shale

Latest Cenomonian to middle Turonian

Long—

Cross section only. Gray to black shale with a several-meter-thick interval of limestone beds in its lower-middle part (the Bridge Creek Limestone). Deep-water calcareous shales are found immediately above and below these limestones but pass outwards into noncalcareous shales (Hook and Cobban, 2015). Thin, tabular beds of sandstone are present near the base. The unit is 130 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

Short—

Cross section only. Gray to black shale with a several-meter-thick interval of limestone beds in its lower-middle part (the Bridge Creek Limestone). Deep-water calcareous shales are found immediately above and below these limestones but pass outwards into noncalcareous shales (Hook and Cobban, 2015). Thin, tabular beds of sandstone are present near the base. The unit is 130 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

Kd Dakota Sandstone

Cenomonian

Long—

Cross section only. Cross-stratified, well-cemented, quartzose sandstone and pebbly sandstones that are white (fresh) and weather to pink, magenta, orange, or dark-brown to blackish. The uppermost strata consists of a fining-upwards, marine, very fine- to fine-grained sandstone, but the underlying strata consists of a medium- to coarse-grained, fluvial sandstone. The unit is 48 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

Short—

Cross section only. Cross-stratified, well-cemented, quartzose sandstone and pebbly sandstones that are white (fresh) and weather to pink, magenta, orange, or dark-brown to blackish. The uppermost strata consists of a fining-upwards, marine, very fine- to fine-grained sandstone, but the underlying strata consists of a medium- to coarse-grained, fluvial sandstone. The unit is 48 m thick in the Victorio wells to the southeast (Lucas et al., 2019).

TRIASSIC

TRu Triassic strata, undivided

Late Triassic

Long—

Cross section only. Reddish-brown to grayish-brown to red sandstone, mudstone, and minor conglomerate and limestone. The sandstones are mostly fine- to medium-grained and occur in broad, tabular or channel-form beds that exhibit cross-bedding and horizontal stratification (from Cather, in prep). The unit is 220 m thick near Socorro but it is inferred to thin down to 130–140 m (possibly <50–100 m) on this quadrangle.

Short—

Cross section only. Reddish-brown to grayish-brown to red sandstone, mudstone, and minor conglomerate and limestone. The sandstones are mostly fine- to medium-grained and occur in broad, tabular or channel-form beds that exhibit cross-bedding and horizontal stratification (from Cather, in prep). The unit is 220 m thick near Socorro but it is inferred to thin down to 130–140 m (possibly <50–100 m) on this quadrangle.

PERMIAN–PENNSYLVANIAN

Although the typical Permian to Pennsylvanian sequence is expected to underlie the quadrangle (e.g., Red House Formation through the San Andres Formation), the particular units that would be present at the depths in the cross section are highly speculative due to the uncertainty of buried structures and their respective displacements.

Psag San Andres Formation and Glorieta Sandstone Tongue

Leonardian

Long—

The San Andres Formation overlies the Glorieta Sandstone. The San Andres consists of thick, tabular beds of limestone. The limestone is light-gray, weathering to light-brownish gray. The underlying Glorieta Sandstone contains thick, tabular beds of white to yellowish-tan sandstone that may intertongue with minor limestone. The sand is very fine- to fine-grained, well-sorted, and quartzose.

Short—

The San Andres Formation overlies the Glorieta Sandstone. The San Andres consists of thick, tabular beds of limestone. The limestone is light-gray, weathering to light-brownish gray. The underlying Glorieta Sandstone contains thick, tabular beds of white to yellowish-tan sandstone that may intertongue with minor limestone. The sand is very fine- to fine-grained, well-sorted, and quartzose.

Pyv Los Vallos Formation

Leonardian

Long—

Intertonguing reddish-brown mudstone to siltstone to very fine-grained sandstone, light-gray gypsum, white to yellow siltstone to fine-grained sandstone, and light-gray to light-brownish-gray limestone to dolomite. Individual tongues are 1–10 m thick. The clastic sediment is well-sorted, quartzose, and internally horizontal-planar-laminated to massive. The carbonates are thin to thick and tabular-bedded. The unit is ≈200–230 m thick.

Short—

Intertonguing reddish-brown mudstone to siltstone to very fine-grained sandstone, light-gray gypsum, white to yellow siltstone to fine-grained sandstone, and light-gray to light-brownish-gray limestone to dolomite. Individual tongues are 1–10 m thick. The clastic sediment is well-sorted, quartzose, and internally horizontal-planar-laminated to massive. The carbonates are thin to thick and tabular-bedded. The unit is ≈200–230 m thick.

IPu Pennsylvanian strata, undivided

Virgilian to Atokan

Long—

Limestone interbedded with clastic sediment. The limestone is a medium- to dark-gray, generally fossiliferous micrite, wackestone, and packstone. The unit includes subequal to subordinate clastic tongues composed of shale, siltstone, and very fine to fine sandstones (1–25 m thick). The unit mostly consists of the Bar B and underlying Gray Mesa Formations. 460–470 m thick (from Lucas et al., 2017a, b; Koning et al., 2020).

Short—

Limestone interbedded with clastic sediment. The limestone is a medium- to dark-gray, generally fossiliferous micrite, wackestone, and packstone. The unit includes subequal to subordinate clastic tongues composed of shale, siltstone, and very fine to fine sandstones (1–25 m thick). The unit mostly consists of the Bar B and underlying Gray Mesa Formations. 460–470 m thick (from Lucas et al., 2017a, b; Koning et al., 2020).

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