Geologic Map of the Williamsburg 7.5-Minute Quadrangle, Sierra County, New Mexico

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Open-file Digital Geologic Map OF-GM 250

Scale 1:24,000

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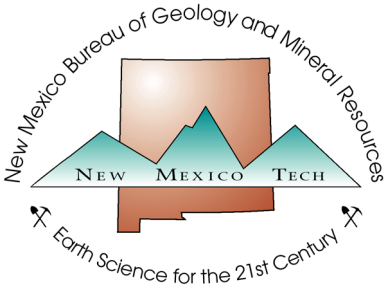

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Appendix

Detailed descriptions of lithologic units on the
Williamsburg 7.5’ quadrangle

UNIT DESCRIPTIONS

The units described below were mapped using aerial photography coupled with field checks, or by examining well cuttings and comparing to existing lithologic descriptions in the case of subsurface units. Stereogrammetry software (Stereo Analyst for ArcGIS 10.1, an ERDAS extension, version 11.0.6) permitted accurate placement of geologic contacts. Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. The term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter. Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to Munsell Soil Color Charts (Munsell Color, 2009). Soil horizon designations and descriptive terms follow those of Birkeland et al. (1991), Soil Survey Staff (1992), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999). Description of sedimentary, igneous, and metamorphic rocks was based on inspection using a hand lens.

Surface characteristics and relative landscape position were used in mapping middle Pleistocene to Holocene units. Surface processes dependent on age (e.g. desert pavement development, clast varnish, calcium carbonate accumulation, and eradication of original bar-and-swale topography) can be used to differentiate stream terrace, alluvial fan, and valley floor deposits. Younger deposits are generally inset below older deposits. However, erosion may create a young surface on top of an older deposit, so Quaternary deposits were field-checked to identify this relationship.

Quaternary eolian units

Qes Eolian sand (Holocene) – Windblown sand occurring in pod-shaped coppice dunes atop flat ridges and on their lee sides. Deposit is unconsolidated and often rippled. Matrix consists of pale to light yellowish brown (10YR 6/3-4), very well sorted, subangular to rounded, very fine- to fine-grained quartzose sand. Commonly vegetated with little or no soil development. Deposited by southerly to southwesterly winds on the leeward (i.e. north) side of ridges (Kelley and Silver, 1952), with sediment derived from the floodplain of the Rio Grande and deflated Palomas Formation deposits. Higher, non-vegetated dunes may be up to 2.3 m (7.5 ft) thick; total thickness unknown but probably no more than 2.5 m (8.2 ft) in most locations. Locally mapped as eolian mantle on older units (**Qes/unit**).

Qesc Eolian sand, slopewash, and hillslope colluvium, undivided (Holocene) – Mixed windblown sand and pebble-cobble-boulder gravel typically found on lee sides of ridges east of the Rio Grande. Deposit is unconsolidated and massive to rippled where dominated by eolian material. Clasts are poorly sorted and angular to subangular. Commonly vegetated with little or no soil development. Maximum thickness likely no more than 3 m (10 ft). Locally mapped as eolian-colluvial mantle on older units (**Qesc/unit**).

Quaternary hillslope units

Qsc Slopewash and colluvium, undivided (upper Pleistocene to Holocene) – Very pebbly sand found in thick beds on bedrock highs and (less commonly) mantling Quaternary deposits. Deposit is very loosely consolidated and massive. Clasts consist of angular to subrounded granules to pebbles. Matrix consists of light yellowish brown (10YR 6/4), very well sorted silt to fine-grained sand. May be very weakly cemented by carbonate. Commonly bioturbated by fine roots. Likely reworked by sheetflooding in most instances. Total thickness typically 1.5-2 m (4.9-6.6 ft). Locally mapped as slopewash mantle on older units (**Qsc/unit**).

Quaternary valley bottom units

daf Disturbed or artificial fill (modern) – Sand and gravel that has been moved by humans to form berms and dams, or has been reworked/remobilized for construction of infrastructure or buildings.

Qaarg Active alluvium of the Rio Grande (present) – Sandy pebble-cobble gravel in the axial channel of the Rio Grande, commonly in longitudinal or transverse bars. Clasts consist of poorly to moderately sorted, subrounded to rounded pebbles and cobbles. Boulders may be present, transported from local tributaries to the active channel during larger flood events. Clast lithologies are diverse, reflecting bedrock exposed throughout Rio Grande catchment. Matrix consists of moderately to very well sorted, subrounded to rounded, fine- to coarse-grained quartzose sand. Total thickness unknown but likely 1-5 m (3.3-16 ft).

Qam Modern alluvium (present to ~50 years old) – Sandy pebble to cobble gravel found in ephemeral channels or adjacent low-lying surfaces, fluvially reworked by modern flow events. Unconsolidated and commonly imbricated. Clasts are poorly to very poorly sorted, angular to subrounded, and consist of 65% pebbles, 30% cobbles, and 5% boulders. Clasts

are dominated by granite, metamorphic lithologies, and Paleozoic carbonates where streams exit the footwall of the Caballo fault system east of the Rio Grande. To the west, clasts are dominated by volcanic lithologies derived from the Sierra Cuchillo and Black Range (including those reworked from the Palomas Formation). Matrix consists of brown to light brown (7.5YR 5-6/3) to dark yellowish brown or light brownish gray (10YR 4/4-6/2), poorly to moderately sorted, angular to subrounded, fine- to very coarse-grained sand. Pronounced bar-and-swale topography exhibits up to 60 cm (24 in) of relief. Sparsely to non-vegetated with no soil development. Total thickness is unknown but likely 1-3 m (3.3-9.8 ft).

Qamh Modern and historical alluvium, undivided (present to ~600 years old) – Modern alluvium (**Qam**) and subordinate historical alluvium (**Qah**). See detailed descriptions of each individual unit.

Qamy Modern and younger alluvium, undivided (present to lower Holocene) – Modern alluvium (**Qam**) and subordinate younger alluvium (**Qay**). See detailed descriptions of each individual unit.

Qah Historical alluvium (~50 to ~600 years old) – Pebbly sand and sandy pebble gravel in very thin to thin (less commonly medium to thick), tabular to lenticular beds. Deposit is loosely consolidated, clast- to matrix-supported, and massive to horizontal-planar laminated or imbricated. Clasts are poorly to moderately sorted, angular to rounded, and consist of 80-90% pebbles, 10-20% cobbles, and 0-5% small boulders. Clasts are dominated by granite, metamorphic lithologies, and Paleozoic carbonates where streams exit the footwall of the Caballo fault system east of the Rio Grande. To the west, clasts are dominated by volcanic lithologies derived from the Sierra Cuchillo and Black Range (including those reworked from the Palomas Formation). Matrix consists of brown (7.5YR 6/4) to grayish or yellowish brown (10YR 5/2-4), poorly to well sorted, angular to subrounded, fine- to very coarse-grained sand and silty sand. Very weak carbonate cement may be present. Surface exhibits subdued bar-and-swale topography and channel forms with 10-40 cm (6-8 in) of relief. Moderately vegetated with little or no soil development (marked by weak ped development yet obvious sedimentary fabric) and commonly mantled by 20-30 cm (8-16 in) of silty fine sand related to slopewash or overbank deposition. Bioturbation by fine to very coarse roots or burrows is common. A radiocarbon date from Cañada Honda returned an age of 630-515 cal yr BP. Tread is 0.4-1.3 m (1.3-4.3 ft) above modern grade. Base not observed in thickest deposits; possibly up to 3 m (9.8 ft) maximum thickness.

Qahm Historical and modern alluvium, undivided (present to ~600 years old) – Historical alluvium (**Qah**) and subordinate modern alluvium (**Qam**). See detailed descriptions of each individual unit.

Qahy Historical and younger alluvium, undivided (~50 years old to lower Holocene) – Historical alluvium (**Qah**) and subordinate younger alluvium (**Qay**). See detailed descriptions of each individual unit.

Qar Recent (historical + modern) alluvium (present to ~600 years old) – Historical alluvium (**Qah**) and modern alluvium (**Qam**) in approximately equal proportions. See detailed descriptions of each individual unit.

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

Qay Younger alluvium (Holocene) – Sand and pebbly sand to sandy pebble-cobble gravel. Finer sediment dominates in low-gradient, low-order drainages and consists of very thin to thick, tabular (minor lenticular) beds of brown to light brown (7.5YR 5/2-4; 6/3-4; 10YR 5/3) to light brownish gray (10YR 6/2), mostly massive (locally horizontal-planar laminated), very fine- to medium-grained sand or clayey-silty, very fine- to medium-grained sand. This finer sediment generally contains minor coarse- to very coarse-grained sand and 1-20% scattered pebbles, with 1-25% very thin to thin lenses of sandy pebble gravel or pebbly sand (locally 1-10% cobbles). In the finer sediment, cumulic soil development is common and characterized by weakly to strongly developed, medium to coarse, subangular blocky peds as well as local minor clay illuviation and stage I carbonate morphology. Coarser sediment dominates in steep canyons incised relatively deeply in the Palomas Formation. These deposits consist of sandy gravel in very thin, tabular to lenticular beds. In larger, deeply incised drainages this coarse sediment is interbedded with finer sediment like that described above. Gravels are typically clast-supported with minor matrix-supported debris flow beds. Imbrication is common in clast-supported beds and sandy or pebbly beds may be cross-stratified (foresets up to 10 cm thick). Gravel consist of poorly to moderately sorted, subangular to rounded (mostly subrounded) pebbles and subordinate cobbles whose compositions reflect lithologies exposed upstream of the deposit (see descriptions of **Qam** and **Qah** clast lithologies). Matrix consists of poorly to moderately well sorted, subangular to subrounded, medium- to very coarse-grained sand. Sand in coarser deposits is brown to light brown (7.5YR 5/2-6/3), dark brown to brown (10YR 3-5/3), or dark yellowish brown to yellowish brown (10YR 4-5/4). Both coarse and fine varieties exhibit little to no pedogenic carbonate development on the surface, but buried calcic horizons are relatively common (stage I to II carbonate morphology). Surfaces locally show signs of erosion. Where erosion is minimal, stage I to II carbonate morphologies in the topsoil are typical, with upper parts locally accompanied by illuviated clay (i.e. Btk horizons overlying a Bk horizon). The calcic or illuviated clay horizons are locally overlain by 10-15 cm (4-6 in) thick, brown (10YR 4-5/3) A horizons marked by accumulation of organic matter and fine sediment deposited by eolian or slopewash processes. Weakly to moderately consolidated and typically 2-5 m (6.6-16.4 ft) thick.

> **Qayi Younger inset alluvium (upper Holocene)** – Pebbly sand, sandy gravel, and sand in very thin to medium, lenticular to tabular beds. Looser than **Qay** deposits and lacks buried soils. Gravel are clast-supported, commonly imbricated, and poorly sorted. Sand is grayish brown to pale brown (10YR 5/2-6/3), poorly to moderately sorted, subangular to subrounded, and very fine- to very coarse-grained. Locally silty (1-15% silt). Soil is marked by weak accumulation of calcium carbonate (stage I carbonate morphology), with <30% thin films of calcium carbonate mostly on undersides of clasts. A radiocarbon date from Cañada Honda returned an age of 630-580 cal yr BP. Up to 4.5 m (15 ft) thick.

Qaym Younger and modern alluvium, undivided (present to lower Holocene) – Younger alluvium (**Qay**) and subordinate modern alluvium (**Qam**). See detailed descriptions of each individual unit.

Qayh Younger and historical alluvium, undivided (~50 years old to lower Holocene) – Younger alluvium (**Qay**) and subordinate historical alluvium (**Qah**). See detailed descriptions of each individual unit.

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

Quaternary terrace deposits

Terrace deposits of the Rio Grande

Qtr Rio Grande terrace deposits, undivided (middle Pleistocene to Holocene) – Pebble-cobble gravel with sand lenses in mostly thick, tabular to lenticular beds. Mostly unconsolidated, clast-supported, and imbricated to trough cross-stratified. Clasts consist of poorly to moderately sorted, subrounded to well rounded pebbles, cobbles, and small boulders of porphyritic volcanic rocks, Cretaceous sandstone, Paleozoic carbonate and jasperoid, quartzite, and granite. Clast undersides occasionally to commonly coated by carbonate. Matrix consists of silty, fine-to coarse-grained sand containing over 55% rounded quartz grains. Deposit may be capped by pedogenic carbonate or eolian silt to fine-grained sand. Locally subdivided into 6-7 deposits based on landscape position:

Qtr1 First or lowest Rio Grande terrace deposit (~260 to ~800 years old) – Weakly to moderately calcareous and thin- to thick-bedded with occasional ripple cross-stratification (foresets up to 15 cm thick) of sandier layers. Contains very few boulders. Brown to pale brown (10YR 5-6/3) matrix. Commonly bioturbated by sedges and salt cedar. Locally subdivided into two deposits, **Qtr1a** and **Qtr1b**, with tread heights <3 and<5 m (<9.8 and <16.4 ft) above modern grade, respectively. Correlative to terrace deposits *IV* and *III* of Mack et al. (2011), respectively. The former was dated at < ~0.3 ka based on air photos and radiocarbon ages for charcoal and bivalve shells, the latter at 0.6-0.8 ka based on radiocarbon ages for microcrystalline calcite filaments in capping soil. Overall, deposits lack strong soil development. Tread height ≤3 m (10 ft) above modern grade. 2.8 to perhaps 7 m (9-23 ft) thick.

Qtr2 Second or middle-lower Rio Grande terrace deposit (~5,300 to ~8,000 years old) – Pebbly to clayey sand with common calcic horizons. Correlative to terrace deposit *II* of Mack et al. (2011) that was radiocarbon-dated at 5.3-8 ka. Tread height 3-6 m (10-20 ft) above modern grade. Approximately 2-3 (6.6-10 ft) thick.

Qtr3 Third or middle Rio Grande terrace deposit (upper Pleistocene to lower Holocene) – Well imbricated with occasional trough cross-stratification. Contains very few boulders. Pale brown (10YR 6/3) matrix. Varnish on 10-12% of clasts at surface. Stage I+ carbonate morphology in upper 80 cm (32 in) indicated by carbonate coats and/or rinds on up to 90% of clasts and common carbonate cement. Capped by up to 40 cm (16 in) of **Qes**. Perhaps correlative to terrace deposit *I* of Mack et al. (2011); calcic nodules from a mature soil capping this deposit were radiocarbon-dated at <12.4 ka. Tread height 5-8 m (16-26 ft) above modern grade. 1.5-3 m (5-10 ft) thick.

Qtr4 Fourth or middle-upper Rio Grande terrace deposit (upper Pleistocene) – Medium- to thick-bedded and well imbricated. Contains up to 15% boulders with ~30% flaggy clasts. Light yellowish brown (10YR 6/4) matrix. Sandy lenses composed of 85-90% pebbles are common and up to 25 cm (10 in) thick. Deposit capped by 35 cm (14 in) thick stage II+ carbonate horizon in which 90% of clasts have carbonate rinds up to 1.5 mm thick. Tread height 18-24 m (59-79 ft) above modern grade. 3.6-9 m (12-30 ft) thick.

Qtr5 Fifth or upper Rio Grande terrace deposit (middle to upper Pleistocene?) – Mostly unconsolidated, non- to moderately calcareous, broadly lenticular, and well imbricated to vaguely trough cross-stratified. Contains up to 5% boulders. Light brownish gray to pale brown (10YR 6/2-3) matrix. Stage II+ carbonate morphology in upper 70-90 cm (28-35 in) indicated by carbonate coats and/or rinds on all clasts and common carbonate cement. May be mantled by 0.5-2 m (1.6-6.6 ft) of **Qes** or **Qesc**. Tread height 24-30 m (79-98 ft) above modern grade. 2-6.8 m (6.6-22 ft) thick.

Qtr6 Sixth or highest Rio Grande terrace deposit (middle Pleistocene) – High exposures of rounded gravel containing exotic clasts such as quartzite. Deposit is highly deflated and lacks obvious structure. Likely represents thin remainder of coarse channel load of the ancestral Rio Grande. Tread height 36-42 m (118-138 ft) above modern grade. Maximum thickness 3 m (10 ft).

Terrace deposits of Palomas Creek

Qtp Terrace deposits of Palomas Creek, undivided (middle to upper Pleistocene) – Sandy pebble-cobble gravel in thin to very thick, tabular to lenticular beds. Unconsolidated and very weakly to moderately calcareous. Clasts consist of poor to moderately sorted, subrounded to well rounded pebbles and cobbles of Tertiary volcanic and Paleozoic carbonate lithologies sourced from the Salado Mountains and eastern Black Range. Older terrace deposits may feature more varnished clasts at surface. Deposits underlie inset surfaces along Palomas Creek; most deposits underlie relatively thin (up to ~5-7 m thick) strath terraces, but thicker fills may be present in places. Locally subdivided into 4-5 deposits based on landscape position:

Qtp1 First or lowest terrace deposit of Palomas Creek (upper Pleistocene) – Sandy gravel in medium to thick beds. Clasts include subequal proportions of pebbles and cobbles with 10-15% boulders. Locally subdivided into **Qtp1a** and **Qtp1b** with tread heights 7-16 m (23-53 ft) and 16-18 m (53-59 ft) above modern grade, respectively. 2-4 m (6.6-13 ft) thick.

Qtp2 Second or middle-lower terrace deposit of Palomas Creek (upper Pleistocene) – Weakly calcareous and thick- to very thick-bedded. Brown (7.5-10YR 4/3) matrix. Contains no more than 3% boulders. Varnish on 20-30% of clasts at surface. Local Fe-oxidation occurs on clast undersides in ~30 cm (12 in) thick zones. Few preserved soils (likely eroded). Well preserved along most of Palomas Creek in quadrangle. Tread height 24-31 m (80-102 ft) above modern grade. 2-6 m (6.6-20 ft) thick.

Qtp3 Third or middle terrace deposit of Palomas Creek (middle Pleistocene?) – Very weakly calcareous and thin- to thick-bedded. Brown (10YR 5/3) matrix.

Imbricated to weakly planar cross-stratified with fine to medium pebbles concentrated along bases of individual foresets. Clast lithologies include up to 35% Kneeling Nun tuff and aphanitic rhyolite. Varnish on up to 50% of clasts at surface. Contains more feldspar grains (up to 70%) than other terrace deposits. Tread height 33-40 m (108-131 ft) above modern grade. 1.4-3 m (4.6-10 ft) thick.

Qtp4 Fourth or upper terrace deposit of Palomas Creek (middle Pleistocene) – Sandy pebble-cobble gravel. Brown (7.5YR 4-5/3) matrix. Varnish on up to 80% of clasts at surface. Soil development uncommon (likely eroded). Moderately dissected in places. Tread height 40-47 m (131-154 ft) above modern grade. 5-8 m (16-26 ft) thick.

Terrace deposits of ephemeral drainages

Qtge Terrace deposits of ephemeral drainages east of the Rio Grande (middle to upper Pleistocene) – Sandy pebble-cobble gravel in medium to thick, tabular to lenticular beds. Unconsolidated, commonly imbricated, and occasionally planar cross-stratified (foresets up to 25 cm thick). Clasts consist of poorly to moderately well sorted, subangular to rounded pebbles (70-90%), cobbles (10-20%), and subordinate boulders (5-10%) derived from the Palomas Gap area. Clasts are composed of Paleozoic sedimentary and Precambrian igneous and metamorphic lithologies. Gravel are better sorted near the top of the deposit and 18-20% of clasts are varnished at the surface. Matrix consists of light grayish brown (10YR 6/2), poorly to moderately sorted, subrounded, very fine- to medium-grained sand that is commonly arkosic (>50% K-spar). May exhibit stage I+ to II carbonate morphology. Tread height up to 19 m (62 ft) above grade. Typically a thin strath terrace deposit that is 1-3 m (3.3-10 ft) thick.

Qtgw Terrace deposits of ephemeral drainages west of the Rio Grande (middle to upper Pleistocene) – Sandy pebble to pebble-cobble-boulder gravel in thin to thick, tabular to lenticular beds. Local sandy sediment in medium, lenticular to tabular beds. Unconsolidated to very weakly carbonate cemented and massive to imbricated. Sandy pebble beds may be planar or trough cross-stratified. Clasts are very poorly to poorly sorted, subangular to rounded, and consist of 50-85% pebbles, 15-50% cobbles, and 3-10% boulders of flow-banded rhyolite (≤30%), vesicular or dense basalt (≤20%), andesite or basaltic andesite, and perhaps Paleozoic sedimentary lithologies. Occasional open-framework lenses of pebbles and cobbles are up to 60 cm (24 in) thick. Matrix consists of reddish brown (5YR 4/4) to light brown (7.5YR 6/3), poorly to moderately sorted, angular to rounded, very fine- to coarse-grained sand composed of 30-60% feldspar, 30-50% lithic, and 10-30% quartz grains with up to 15% reddish clay films. Rare sand lenses are under 25 cm (10 in) thick and consist of planar cross-stratified sand with <15% granules. Deposit exhibits stage I-II carbonate morphology and is capped by A and Bw to Bt horizons up to 50 cm (20 in) thick in places. Typically comprises thin strath terrace deposits that underlie treads 6-20 m (20-66 ft) above modern grade. 1-2 m (3.3-6.6 ft) thick.

Quaternary alluvial fan units

Qfam Modern alluvial fan deposits (present to ~50 years old) – Unconsolidated pebbly sand and sandy pebble-cobble gravel in channels and low-lying bars of small fans, subjected to fluvial reworking in modern times. Sand consists of light yellowish brown to pale brown

(10YR 6/4 to 7/2-3), moderately sorted, subangular to rounded, very fine to medium grains of 50-60% quartz, 30-40% feldspar, and 5-15% lithic grains. Sand is locally ripple laminated. Gravel clasts are poorly to moderately sorted, subangular to rounded, and consist of 80-90% pebbles and 10-20% cobbles. Both sand and gravel-dominated units form bars, but gravel bars form greater local relief (up to 0.8 m). Maximum thickness approximately 2.5 m (8 ft).

Qfamh Modern and historical alluvial fan deposits, undivided (present to ~600 years old) – Modern alluvium (**Qfam**) and subordinate historical alluvium (**Qfah**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfamy Modern and younger alluvial fan deposits, undivided (present to lower Holocene) – Modern alluvium (**Qfam**) and subordinate younger alluvium (**Qfay**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfah Historical alluvial fan deposits (~50 to ~600 years old) – Sandy pebble-cobble gravel in very thin to very thick, tabular beds. Unconsolidated, moderately to strongly calcareous, clast- to matrix-supported, and massive/poorly stratified to weakly imbricated. Clasts consist of poorly sorted, subangular to rounded pebbles (60-80%), cobbles (10-40%), and small boulders (0-10%) Matrix consists of very pale brown (10YR 7/3), poorly to moderately sorted, subangular to rounded, fine- to medium-grained sand composed of 40-60% lithic, 20-40% quartz, and 10-20% feldspar grains. Clasts are covered by up to 70% by carbonate coats, indicating stage I carbonate morphology. Moderately bioturbated by medium to coarse roots and burrows up to 6 cm (2.4 in) in diameter. Surface is non-varnished and has 10-20 cm (4-8 in) of bar-and-swale relief. Deposit surface is graded to a surface 1.5 m (5 ft) above modern grade. 1.2-2 m (3.9-6.6 ft) thick.

Qfahm Historical and modern alluvial fan deposits, undivided (present to ~600 years old) – Historical alluvium (**Qfah**) and subordinate modern alluvium (**Qfam**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfahy Historical and younger alluvial fan deposits, undivided (~50 years old to lower Holocene) – Historical alluvium (**Qfah**) and subordinate younger alluvium (**Qfay**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfar Recent (historical + modern) alluvial fan deposits (present to ~600 years old) – Historical (**Qfah**) and modern (**Qfam**) fan alluvium in approximately equal proportions. See detailed descriptions of each individual unit.

Qfary Recent (historical + modern) and younger alluvial fan deposits, undivided (present to lower Holocene) – Recent fan alluvium (**Qfah** + **Qfam**) and subordinate younger fan alluvium (**Qfay**). See detailed descriptions of each individual unit.

Qfay Younger alluvial fan deposits (lower to upper Holocene) – Pebbly sand to sandy gravel in very thin to medium, tabular to lenticular beds. Overall, bedding is convex-up transverse to the fan, centered on fan axis. Unconsolidated to weakly carbonate-cemented, mostly clast-supported, and massive to locally planar cross-stratified (up to 15% of a given exposure). Clasts are poorly to moderately sorted, subrounded, and consist of ≤95% pebbles, ≤30% cobbles, and ≤5% boulders. Clasts are dominated by granite, metamorphic lithologies, and Paleozoic carbonates where streams exit the footwall of the Caballo fault system east of

the Rio Grande. To the west, clasts are dominated by volcanic lithologies derived from the Sierra Cuchillo and Black Range (including those reworked from the Palomas Formation). Matrix consists of brown to light brown (7.5YR 4-6/3-4; 10YR 4-5/3) to pinkish gray (7.5YR 6/2) to grayish or yellowish brown (10YR 5/2-4), poorly to moderately well sorted, subrounded, very fine- to very coarse-grained sand that is locally silty. Mostly deposited by stream-flow processes, but 5-25% of outcrops are matrix-supported debris flows or hyperconcentrated flows that are in either: 1) pebbly, internally massive beds; or 2) thin to medium, lenticular beds with pebbles and cobbles in a relatively fine matrix. Sandy sediment is typically bioturbated by medium to very coarse roots. Buried soils are common and marked by accumulation of calcium carbonate (stage I to II carbonate morphologies). Lowest strata is redder and finer-grained (i.e., more clay and fewer cobbles), and may be overprinted by a paleosol marked by illuviated clay. Unit fines in distal part, where it interfingers with and grades into unit **Qay**. Deposit is commonly capped by 10 cm (4 in) thick A horizons exhibiting ped development, finer textures, and slight accumulation of organic matter. Underlying the A horizon are: 1) Bt horizons where clasts and peds are covered by clay films (only locally observed); and 2) common calcic horizons with stage I to I+ carbonate morphology that are 10-80 cm (4-32 in) thick. Surface commonly shows evidence of erosion, such as gullies up to 2 m (6.6 ft) deep or an erosional lag of coarse pebbles to cobbles, and in these areas lacks notable soil development. On higher, relatively stable surfaces the clasts are weakly varnished and undersides are reddened. Less than 20 cm (8 in) of bar-and-swale topographic relief, which is imperceptible on many of the higher surfaces. Maximum thickness ~4 m (13.1 ft). Locally subdivided into 2 units:

> **Qfayi Younger alluvial fan deposits graded to Qayi (upper Holocene)** – Deposit is as described for Qfay, with weak surface clast varnish and soil development. Perhaps less eroded and featuring greater (up to 20 cm) of bar-and-swale topographic relief than Qfayo. A radiocarbon date from Cañada Honda returned an age of 2720-2385 cal yr BP.

Qfaym Younger and modern alluvial fan deposits, undivided (present to lower Holocene) – Younger alluvium (**Qfay**) and subordinate modern alluvium (**Qfam**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfayh Younger and historical alluvial fan deposits, undivided (~50 years old to lower Holocene) – Younger alluvium (**Qfay**) and subordinate historical alluvium (**Qfah**) deposited on alluvial fans. See detailed descriptions of each individual unit.

Qfayr Younger and recent (historical + modern) alluvial fan deposits, undivided (present to lower Holocene) – Younger fan alluvium (**Qfay**) and subordinate recent fan alluvium (**Qfah** + **Qfam**). See detailed descriptions of each individual unit.

Qfao Older alluvial fan deposits (middle to upper Pleistocene) – Alluvial fan deposits underlying surfaces graded to higher positions above modern grade than those of **Qfay**. Deposit consists of sandy pebble-cobble gravel in thin to thick, tabular to lenticular beds. Unconsolidated to somewhat carbonate-cemented and massive to weakly imbricated. Clasts are poorly sorted, subangular to subrounded, and consist of 55-75% pebbles, 30-40% cobbles, and 0-10% boulders of lithologies reflecting local source areas. Generally features moderate to strong varnish on clasts at surface, which have reddened undersides (more varnished than **Qfay** surface, except where severely eroded). Matrix consists of mostly

brown to light brown (7.5YR-10YR 4-6/3-4), poorly to moderately sorted, subangular to subrounded, very fine- to very coarse-grained sand composed of 60-70% lithic (volcanic+carbonate), 30-40% feldspar, and 5-10% quartz grains. Surface generally shows signs of erosion. Maximum thickness approximately 3-4 m (10-13 ft). Subdivided into 4 deposits along Palomas Creek:

Qf1 Deposits of alluvial fans graded to lowest terraces (upper Pleistocene) – Light yellowish brown (10YR 6/4) matrix. Unconsolidated but strongly calcareous, tabular, and massive to weakly imbricated. Features stage I carbonate morphology in upper part. Generally over 2 m (6.6 ft) thick.

Qf2 Deposits of alluvial fans graded to middle-lower terraces (upper Pleistocene) – Brown (7.5YR 5/4) matrix. Unconsolidated, calcareous, tabular to lenticular, and weakly imbricated. Varnish on 60-70% of clasts at surface. Maximum thickness 4 m (13 ft).

Qf3 Deposits of alluvial fans graded to middle terraces (middle Pleistocene?) – Pinkish gray (7.5YR 6/2) matrix. Somewhat calcareous, tabular, and massive to weakly imbricated. Features stage I+ carbonate morphology in upper part, indicated by carbonate coatings on up to 50% of clasts. Fe-oxide staining observed on up to 10% of clasts. 2-3 m (6.6-10 ft) thick.

Qf4 Deposits of alluvial fans graded to upper terraces (middle Pleistocene) – High, poorly preserved deposit observed near western quadrangle boundary, south of Palomas Creek. Not described in detail.

Qtfw Fan terrace deposits graded to terraces in Cañada Honda (middle to upper Pleistocene) – Sandy fan gravel interbedded with **Qtgw** terrace surfaces in Cañada Honda. Likely correlative with **Qf2** or **Qf3** deposits. Perhaps up to 3.5 m (11.5 ft) thick.

Qfe Older alluvial fan deposits east of the Rio Grande (middle to upper Pleistocene) – Sandy pebble-cobble gravel in thick, tabular to broadly lenticular beds underlying surfaces graded to or below **Qtr** deposits east of the Rio Grande. Weakly to moderately consolidated, moderately to strongly calcareous, clast-supported, and massive to moderately well imbricated. Clasts are very poorly to poorly sorted, subangular to subrounded, and consist of 50-70% pebbles and 30-50% cobbles of Precambrian granite and metamorphic lithologies (50%), Paleozoic carbonates (45%), and exotic volcanic and quartzite clasts reworked from **QTpa** (5%). Matrix consists of light yellowish brown (10YR 5-6/4), poorly sorted, mostly subrounded, fine- to medium-grained sand composed of 35% quartz, 35% lithic (carbonate+granite), and 30% feldspar (K-spar>plagioclase) grains. Occasional (15%) matrix-supported intervals are massive and composed of material similar to the gravel matrix. Commonly contains gastropods in sandier beds. Correlates to alluvial fan deposits in unit *Qvo* of Seager and Mack (2005). >18 m (59 ft) thick.

Quaternary-Tertiary basin-fill units

QTp Palomas Formation (lowermost Pliocene to lower Pleistocene) – Sand, silt, gravel, and clay deposited by coalesced fan complexes and the ancestral Rio Grande in the Palomas

and Engle basins. The term "Palomas" was first applied to outcrops of upper Santa Fe Group basin fill by Gordon and Graton (1907), Gordon (1910), and Harley (1934). Lozinsky and Hawley (1986) formally defined the Palomas Formation and additional detailed descriptions of the unit are found in this work and Lozinsky (1986). Fossil data (summarized by Morgan and Lucas, 2012), basalt radiometric dates (Bachman and Mehnert, 1978; Seager et al., 1984), together with magnetostratigraphic data (Repenning and May, 1986; Mack et al., 1993, 1998; Leeder et al., 1996; Seager and Mack, 2003), indicate an age range of ~5.0-0.8 Ma for the Palomas Formation. Where not significantly eroded, the surface soil is marked by a petrocalcic horizon that is 1-2 m (3.3-6.6 ft) thick and generally exhibits stage IV carbonate morphology. More information on this horizon and the constructional surface developed on the Palomas Formation, the Cuchillo surface, can be found in McCraw and Love (2012). Type sections of the Palomas Formation in the Williamsburg quadrangle are found at NW¼ NW¼ sec. 30 and NE¼ SW ¼ sec. 33, T. 14 S., R. 4 W. Initially thought to be 100-131 m (328-439 ft) thick (Lozinsky and Hawley, 1986), our work suggests a total thickness for the Palomas Formation of 240-275 m (800-900 ft) in this quadrangle. Subdivided into 12 units:

QTpa **Axial facies of the Palomas Formation** – Pebbly to silty sand that is horizontal-planar laminated to planar or trough cross-stratified; also in laminated to very thick, lenticular beds. Subordinate facies are sandy pebble-cobble gravel in medium to thick, lenticular to broadly lenticular beds or cross-stratified (up to 1 m thick). This coarse facies dominates the lower 20-25 m (66-82 ft) of the unit, as exposed north of Truth or Consequences. Locally reverse graded. Unconsolidated to weakly carbonate- or silica-cemented. Fluting occurs in select beds. Clasts consist of moderately to moderately well sorted, subangular to subrounded pebbles and cobbles of basalt, rhyolitic ash-flow tuff, andesite, dacite, quartzite, granite, chert, and carbonate and clastic sedimentary strata. Matrix consists of light brown (7.5YR 6/4) to pale brown (10YR 6/3) or light gray (10YR 7/2), moderately to very well sorted, subrounded to rounded, very fine- to coarse-grained sand comprised of 65-85% quartz, 10-25% feldspar, and 5-10% lithic grains. Yellowish tan to very pale green clay occurs in thin lenses in sandy deposits. Deposit commonly features nodular or ellipsoidal concretions of iron-oxide minerals. The former may be up to 30 cm (12 in) across, the latter up to 8 cm (2.4 in) across. Sandy beds typically represent channel margin or sandbar deposits of the ancestral Rio Grande. Silty to clayey beds are floodplain deposits, while gravel beds are intra-channel facies. Fossils recovered from this unit include gastropods and shells less than 1.5 cm (0.6 in) across, as well as freshwater species represented by salamander (*Amystoma sp.*), frog (*Rana sp.*), and a medium-sized rodent (e.g. a packrat). A tooth of the late Hemphillian horse *Neohipparion eurystyle*, collected from spoil piles just north of the quadrangle, suggests an age of 5.3-4.9 Ma for the earliest ancestral Rio Grande gravels (G. Morgan, personal communication, 2015). 40-115 m (130-380 ft) in a ~1.5 km (0.9 mi) belt on either side of the Rio Grande in the Williamsburg quadrangle. Locally divided into 2 subfacies:

QTpac **Coarse-grained axial facies of the Palomas Formation** – Sandy pebble-cobble and pebble-cobble-boulder gravel/conglomerate in medium to very thick, tabular to lenticular beds deposited in laterally extensive channel-fill complexes. Weakly to strongly consolidated, moderately calcareous, and massive to well imbricated and/or planar cross-stratified (foresets up to 50 cm thick). Lateral accretion sets are occasionally observed. Strongly indurated exposures preserve flute casts in rare instances. Clasts are very poorly to moderately sorted, subangular to rounded, and consist of 40-50% pebbles, 30-50% cobbles, and 0-20% boulders of

diverse lithologies including Tertiary volcanics, Cretaceous sandstone, Paleozoic carbonates, and quartzite. Limestone, sandstone, and siltstone constitute a greater proportion (up to 80% total) of clasts in basal beds; volcanics and quartzite increase up-section. Imbricated gravel beds yield paleocurrent directions averaging SSE, but in the lowest part paleoflow is to the SSW. Matrix consists of light yellowish brown to very pale brown (10YR 6/4-7/3), poorly sorted, subrounded to rounded, fine- to coarse-grained sand composed of 40-65% quartz, 25-35% feldspar, and 10-25% lithic grains, with 5-25% clay chips and films. Common mud rip-ups and manganese coats on clasts. Deposit typically exhibits basal scour contacts on finer-grained sediment with up to 3 m (10 ft) of relief.

QTpaf Fine-grained axial facies of the Palomas Formation – Pebbly sand/sandstone and mudstone in thick laminations to thick beds deposited in channel margin or floodplain settings. Unconsolidated, non- to weakly calcareous, and massive to trough or planar cross-stratified (foresets up to 50 cm thick). Moderately well sorted, subrounded pebbles comprise no more than ~10% of a given deposit and are commonly concentrated at the base of cross-beds. Sand is pale brown to light gray (10YR 6/3 to 7/2), very fine- to coarse-grained (commonly fine to medium or medium to coarse), moderately to very well sorted, and subangular to well rounded. Grains consist of 55-85% quartz, 10-40% feldspar (plagioclase~K-spar), and 5-15% lithics (carbonates+chert+volcanics). Deposits often feature ellipsoidal concretions and/or rounded concretions of manganese-rich material up to 30 cm (12 in) across; mud rip-ups up to 45 cm (18 in) across are common at the base of beds. Unit features up to 30% medium to thick beds of yellowish red (5YR 5/8) to olive (5Y 5/3) mudstone, typically containing fossils (e.g. Amystoma sp., Rana sp., etc.; G. Morgan, personal communication, 2015).

QTpe Eastern piedmont facies of the Palomas Formation – Sandy granule-pebble, pebble-cobble, and pebble-cobble-boulder gravel derived from the Caballo Mountain fault block. Occurs in thin to very thick, tabular to lenticular to wedge-shaped beds. Subordinate facies include silty sand and silty clay in thinly laminated to very thick, tabular to lenticular beds. Cementation and sedimentary structures vary according to relative fan position (proximal, medial, and distal). Proximal deposits consist of massive to imbricated, poorly sorted, subangular to subrounded, sandy pebble-cobble gravel in clast- to matrix-supported, medium to very thick, tabular beds. Proximal beds may feature rare cross-stratification and are weakly to moderately carbonate-cemented. These facies commonly include authigenic carbonate precipitated from shallow groundwater in gravelly gully beds (Mack et al., 2000). Medial deposits consist of massive or imbricated to planar cross-stratified sand and gravel in clast- to matrix-supported, medium to thick, tabular to lenticular beds. Sandy beds may be thickly laminated. Occasional paleosols in finer-grained medial facies may feature Btk horizons and illuviated clay (Bt) horizons above them. Distal deposits consist of poorly to moderately sorted, subangular to rounded pebble or pebble-cobble gravel interbedded with silty to sandy facies in mostly matrix-supported, medium to very thick, tabular to lenticular beds. Well-defined imbrication of gravel clasts is more common in distal facies than in proximal and medial gravels. Paleosols with Btk to K horizons are common in distal silt beds. In general, eastern piedmont facies matrix consists of poorly to moderately sorted, subangular to subrounded, fine- to coarse-grained sand comprised of 15-80% feldspar, 10-65% quartz, and 5-30% lithic grains. Matrix is typically reddish brown (5YR 4-5/4) to strong brown

(7.5YR 4-5/4) in proximal facies, and brown (7.5YR 5/4) to light gray (10YR 7/1-2) in distal facies. Maximum thickness 110 m (361 ft).

QTper Paleo-Red Canyon alluvial fan deposits of the eastern piedmont facies of the Palomas Formation – Siltstone, sandstone, and sandy pebble-cobble-boulder conglomerate in multi-story, thin to thick, tabular to lenticular beds. Moderately to strongly consolidated, commonly carbonate-cemented, mostly clast-supported, and massive to imbricated to planar cross-stratified. Scoured contacts on underlying sandstone and siltstone beds are common. Clasts are very poorly to moderately sorted, angular to subrounded, and consist of 45-100% pebbles, 35-45% cobbles, and 0-20% boulders of 50-60% Paleozoic carbonates and chert, 20-30% Abo Formation siltstone and sandstone, and 10-20% granite and metamorphics. Matrix consists of yellowish red to reddish brown (5YR 4-5/6 to 5-7/4), poorly to moderately sorted, subrounded, very fine- to coarse-grained sand composed of 40-80% lithic (carbonate+chert+mica), 40-45% feldspar, and 10-20% quartz grains. Rare stage IV carbonate morphology with carbonate laminae and rinds on all clasts. Interfingers with **QTpa** along lower 1.7 km (1.1 mi) of modern Red Canyon. 60-140 m (200-460 ft) thick.

QTpef Fine-grained eastern piedmont facies of the Palomas Formation – Clayey to silty sand with less than 40% gravel in thin to medium, tabular to lenticular beds. Reddish yellow (5YR 6/6) to pink (7.5YR 6-8/3-4) to very pale brown (10YR 8/2). Mostly unconsolidated and typically massive. Less commonly, unit is horizontal-planar to ripple laminated or planar cross-stratified. Gravel beds are clast- to matrix-supported and may be imbricated with poorly sorted, subangular to subrounded pebbles (>60%) and cobbles (<40%). Sand consists of moderately to well sorted, subangular to subrounded, very fine to fine grains dominated by feldspar (50-80%). Buried soils are common and include stage I to II+ carbonate morphology with Btk, Bk, and K horizons up to 0.8 m (2.6 ft) thick. Interfingers with basal **QTpe** beds to the east. Perhaps as much as 140 m (460 ft) thick near Red Canyon, thinning northwards to approximately 30 m (100 ft).

QTpwuc Upper coarse unit of the western piedmont facies of the Palomas Formation – Uppermost unit of western piedmont facies, consisting of sandy pebble-cobble gravel in amalgamated, laterally continuous channel-fill complexes that are generally 2-6 m (6.6-20 ft) thick. Unit defined where coarse channel-fills occupy more than 65% of sediment volume, the remainder being fine-grained, extra-channel sediment. Basal contact is transitional with unit **QTpwu** and may vary in elevation by as much as 20 m (66 ft) due to lateral terminations of lower gravelly channel-fills. These coarse channel-fill complexes exhibit scoured lower contacts, with up to 1 m (3.3 ft) of relief, and typically abrupt upper contacts (consistent with channel avulsion). Within coarse channel-fills, bedding is very thin to thick (mostly thin to thick), commonly vague, and lenticular to tabular; 0-7% cross-stratification includes lateral accretion sets up to 1.5 m (5 ft) thick, low-angle cross-stratification, trough cross-stratification, and bar-related cross-stratification with planar foresets (up to 60 cm thick). Gravel is generally clast-supported and imbricated, consistent with being deposited predominately by stream-flow. Gravel fraction consists of 50-80% pebbles with 25-50% cobbles and 1-20% boulders. Clasts are poorly sorted (lesser moderately sorted), subrounded (lesser rounded), and composed of crystal-poor rhyolites, 5-25% andesite-dacite (dark-colored to north, where plagioclase- and/or pyroxene-phyric types dominate; lighter-colored to south, where feldspar-phyric types dominate), 10-20% tuffs, 1-5% basaltic andesite, 0-10% Paleozoic

sedimentary types (mostly <3%), 1-3% hornblende-biotite intrusive found only to the north, and trace to 1% (less commonly up to 15%, particularly near the top of unit) vesicular basalt. Color of sandy matrix ranges from reddish brown (5YR 5/3-4) to light reddish brown (5YR 6/4) to pink or light brown (7.5YR 6-7/4). Fine- to very coarse-grained sand is poorly to moderately sorted, subangular to subrounded, and composed of 55-80% lithic (volcanic), 15-30% feldspar, and 5-15% quartz grains. Sandy matrix contains notable orange clay as chips or coatings/films (1-20%). Extra-channel sediment consists of very fine- to medium-grained sand (mostly very fine- to fine-grained) and clayey-silty fine sand with minor (5-20%), scattered medium to very coarse sand grains and pebbles. Color of extra-channel sediment ranges from reddish yellow to light brown (7.5YR 6/4-6) to strong brown or reddish yellow or yellowish red (5YR 4-5/6; 7.5YR 5-6/6). Commonly capped by a 1-1.5 m (3.3-5 ft) thick stage III-IV carbonate horizon. Moderately to well consolidated, weakly cemented by clay. Preserved top of unit is typically moderately to strongly cemented by soil carbonate. Maximum thickness 1.5-45 m (5-145 ft).

QTpwu Upper western piedmont facies of the Palomas Formation – Interbedded fine-grained sediment and subordinate to subequal, laterally continuous, coarse channel-fill complexes. Upper and lower contacts are transitional with **QTpwuc** and **QTpwm**, respectively. Base is placed at the bottom of predominately reddish sediment, locally coinciding with a thick clayey bed. Fine-grained, extra-channel sediment consists of clayey-silty fine sand, very fine- to fine-grained sand, and clay-silt that are in thin to thick, tabular beds that are commonly internally massive; <1-20% very thin to medium, lenticular (lesser tabular to trough-shaped) interbeds of coarse sand ± pebbles. Locally present in the clayey-silty fine sand and very fine- to fine-grained sand is minor (trace-25%), scattered medium to very coarse sand ± volcanic pebbles, consistent with deposition by hyperconcentrated flows. Clayey sediment is reddish brown to light brown to brown to light reddish brown (5-7.5YR 5-6/3-4; 5YR 5/4), clayey fine sand and silt is pinkish gray to pink to light brown (7.5YR 7/2 to 6-7/3-4; 5YR 6-7/2) to brown (7.5YR 5/4) to light reddish brown (5YR 6/3). Clay-silt floodplain deposits appear most abundant along Palomas Creek. Coarse channel-fill complexes are 2-5 m (6.6-16 ft) thick and generally laterally continuous (extending 10s to 100s of meters transverse to paleoflow direction), with scoured bases and typically abrupt tops. These coarse channel-fills consist of clast-supported sandy gravel in vague, thin to thick (mostly thin to medium), lenticular (lesser tabular) beds with minor (1-15%) cross-stratification up to 1 m (3.3 ft) thick and very thin to thin foresets that are tangential, planar, or trough-cross-stratified; sandy sediment is commonly horizontal-planar laminated to low-angle cross-stratified. Gravel is comprised of pebbles with 15-40% cobbles and 0-10% boulders. Within a bed, gravel are generally clast-supported, commonly imbricated, poorly sorted (minor moderate sorting), and subrounded to rounded. Gravel are composed of rhyolite and lesser felsic tuffs, together with 10-30% andesite and dacite (with plagioclase ± pyroxene phenocrysts), 0-7% basaltic andesites, 0-1% intermediate intrusive lithologies, and trace to 7% vesicular basalt (basalt decreases near the northern quadrangle boundary). Sand that is associated with the gravels is fine- to very coarse-grained (mostly medium- to very coarse-grained), moderately to poorly sorted, subrounded to subangular, and composed of volcanic grains, slightly lesser feldspar grains, and minor quartz grains. Sand color ranges from reddish brown to brown to light brown (2.5-7.5YR 4-5/4; 7.5YR 5/2-4/3; 7.5YR 5-6/3-4) to yellowish red (5YR 4/4-6) to light reddish brown (5YR 6/3) to pinkish gray (7.5YR 6/2). 0.5-15% clay argillans that coat clasts and sand grains or occur as

interstitial particles. Sand and gravel is weakly to well consolidated and non- to weakly cemented by clay. Clayey-silty sediment is moderately to well consolidated. 10-40 m (30-120 ft) thick.

QTpwt Transitional zone below the upper western piedmont facies of the Palomas Formation – Predominately fine-grained sediment that is redder than **QTpwm** and slightly less red than **QTpwu**. Lies gradationally between these two units, both in a vertical and lateral sense (the latter mapped south of Palomas Creek). Fine sediment consists of silt-clay (silt>clay), very fine- to medium-grained (mostly very fine- to fine-grained) sand, and slightly silty-clayey sand in thin to thick (mostly medium to thick), tabular beds. Locally within these fine beds are 1-10% thin to medium, sandy pebble-cobble beds and 1-15% scattered, medium to very coarse-grained sand. Fine beds range in color from light reddish brown to pink to light brown to pinkish gray (5YR-7.5YR 6/3-4; 7.5YR 7/3; 5YR 6/2); 0-5% reduced (yellowish-light greenish) beds. Subordinate coarse channel-fill complexes are lenticular to laterally continuous and up to 3 m (10 ft) thick. Bedding within these complexes is relatively thin and mostly tabular to lenticular. Gravel is comprised of pebbles with subordinate cobbles that are poorly to moderately sorted and mostly subrounded (minor rounded). Gravel is composed of rhyolite, lesser felsic tuffs, and 5-25% andesite-basaltic andesite. Channel-fill sand is brown to gray (7.5YR 5/2-6/1), mostly medium- to very coarse-grained, moderately sorted, subrounded, and composed of volcanic grains, lesser feldspar, and 10-25% quartz. Fining-upward trends observed in individual beds or channel-fills. Interbedded carbonate ledges are observed south of King Arroyo and are pale yellowish pink (7.5YR 9.5/2) to pinkish white (5YR 8/2), weakly to moderately indurated, medium-bedded, and massive. These beds contain rare, randomly dispersed pebbles up to 3.5 cm (1.4 in) across and common root mats, and likely represent spring deposits (Mack et al., 2000). Fossils of turtles, rodents, rabbits, *Equus* sp., and Gomphotheriidae recovered south of Palomas Creek. A tooth from the extinct rabbit species *Sylvilagus hibbardi* indicates a late Blancan (2.5-2.0) North American Land Mammal age for this deposit (G. Morgan, personal communication, 2014). Moderately to well consolidated; mostly non-cemented but with localized strong cement (1-5%). Up to 35 m (115 ft) thick.

QTpwm Middle western piedmont facies of the Palomas Formation – Very fine to fine-grained sand, silty fine sand, and silt in thin to thick (mostly medium to thick), tabular beds that are internally massive to horizontal-planar laminated. Intertongues with **QTpa**. Colors are generally pink to light brown to pinkish gray (7.5YR 7/3; 6/ 3-4; 5-7.5YR 6-7/2); clayey sediment may be light reddish brown (5YR 6/3). Locally within the fine sediment are minor (1-10%), scattered medium to very coarse sand grains (± trace to 5% very fine to medium pebbles) or relatively thin, coarse-grained interbeds. <15% clayey beds. Minor (5-20%) tongues of pebbly sand and sandy pebbles are tabular to lenticular and up to 3 m (10 ft) thick. Unit gradationally underlies **QTpwt** or **QTpwu** (in the latter, the vertical gradation is generally <10 m thick). Coarser intervals consist of amalgamated channel-fills with laminated to medium, lenticular to tabular, cross-stratified bedding. Occasional fining-upward trends observed in channel-fills. Gravel consists of very fine to very coarse pebbles and 0-20% cobbles; clasts are poorly to moderately sorted, subrounded to rounded, and composed of rhyolite, 10-20% tuff, 5-30% intermediate volcanics, and 1% andesitic to dioritic intrusives. Sand in gravelly beds is fine- to very coarse-grained, poorly to moderately sorted, subrounded to subangular, and composed of volcanic and feldspar grains with 10-30% quartz; colors range from

brown (7.5YR 5/2-4) to pinkish gray-white (7.5YR 6-8/2) to pink (7.5YR 7/3). Sand in finer strata are well sorted, subangular, and composed of quartz, 5-25% feldspar, and 15% volcanic lithic grains and subequal mafic grains. 3-15% strongly cemented beds are mostly medium- to thick-bedded and composed of dense calcium carbonate impregnating sand and pebbles. The basal contacts of these beds are commonly sharp and likely represent shallow groundwater cementation features. Cemented beds that are predominately calcium carbonate (<30% sand grains), imparting a white color, and exhibiting laminations or vugs are inferred to be precipitated from surface water (seeps or spring mounds; Mack et al., 2000). 1-5% localized calcium carbonate nodules and local paleo-burrows. Poorly sorted and internally massive, fine sand beds (medium- to thick-bedded with 1-5% clay-silt, 10% "floating" medium to very coarse sand grains, and 3% very fine to fine pebbles) are common and interpreted as hyperconcentrated flows (Seager and Mack, 2003). Moderately to well consolidated and weakly to moderately cemented by calcium carbonate. Approximately 100 m (300 ft) thick in northern quadrangle based on comparison of top of exposed unit near the town of Williamsburg with the interpreted base of the unit in City Well 8. About 75-85 m (250-280 ft) thick in the southern quadrangle, where interpretations of lithologic descriptions from the Barney Iorio Fee #1 well suggest that it is underlain by 45 m (150 ft) of ancestral Rio Grande sediment.

QTpwmc Coarse sediment in the middle western piedmont facies of the Palomas Formation – Strata dominated by coarse channel-fills, as described in unit **QTpwm** that are thick enough to be mappable. 10-20 m (30-60 ft) thick.

QTpwl Lower western piedmont facies of the Palomas Formation – Sediment dominated by stacked, coarse channel-fills composed of clast-supported, imbricated sandy gravel. On footwall of Mud Springs fault, lower contact locally is gradational, coarsening upward over 4-10 m (13-33 ft) as observed immediately east of Interstate 25 along the northern quadrangle boundary. In other exposures, the basal contact is sharp and has >1 m (3.3 ft) of scour relief. In the subsurface south of the Mud Springs fault, the base is transitional over ~30 m (100 ft). Sediment is in thin to medium, lenticular to tabular beds. Gravel includes pebbles, 5-40% cobbles, and 1% boulders. Clasts are poorly sorted, subrounded (lesser rounded), and composed of pinkish to gray rhyolite, 10-25% tuff, 10-15% plagioclase- or pyroxene-phyric andesite to basaltic andesite, 0-5% granite, trace to 1% vesicular basalt, and trace to 1% Paleozoic clasts (quartzose sandstone and limestone). About 5% of sediment is pebbly sand in thin to medium, lenticular beds. Sand is brown to reddish brown (5-7.5YR 5/4), poorly to moderately sorted, subangular to subrounded, and fine- to very coarse-grained. Basal 1-2 m (3.3-6.6 ft) is locally strongly cemented; otherwise, generally non-cemented and moderately consolidated. 100-115 m (325-380 ft) to north based on subsurface data in City Wells 7 and 8, appearing to thin to 50 m (170 ft) near Palomas Creek at the Barney Iorio Fee #1 well.

Tertiary Santa Fe Group units (pre-Palomas Formation)

Tsu Upper Santa Fe Group underlying the Palomas Formation (middle to upper Miocene) – Units **Tsupw** and **Tsubf**, undivided. As described in the Barney Iorio Fee #1 well log, the unit consists of interbedded clay and sandstone. Clays are sticky and mostly

pink at 632-802 ft, gray at 802-975 ft, and pink to red at 975-1165 ft. At 1170-2100 ft, the unit is harder (better cemented), exhibits gypsum laminations, and may contain ash and/or carbonate beds. ~600 m (1970 ft) thick. Cross-section only.

Tsupw Upper Santa Fe Group, western piedmont facies (upper Miocene) – Exposed in the bluffs north of lower Mud Springs Canyon along the northern quadrangle boundary. Here, strata are light reddish brown (5YR 6/3-4), in medium to thick, tabular beds, and composed of: 1) siltstone and very fine- to fine-grained sandstone (about 50-70%); and 2) fine- to medium-grained sandstone (~20%), and coarse channel-fills (increasing up-section from 10 to 25%) Locally in the finer sand are scattered, coarse sand grains. Coarse channel-fills are as much as 2 m (6.6 ft) thick and consist of thin to medium, tabular beds composed of pebbly sand or sandy pebbles (with as much as 10% cobbles). Pebbles are very fine to medium, subangular to subrounded, and composed predominately of volcanic clasts (mostly rhyolite with 10% tuffs, 10% intermediate volcanics, 1% basaltic andesite, and perhaps trace basalt) together with 1-5% chert and 0-1% granite (both from the Mud Springs Mountains). Sub- or superjacent to large channel-fills may lie floodplain deposits of mudstone, siltstone, and very fine to fine-grained sandstone (commonly horizontal-planar to ripple-laminated). Proportion of cemented beds increases up-section from 5 to 50%. Cementation is often nodular (5-10 cm across) and probably controlled by bioturbation or burrowing. At top of exposure lies a 1-2 m (3.3-6.6 ft) thick, laterally extensive, calcium carbonate bed mixed with 20-40% sand and gravel. Well consolidated. Unit is >20 m (60 ft) thick in exposures in northernmost of quadrangle; perhaps up to 400 m (1300 ft) thick in the Barney Iorio Fee #1 well.

Tsubf Upper Santa Fe Group, basin-floor facies (upper Miocene) – Thin to thick, tabular beds of light reddish brown to yellowish red (5YR 6/4-5/6), very fine- to medium-grained sand and clayey-silty sand. Sand is moderately sorted and subangular to subrounded. Minor (~5%) beds composed of very fine- to very coarse-grained sand with 5% pebbles. Pebbles are mostly very fine to fine, poorly to moderately sorted, angular to rounded (mostly subangular), and composed largely of aphanitic (likely felsic) volcanic rocks, ~25% chert, trace to 10% greenish sandstone (Mesozoic?), ~5% granite, and ~5% gneissic (Proterozoic) clasts. Moderately to well consolidated, with 5% well-cemented, medium to thick layers. 165-180 m (550-600 ft) thick based on interpretations of the Barney Iorio Fee #1 well log.

Tsus Upper Santa Fe Group, silicified (upper Miocene) – Strongly silicified Santa Fe Group conglomerate found in a sliver of the Hot Springs fault zone in the eastern part of the quadrangle. Clasts consist of poorly sorted, angular to subangular pebbles and cobbles of aphanitic volcanic lithologies, chert, granite, and metamorphic rocks. Matrix is replaced by silica cement that is weak red (10R 4-5/) to reddish brown (2.5YR 4-5/). Total thickness >15 m (50 ft).

Paleozoic bedrock units

Om Montoya Formation (middle to upper Ordovician)

Oma Aleman Member – Dark gray to dark brownish gray, thin- to medium-bedded, massive to occasionally laminated, non- to sparsely fossiliferous dolostone and

subordinate wackestone and packstone. Less commonly features light to medium gray or purplish brown, medium-bedded, massive to laminated packstone interbedded with jasperoid. Packstone contains lacy networks of dark brown chert. Jasperoid contain relict nodules of limestone and secondary hydrothermal alteration products of quartz and barite. Contains the brachiopods *Rafinesquina* and *Zygospira* in the lower half (Mason, 1976). Forms dark colored slopes with isolated outcrops. 53 m (174 ft) thick in quadrangle.

Oml **Lower Member of the Montoya Formation** – Brownish gray, cherty dolostone overlying white to medium gray, quartzose sandstone with a dolomitic matrix. Dolostone occurs in thick to very thick, tabular beds and is massive to laminated with laminae of dark brown chert. Vertical burrows in-filled by light gray chert. Poorly outcropping jasperoid observed in upper 12 m (40 ft). Sandstone occurs in medium, tabular to lenticular, reverse-graded beds and is fine- to medium-grained. In upper part, sandstone grades to subangular or subrounded granules to pebbles of quartz and black chert interfingering with dolostone. Total thickness 37 m (121 ft).

Oep ***El Paso Formation (lower Ordovician)***

Oepb **Bat Cave Member** – Medium to dark gray or pinkish gray, ledge-forming, thin- to thick-bedded, massive to wavy-bedded to occasionally ripple laminated, fossiliferous, cherty wackestone to grainstone. At least two beds of light to brownish gray, matrix-supported, medium-bedded, massive limestone breccia occur in the upper half. Clasts in these beds feature poorly sorted, angular fragments of limestone and dolostone in a fine- to medium-grained grainstone matrix. Fossils include brachiopods, crinoid columnals, trilobites, and stromatolites. The latter occur as 3 cm (1.2 in) thick algal mats or domal structures up to 30 cm (12 in) in diameter. Chert occurs as wavy laminae, vertical veinlets up to 6 cm (2.4 in) wide, or pebble-sized nodules to extensive lenses forming protruding layers up to 40 cm (16 in) thick. Total thickness approximately 65 m (213 ft).

Oeps **Sierrite Limestone** – Medium to dark brownish gray or occasionally reddish, thin- to medium-bedded, tabular, mostly massive, sparsely fossiliferous, cherty, dolomitic packstone. Occasional dark gray dolostone beds up to 15 cm (6 in) thick. Chert occurs in 1-3 cm (<1.2 in) wavy bands, vertical veinlets up to 2 cm (0.8 in) wide, ribbons up to 15 cm (6 in) wide, or lenses and nodules up to 6 cm (2.4 in) thick, and weathers black or dark brown. Weakly to strongly bioturbated, with vertical burrows filled with dolomite. Gradational basal contact with Bliss Formation features several very thin (1-2 cm) layers of gray to very dark brown, interbedded siltstone and limestone. Elsewhere, lower 3-3.5 m (10-12 ft) consists of limestone altered to jasperoid. Total thickness 53 m (174 ft).

ꞒOb **Bliss Formation (upper Cambrian to lower Ordovician)** – Very dark brown to nearly black, well indurated, thin- to medium-bedded, occasionally wavy-bedded, tabular, massive to broadly cross-stratified sandstone. Well sorted, subangular to subrounded, quartzose, and very fine- to fine-grained with subordinate, non-calcareous siltstone. Common peloidal glauconite. Generally forms slopes beneath ledges of **Oeps**. Total thickness 12 m (39 ft).

Proterozoic bedrock units

pЄu Plutonic and metamorphic rocks, undivided (Paleo- to Mesoproterozoic) – Granitic gneiss, quartzo-feldspathic schist, amphibolite, metasiltstone, and granite in unknown proportions. See individual descriptions for Proterozoic granite and metamorphic rocks. Total thickness unknown.

pЄg Granite (Paleo- to Mesoproterozoic) – Pink to pinkish gray to red, hypidiomorphic granular, phaneritic, fine- to very coarse-grained, locally gneissic granite exposed in footwall of Hot Springs fault. Phenocrysts include plagioclase, microcline, quartz, and biotite. Exsolution lamellae of plagioclase are commonly found in microcline crystals and define a perthitic texture. Groundmass is composed of feldspar, quartz, and minor chlorite. Quartz veins are common and range from mm to m-scale thickness. Pink granite is poorly to moderately foliated; gneissic granite is well foliated. Total thickness of plutonic rocks unknown.

pЄm Metamorphic rocks (Paleo- to Mesoproterozoic) – Unit mapped where metamorphic rocks constitute over 60% of exposure. Dark gray gneiss is commonly intruded by granitic to quartzose pegmatite veins up to 25 cm (10 in) wide. Quartzo-feldspathic schist is dark to tannish gray and micaceous (biotite+muscovite). Both gneiss and schist are strongly foliated. Metamorphic units often exhibit low amplitude (less than 30 cm) folding and may be boudinaged. Occasional amphibolite pods (roof pendants) contain phenocrysts of plagioclase, biotite, and hornblende, and are <10 m (33 ft) in diameter. Minor reddish brown metasiltstone is observed in places. Total thickness unknown.

Subsurface units

QTpwlt Transitional base of the lower western piedmont facies of the Palomas Formation (lower Pliocene) – Pinkish gray to light brown to pink (7.5YR 7/2-3; 6/3) clay, silt, and fine sand interbedded with minor channel-fills of coarse sand and felsic-intermediate volcanic pebbles (with trace dark, aphanitic clasts that could be basalt). Interpreted to be 51 m (169 ft) thick in the Barney Iorio Fee #1 well. Unit is only ~6 m (20 ft) thick where **QTpwl**/**Tsupw** contact is exposed and is accordingly subsumed into **QTpwl**. Cross-section only.

Tsl Lower Santa Fe Group (Oligocene to middle Miocene) – Relatively well-cemented Santa Fe Group consisting of volcaniclastic sandstone and conglomerates. Correlative to the Hayner Ranch Formation and possibly to the Thurman Formation (Seager et al., 1971; Seager et al., 1982). Described using exposures on the Skute Stone Arroyo quadrangle (Koning et al., 2015). Estimated to be 1100 m (360 ft) thick using cross-section on Skute Stone Arroyo quadrangle. Cross-section only.

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