GEOLOGIC MAP OF THE OSCURA 7.5-MINUTE QUADRANGLE, LINCOLN AND OTERO COUNTIES, NEW MEXICO

BY

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INTRODUCTION

Below are descriptions for geologic map units depicted in the Oscura 7.5-minute quadrangle, New Mexico. This quadrangle extends from the Phillips Hills on the west to the Godfrey Hills on the east; occupying an elevation range between 2070 m (6787 ft) in the Godfrey Hills and 1340 m (4400 ft) on the alluvial fans west of the Phillips Hills. Bounded on their western side by the west-down Alamogordo fault, the Phillips Hills exhibit 130-150 m of topographic relief. These are underlain by the San Andres Formation, which consists of limestone and dolomite in its lower part, and interbedded carbonates and gypsum in its upper part. Latest Quaternary movement on the Alamogordo fault has created fault scarps in Quaternary alluvium. Despite the linear, steep nature of the western front of the Godfrey Hills, there is no outcrop or stratigraphic evidence that this front corresponds with a significant fault. The Godfrey Hills exhibit 180-425 m of topographic relief, and are underlain by Eocene-Oligocene, intermediate volcanic rocks and related volcaniclastic sediments. In-between the Godfrey and Phillips Hills are coalesced alluvial fans deposited by drainages exiting the Godfrey Hills. Drainages on the alluvial fans converge into one of three large drainages -- New Well Draw, Jackson Draw, and North Mill Arroyo -- which flow across, or around, the Phillips Hills. An alluvial fan formed at the mouth of the Jackson Draw drainage on the west side of the Phillips Hills. Other small alluvial fans were deposited at the mouths of small drainages eroded into the western flank of the Phillips Hills. A blanket of eolian sediment, typically reworked by sheetwash between coppice dunes, blankets much of the distal and medial alluvial fans; in the case of the alluvial fans west of the Phillips Hills, this blanket extends onto the proximal alluvial fans. The climate is arid to semiarid, with an average annual air temperature of 14-16° C (57-60° F; Sprankle, 1983). Precipitation comes during winter storms and summer monsoons and averages 20-36 cm (8 to 11 in; Sprankle, 1983). Vegetation consists largely of mesquite, saltbrush, creosote, and various grasses.

DESCRIPTION OF MAP UNITS

Note: All descriptions were conducted using a hand lens and a Munsell Soil Color Chart (Munsell Color, 1994). References and discussion of a unit's age control is presented in the accompanying report. The report also presents interpretations regarding structure and geologic history.

MODERN AND HISTORICAL ALLUVIUM

Qam **Modern alluvium (less than 50 years old) –** Sand and gravelly sand deposited by recent discharge events in topographically low, but relatively wide, areas or as lobes at the mouths of incised arroyos. Bedding is very thin to medium and horizontal-planar, with internal planar-laminations(minor wavy laminations) and local cross-stratification. Gravel includes volcanic pebbles and cobbles that are subrounded to subangular and poorly sorted. Sand is very fine- to very coarse-grained, subangular to subrounded, and

moderately to poorly sorted. Surface has fresh bar- and swale topography up to ~50 cm. No soil development. Loose. Inferred to be 1-2 m-thick.

Qamg **Modern alluvium deposited in gullies or arroyos (less than 50 years old) –** Gravelly sand, sandy gravel, and sand deposited by recent discharge events at the bottoms of incised gullies or arroyos. Unit typically incised below the top of unit **Qay**. There may be up to 1.5 m of erosional (gullied) relief on the surface of this unit; typical bar and swale topography is generally 30-60 cm-tall. Bedding is very thin to medium and planar-horizontal, with internal planar-laminations (minor wavy laminations) and local cross-stratification. Gravel consist of poorly to very poorly sorted pebbles, cobbles, and boulders that are mostly subrounded. Clasts are composed primarily of Tertiary volcanic rocks east of the Phillips Hills. Sand is very fine- to very coarse-grained (mostly medium- to very coarse-grained), subangular to subrounded, and moderately to poorly sorted. No soil development. 1-3 m-thick.

Qah **Historical alluvium (50-150? years old) –** Well-bedded sand and gravel with no notable soil development. Commonly found at the mouths of incised, narrow gullies. Generally less than 2 m-thick.

Qamh **Undifferentiated modern and historical alluvium (0-150 years? old) –** Undifferentiated modern and historical alluvium. See descriptions for units **Qam** and **Qah** for more detail. Generally 2 m or less in thickness.

Qaymh **Undifferentiated Holocene alluvium filling incised, narrow valleys (Holocene) –** A combination of units **Qam**, **Qah**, and **Qay** that fills the bottoms of relatively narrow valleys; the individual units are too small to be differentiated out separately. Less than 3 m-thick.

ARTIFICIAL FILL

af **Artificial fill (modern) –** Compacted silt, clay, and sand (minor pebbles) under highways and railroads. In the case of railroads, coarse to very coarse pebbles and fine cobbles drape compacted fill.

COLLUVIAL AND DEBRIS FLOW DEPOSITS

Qc **Colluvium (Holocene) --** Gypsiferous sand and gravel deposited adjacent to steep slopes. Only mapped locally adjacent to the Alamogordo fault scarp in the southwestern part of the quadrangle. Not accessible for field description. Probably 1-3 m-thick.

Qdct **Debris flows, colluvium and talus (upper Pleistocene through upper Holocene) –** Sandy gravel that has poor to no bedding. Unit is dominated by debris flow sediment, but includes colluvium and talus at the base of steep, rocky slopes. Debris flows lack

internal bedding and generally have relatively high proportions of cobbles and boulders. Gravel dominated by pebbles and cobbles, with minor to subordinate boulders. Clasts are angular to subangular, poorly to very poorly sorted, and composed of intermediate volcanic rock types. Matrix is composed of very fine- to very coarse-grained sand with 3-25% silt and clay. Color of matrix ranges from brown to light brown, pink to very pale brown, or brown to yellowish brown. Sand is subangular to subrounded and poorly sorted. Medium to very coarse sand is composed of volcanic lithic grains whereas very fine to fine sand is composed of volcanic lithic grains, feldspar, quartz, and gypsum. No effort was made to differentiate deposits of differing ages, although variances in soil development were observed. 1-20(?) m-thick.

SHEETFLOOD AND EOLIAN DEPOSITS

Note: These two deposits are grouped together because most eolian sheet deposits have been affected to some degree by sheetflooding. The surface of both deposits correlate with mesquite and saltbrush vegetation and a lack of creosote.

Qec **Coppice dunes (upper Holocene) --** Mounds of sand accumulated under and in the immediate vicinity of mesquite bushes (and cresosote bushes, to a lesser extent). Mapped where coppice dunes exceed 5% surface cover. Mounds range from 10 to 100 cm in height. Sand is light brown to strong brown, mostly fine-grained but ranging from very fine- to medium-grained (with very minor coarse and very coarse sand), subrounded to subangular, moderately sorted, and composed of quartz with subordinate feldapr and 15-20% volcanic lithic grains. Coppice dunes overlie a bioturbated eolian sand sheet or sheetflood deposits (with a sparse pebble lag); this underlying deposit is grouped with this unit. The coppice dunes are likely upper Holocene in age, but underlying deposit may be lower to middle Holocene. Loose. Deposit under the dunes is up to ~ 2 m-thick.

Qse **Sheetflood and deposits reworked from eolian sand sheets (uppermost Pleistocene to upper Holocene) --** Light brown to brown, pale brown, and strong brown to reddish yellow, lower-fine to lower-medium sand with minor coarser-grained sand. Minor (~1-5%) very fine to coarse pebbles. A very thin pebble bed may be present at base of deposit. Internally massive, with weak soil development characterized by ped development and minor gypsum accumulation (marked by gypsum filaments). Local, very thin to thin pebble lenses. Sand is subrounded, moderately to well sorted, and composed of quartz with subordinate plagioclase and potassium feldspar; estimate 12-15% lithic and mafic grains. Very minor coppice dunes may be present on the surface, covering generally less than 5% of the surface area. Surface commonly has a sparse lag gravel and no desert pavement development. Loose to moderately consolidated. 1-3 m-thick.

Qsec **Sheetflood deposits and coppice dunes, undivided (uppermost Pleistocene to upper Holocene) –** See descriptions of **Qse** and **Qec**.

Qer **Eolian sand ramp (upper Holocene) –** An eolian sand ramp that slopes away from a topographic high. Sand is mostly brown to light brown, very fine- to medium-grained (minor coarser sand), subrounded, moderately to well sorted, and composed of quartz grains (with subordinate feldspar and lithic grains). Loose and several meters thick.

Qerc **Eolian sand ramp with coppice dunes on surface (upper Holocene) --** Coppice dunes (as described in unit **Qec**) that overlie several meters of sand deposited as an eolian sand ramp (as described in unit **Qer**). Loose and several meters thick.

Qed **Eolian sand in dune forms other than coppice dunes (upper Holocene) --** Eolian sand in mound-like deposits that extend over several meters. Dunes are 30-100 cm in height, commonly elongated (3-30 m in length), and overlie sheetflood deposits or eolian sand sheets (included with this unit). Sand is light brown to reddish yellow and fine- to medium-grained (mostly fine-upper to medium-lower). Sand is subrounded, moderately well to well sorted, and composed of quartz, subequal to subordinate feldspar, and 10-15% volcanic and mafic lithic grains. Loose and up to 3 m-thick.

Qe **Undifferentiated eolian sand deposits (upper Holocene) --** Unit includes undifferentiated **Qse**, **Qsec**, **Qec**, and **Qer** (see descriptions of these units above). Up to several meters thick.

Qgy **Gypsum eolian sheet or dunes (upper Pleistocene to Holocene) –** Gypsum in a tabular layer or in eolian dunes. Generally present near the western border of the quadrangle. Inferred to have been deposited by wind and then later experienced dissolution-precipitation events. 1-3 m-thick but mostly non-accessible for measurement.

Qec/Qse **Coppice dunes developed on sheetflood deposits (upper Holocene) --** see individual descriptions for **Qec** and **Qse**.

Qe/Qao1 **Undifferentiated eolain sand deposits overlying older alluvium --** see descriptions for **Qe** and **Qao1**.

Qse/Qao1 **Sheetflood deposits overlying older alluvium --** see descriptions for **Qse** and **Qao1**.

Qse/Kcc **Sheetflood deposits overlying Crevasse Canyon Formation –** see descriptions for **Qse** and **Kcc**.

ALLUVIAL FAN AND ALLUVIAL SLOPE DEPOSITS

Qay2 **Younger alluvium, younger subunit alluvium (upper Holocene) –** Sand with subordinate, but variable, gravel interbeds. Sand typically has low amounts of fines (less than 10%) and is well-bedded to massive. Unit disconformably overlies older sediment of **Qay1** over much of the quadrangle, although near the base of the Godfrey

Hills it is inset significantly into **Qay1**. Stratification is typically planar-horizontal laminated to very thinly bedded. Gravel consists of very fine to very coarse pebbles, subordinate cobbles, and 0-10% boulders. Clasts are predominately composed of intermediate volcanic rocks. Sand is light yellowish brown to pale brown to light brownish gray; sand is very fine- to very coarse-grained (mostly fine- to medium-grained) and composed of quartz, subordinate feldspar, and 10-20% lithic and mafic grains. Relatively weak soil development characterized by stage I to I+ carbonate morphology. Loose to weakly consolidated. Up to 2 m-thick but mostly <0.5 m (where it overlies **Qay1**).

Qay1 **Younger alluvium, older subunit (uppermost Pleistocene to middle Holocene) –** Interbedded sand and sandy gravel in varying proportions (with gravel beds increasing towards the Godfrey Hills). Near the base of the Godfrey Hills, this unit was deposited on large areas of the proximal and medial alluvial fans and then partially buried by eolian deposits (e.g., **Qec** and **Qse**). Sandy gravel are commonly in very thin to medium (mostly very thin to thin), horizontal-planar to lenticular beds that are clast-supported. Sparse, medium to thick beds of cobble-dominated gravel are generally interpreted as debris flow deposits. Gravel consist of very fine to very coarse pebbles with subordinate cobbles; gravel composed of intermediate clasts (except in alluvial fans associated with the Phillips Hills). Sand in gravel beds is fine- to very coarse-grained, subrounded, poorly sorted, and mostly trachyandesite grains. Sand increases in abundance westwards and is massive or horizontal-planar, laminated to thinly bedded. In the central part of the quadrangle, the sand is light brown to very pale brown, very fine- to medium-grained (mostly fine-grained), and composed of quartz, subordinate plagioclase and potassium feldspar, and 20-30% dark lithic grains (probably trachyandesite). 1-10% medium- to very coarse-grained sand or pebbles are scattered or in very thin to thin lenses. Top of unit generally has a calcic horizon with stage II carbonate morphology, although in many places this soil has been eroded and then partially reburied by late Holocene alluvium, sheetflood, and eolian deposits. A cumulic soil is generally present in the interior of the unit, characterized by moderate, fine to very coarse, subangular blocky peds (with no clay films) and 5-15% gypsum filaments. Moderate to well consolidated. 0.5-3 m-thick.

Qay **Younger alluvium (latest Pleistocene to Holocene (uppermost Pleistocene to upper Holocene) –** Units **Qay1** and **Qay2**, undifferentiated. See descriptions for those individual units. 0.5-3 m-thick.

Qao **Older alluvium (Pleistocene) --** Undifferentiated older alluvium. Generally categorized as unit **Qao1**, with much less exposures of **Qao2** (see descriptions below).

Qao2 **Inset valley-fill associated with older alluvium (upper Pleistocene) --** Inferred valley-fill inset into the **Qao1** unit. Because a buttress or inset contact was not observed during field work, it is possible that this unit is part of **Qao1**. Unit is characteristically gravelly and in laminated to medium, tabular to lenticular beds. Gravel are clast-supported, locally imbricated, and consist of very fine to very coarse pebbles with subordinate cobbles and 1-10% boulders. Clasts are predominately

intermediate volcanic types. Debris flow sediment is locally observed (<10% of sediment volume away from bedrock highs) and commonly has matrix-supported cobbles. Sand is strong brown to brown (7.5YR 4/4 to 5/6), mostly medium- to very coarse-grained, with subordinate very fine- to fine-grained sand and minor clay-silt. Matrix is typically not as gypsiferous as units **Qao1** and **QTa**. Unit has similar soil development as **Qao1** (i.e., stage III calcic horizon underlain by a strong gypsic horizon). 1-4(?) m-thick.

Qao1 **Younger subunit of older alluvium (middle? to upper Pleistocene) --** This deposit commonly contains buried soils, is gypsiferous, and consists of gravel, pebbly sand, sand, and clayey fine sand beds. The base of the deposit is not exposed except within ~1 km of the Godfrey or Phillips Hills. Color of sandy sediment ranges from light brown, pink, very pale brown, pinkish gray, to reddish yellow – with redder colors generally associated with higher clay concentrations. Finer sediment consists of gypsiferous, very fine- to medium-lower sand and clayey fine sand, with minor medium- to very coarse-grained sand and pebbles (scattered or in very thin to medium lenses). Gypsum precipitates as coarse, sand-size crystals in clayey very fine- to fine-grained sand. Sand is internally massive and commonly affected by pedogenesis. Buried soils commonly have a relatively thin, somewhat reddened horizon (locally with illuviated clay) underlain by a calcic horizon (stage I to II carbonate morphology, with nodules common) underlain by a gypsic horizon. Locally, rhizoliths are present that are cemented by gypsum. Gravel is in very thin to medium (mostly very thin to thin), horizontal planar to lenticular beds; clasts contain abundant pebbles and subordinate cobbles, with very minor (10% or less) boulders. Gravel are composed of intermediate volcanic types. Gravel is commonly clast-supported and imbricated, consistent with stream-flow processes. However, usually some debris flow deposits are observed at a given exposure. Debris flow deposits tend to have abundant cobbles and are in medium to thick, lenticular beds that lack internal bedding. Sand associated with gravel beds is mostly medium- to very coarse-grained and mostly composed of intermediate volcanic grains (fine sand has abundant quartz and feldspar). A calcic horizon overlying a gypsic horizon is commonly preserved at the top of the deposit, with a stage III to IV carbonate morphology in the calcic horizon. Base of deposit not observed, but likely overlies Mesozoic strata or various Tertiary igneous rocks. Weakly to well consolidated and greater than 3 m-thick.

QTa **Quaternary-Tertiay alluvium (upper Pliocene to lower(?) Pleistocene) –** Sandy gravel dominated by stream-flow facies, with lesser amounts of debris flow facies. Unit lacks the buried soils that are commonly observed in **Qao1** and is locally very gypsiferous. The base of the deposit is locally exposed and commonly is cemented to varying degrees. Stream-flow sediment is in very thin to thin, tabular beds or thin to thick, lenticular beds. Gravel is mostly clast-supported and locally imbricated. Gravel consists of pebbles with subordinate cobbles and boulders. Sand is very fine- to very coarse-grained (mostly medium- to very coarse-grained) and composed of volcanic lithic grains and feldspar. Colors of the fine and sand fraction ranges from reddish gray to reddish brown, light brown, very pale brown, light gray, to pale yellow. Away from the mountain-front, clay, silt, and very fine- to fine-grained sand become increasingly

common. Debris flow sediment is in medium to thick, lenticular beds. Debris flow sediment contains abundant cobbles and boulders that are commonly matrix-supported. Largest boulder size is 1 m. Weakly consolidated. 1-15 m-thick.

TERTIARY INTRUSIVES

Ti **Undifferentiated hypabyssal intrusive –** Not accessible for description because of location on the White Sands Missile Range.

Ttaf **Fine-grained trachyandesite (upper Oligocene) –** Light gray, aphanetic dike. Trace hornblende phenocrysts up to 3 mm-long. Locally subjected to vapor phase alteration. Emplaced in a wide (up to 70 m), east-west striking dike in the Godfrey Hills. This unit cross-cuts unit **Ttfu** so it must post-date that unit.

Tiota **Oscura trachyandesitic dike (lower Oligocene?) –** A long dike near the center of the quadrangle filled by porphyritic trachyandesite. Fresh color of gray, weathering to light brownish gray. Rock does not develop a strong varnish. Phenocrysts include: 5-25% feldspar (probably plagioclase; euhedral to subhedral, 0.5-4.0 mm-long) and 3-5% pyroxene (euhedral to subhedral, 0.5-5 mm-long). Groundmass is 0.2-0.3 mm and consists of feldspar with 10-20% unidentifiable mafic minerals (probably pyroxene). Dike erodes to form spheroidal boulders.

Titap **Porphyritic trachyandesite (upper Eocene to lower Oligocene) –** A common dike- or sill-filling intrusive present in the southwestern part of the quadrangle. Fresh color of gray to dark bluish gray to black, weathering to reddish brown to gray shades. Rock has up to 35% phenocrysts of pyroxene (0.1-8 mm-long, subhedral to anhedral) and feldspar (probably plagioclase, 1-10 mm-long, and subhedral); feldspar phenocrysts are typically more abundant than mafic phenocrysts. Feldspars are commonly aligned. Groundmass is composed of subhedral feldspar that ranges from 0.1-0.5 mm (less commonly to 2.0 mm) together with 20-35% anhedral pyroxene(?) +/- biotite (0.1-0.3 mm-long).

Titapd **Porphyritic trachyandesite dike (upper Eocene to lower Oligocene) –** Unit **Titap**, as described above, filling dikes. Dikes are mostly 1-2 m-wide, occasionally as much as several meters wide.

Titaps **Porphyritic trachyandesite sill (upper Eocene to lower Oligocene) –** Unit **Titap**, as described above, filling a sill. Sills are generally less than ~4 m-thick.

Tita **Trachyandesite (upper Eocene to lower Oligocene) –** Gray trachydacite intrusive. Rock is composed of plagioclase and ~20-25% pyroxene +/- biotite whose sizes are well-graded (0.1-3.0 mm). Plagioclase laths may be aligned. Less than 10% phenocrysts of plagioclase (1-4 mm-long).

Titad **Trachyandesite dike (upper Eocene to lower Oligocene) –** Unit **Tita**, as described above, filling a dike.

Titas **Trachyandesite sill (upper Eocene to lower Oligocene) –** Unit **Tita**, as described above, filling a sill.

Tim **Megacrystic trachygabbro (lower Eocene) –** Dark gray to gray intrusive composed of trachygabbro. Rock has 2-25% phenocrysts of euhedral to subhedral hornblende +/- minor pyroxene in addition to plagioclase. Hornblende is 1-20 mm-long while plagioclase is smaller (commonly 0.5-2.0 mm). Groundmass consists of plagioclase with subordinate, but variable, amounts of mafic minerals and plagioclase (mostly 0.1-0.5 mm in size). Exposed rock commonly develops a strong varnish.

Timd **Megacrystic trachygabbro dike (lower Eocene) –** Unit **Tim**, as described above, filling a dike. Dikes are typically a few meters wide, but locally are as wide as 10 m.

Tims **Megacrystic trachygabbro sill (lower Eocene) –** Unit **Tim**, as described above, filling a sill. Sills are ~10 m-thick or less.

TERTIARY LAVAS AND VOLCANICLASTIC SEDIMENT

Ttfu **Upper trachyte (upper Oligocene):** Light to dark gray, fine-grained lava with a trachytic texture and platy flow foliation. The unit is composed of a series of thin flows 1-10 m thick with basal scoriaceous breccia and vesicular flow tops with elongated vesicles. Base fills paleo-canyons and top is eroded. Red to yellow alteration of the flow breaks is common. Greater than 80 m-thick.

Tbr **Trachyandesite breccia (upper Oligocene)**: Interbedded trachyandesite flows and breccias. The lava flows are light gray and contain phenocrysts (<5-7%) of sanidine, plagioclase, and pyroxene (1-10 mm long). Most breccias are monolithologic and contain subrounded to angular clasts in a light gray matrix. Clast size generally corresponds to pebbles and cobbles. Locally, heterolithic breccias are present as debris flow deposits. Base is flat and top is eroded. A $^{40}Ar/^{39}Ar$ age of 28.59±0.05 Ma was obtained from sanidine in the unit (Peters, personal communication, 2010). 110-120 m-thick.

Tpt **Palisades Tuff (Oligocene) –** Cliff-forming welded tuff with pronounced eutaxitic foliation and taphony weathering texture. Contains < 2% lithic fragments composed of trachytic lavas. Phenocrysts include plagioclase, sanidine, pyroxene, and sparse biotite. The tuff is generally crystal-poor (~5-10% phenocrysts), but the more welded intervals are 15-20% phenocrysts. The base is unwelded or a black vitrophyre. Pumice lapilli in the unwelded tuff are < 2 mm. The tuff is generally strongly welded, with red -brown, knobby-weathering, glassy intervals separated by pinkish gray intervals. Occasionally, the tuff has flattened mafic clots neat the base. Both the top and bottom of this unit is

fairly flat. An $^{40}Ar/^{39}Ar$ age of 28.67±0.07 Ma was obtained from sanidine in the tuff (Peters, personal communication, 2010). 55-60 m-thick.

Tts **Intercalated volcaniclastic sediment and minor trachytic lava flows (lower Oligocene) –** Volcaniclastic sediment is mostly composed of debris flow deposits. Bedding is vague to non-existent. Associated clasts are subrounded to subangular, very poorly sorted, and comprised of pebbles and cobbles, with 5-15% boulders. Clasts are of andesitic to dacitic composition. Sand is light brownish gray to light gray to white, fine- to very coarse-grained, angular to subrounded, poorly sorted, and a litharenite. Biotite grains are commonly observed in the sand fraction. Sand contains variable amounts of tuff. Sediment is mostly moderately to strongly cemented, but may be non- to weakly cemented and weakly consolidated. Volcanic flows near the north end of the escarpment are dark gray, porphyritic trachyandesite; rocks have 20% plagioclase phenocrysts (1-2 mm long) and 10-15% pyroxene phenocrysts (1-2 mm long). Volcanic flows in this unit to the south include dark basaltic andesite(?), To south, a volcanic package near the top of the unit is differentiated as unit **Ttabd** (described below). This volcanic package divides an upper volcaniclastic unit (**Ttsu**) from a lower volcaniclastic unit (**Ttsl**). Approximately 560-570 m-thick.

Ttsu **Upper volcaniclastic unit (lower Oligocene) –** Volcaniclastic unit that overlies the flow package of **Ttabd**. Very poorly exposed. Unit thickens to the south to as much as 25 m.

Ttabd **Trachyandesite, basaltic andesite, and dacite flows near the top of unit Tts (lower Oligocene) –** Flows include a fine-grained, sugary, basaltic andesite; brown, fine-grained, platy, basaltic andesite (with 1-3% phenocrysts of plagioclase and pyroxene); porphyritic dacite (light gray, with 25-35% phenocrysts of plagioclase, biotite, and hornblende); and gray trachyandesite (5% phenocrysts of plagioclase). About 100 m-thick.

Ttsl **Lower volcaniclastic unit (lower Oligocene) –** Volcaniclastic unit that underlies the flow package of **Ttabd**. Strata are similar to that described in unit Tts. Approximately 440-450 m-thick.

Ttbs **Intercalated trachybasalt lava flows and volcaniclastic sediments (upper Eocene to lower Oligocene) –** Flows erode to form platy talus. Fresh surfaces are typically very dark gray to black, but weathered surfaces are gray and commonly exhibit a silvery sheen with ~30% light-colored spots (1-3 mm-wide). Rock is slightly porphyritic, with 1-5% pyroxene phenocrysts (0.5-2.0 mm and subhedral). Groundmass is 0.1-0.3 mm and consists of plagioclase with pyroxene. Some flows obtain a very dark varnish. Flows are interbedded with volcaniclastic sediment that is commonly reddish brown clay with 10-15% scattered andesite pebbles. Pebbles are very fine to very coarse and subangular. 115-130 m-thick.

Twl **Walker trachyandesite lavas and volcaniclastic sediments (upper Eocene to lower Oligocene) –** Gray to dark gray, porphyritic trachyandesite. Commonly weathers to

produce a dark, crumbly outcrop (in contrast to the platy outcrop appearance of unit **Ttbs**). Phenocrysts comprise 5-30% of the rock and consist of subhedral plagioclase and pyroxene (0.2-10.0 mm-long, mostly less than 6 mm-long); in most flows there is more plagioclase than pyroxene. Groundmass is 0.1-0.5 m and composed of plagioclase and pyroxene(?). Lavas are variably crystal-poor (5%) to crystal- rich (30%). The basal contact with the underlying Walker volcanic breccia is gradational. Unit is 200 m-thick on northeast side of the Jackass Mountain fault. However, on the southwest side of the fault it may be considerably thicker.

Twb **Walker volcanic breccia (middle to upper Eocene) --** Unit largely consists of purplish gray to gray, poorly bedded debris flow deposits that are variably cemented. Gravel includes pebbles, cobbles, and boulders in various proportions. Clasts are subrounded to subangular, poorly to very poorly sorted, and composed of porphyritic, intermediate volcanic rocks. Matrix consists of purplish gray, very fine- to very coarse-grained sandstone. Sand is angular to subrounded, poorly sorted, and a volcanic lithic wacke to litharenite (sand locally includes single grains of green pyroxene or black hornblende). Unit includes minor pyroxene- and plagioclase-bearing trachyandesite flows that are generally less than 3 m-thick. Total unit thickness is variable. On the northeast side of Jackass Mountain fault, it is about 270 m-thick.

Twbd – Dacite flow in Walker Breccia (middle to upper Eocene) -- A gray, hornblende- and biotite-bearing dacite flow (hornblende > biotite) within the Walker volcanic breccia. Flow is about 12-15 m-thick.

LOWER TERTIARY STRATA

Tsc **Sanders Canyon Formation (middle Eocene) --** Poorly exposed, volcanic lithic arenite sandstone. Color ranges from greenish gray, pinkish gray, slightly purplish white, to light greenish white. Where exposed, sandstone is in thin, tabular beds or is massive. Sand is fine- to coarse-grained, subangular (minor subrounded), well-sorted, and composed of quartz and plagioclase with 20% mafic and lithic grains. Weakly to moderately cemented. Interpreted as a fluvial deposit. Thickness is not constrained.

Tcm **Cub Mountain Formation (lower to middle Eocene) --** White to pale yellow, channel-fill sandstones interbedded with reddish floodplain deposits of mudstone and very fine- to fine-grained sandstone. The slightly coarser texture of the sand (mostly medium-grained) and the reddish fine-grained sandstone beds serve to distinguish this unit from the underlying Crevasse Canyon Formation. Channel-fill sandstones are mostly in thin to thick beds that are internally horizontal-planar- to cross-laminated (locally very thinly bedded). Sand is fine- to coarse-grained (mostly medium-grained), subrounded to subangular, moderately to well-sorted, locally glauconitic, and composed of quartz with subordinate feldspar and 3-15% mafic and lithic grains. Locally, very coarse sand and pebbles are present in the channel-fills; gravel are round to very round, poorly sorted, include 0-10% fine cobbles, and are composed of quartzite, chert, gray limestone, rhyolite, and yellowish granite. Sand matrix of

conglomerate beds consists of medium- to very coarse-grained sand that is subrounded to subangular, moderately sorted, and composed of quartz, ~25% feldspar, and 15% lithic grains comparable in composition to the gravel. Floodplain deposits consist of reddish gray to reddish brown to red clayey mudstone (in medium to thick beds that are locally bioturbated and rhizolith-bearing), reddish brown siltstone (horizontal planar-laminated to ripple-marked), and red to light gray, very fine- to fine-grained sandstone (in very thin to medium, tabular beds). Floodplain sandstone is subangular (minor subrounded), well-sorted, and composed of quartz and feldspar(?) with ~25% lithic and mafic grains. Locally, beds of light gray, fine- to medium-grained sandstone are present that have 20% lithic (including abundant biotite) + mafic grains. Interpreted as a fluvial deposit. Approximately 250-280 m-thick.

MESOZOIC STRATA

Kcc **Crevasse Canyon Formation (Upper Cretaceous, Coniacian North American Stage) --** Intercalated channel-fill sandstones and floodplain deposits that form the thickest stratigraphic unit in the map area. Sandstone is in medium to thick, tabular beds that are internally cross-stratified to horizontal planar (laminated to medium-bedded) or massive. Sand is generally pale yellow to yellow, usually glauconitic, typically fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, 3-15%(?) feldspar, and 5-15% green-gray lithic grains and black mafic grains. Locally, minor pebbles are present in fine- to very coarse-grained sandstone; these pebbles are scattered, very fine to very coarse, subrounded to rounded, and composed of red chert and gray-brown quartzite. Floodplain deposits are poorly exposed and possibly subordinate to the sandy channel-fills. They consist of weak red, purplish, or gray mudstone and greenish gray very fine- to fine-grained sandstone that are in medium to thick, tabular beds. Coal beds are found in floodplain deposits at the base of the unit. Base of deposit is placed at the highest, yellow-orange, marine shell-bearing, calcareous sandstone bed of unit **Kgs** or, if exposed, the stratigraphically lowest coal bed of this unit. Interpreted as a fluvial deposit. Thickness is approximately 800-840 m.

Kccmu Crevasse Canyon Formation, mottled upper zone (Upper Cretaceous to possibly upper Paleocene) -- A distinctive, glauconitic, yellow, fine- to coarse-grained sandstone that is internally massive and likely bioturbated. It has 10% purplish manganese or iron oxide splotches. Interpreted to be a weathered zone at the top of the Crevasse Canyon Formation that was formed during a prolonged period of non-deposition or erosion. Approximately 5-6 m-thick.

Kgs **Gallup Sandstone (upper Cretaceous, lower Coniacian Stage) --** Two tongues of sandstone separated by a poorly exposed, shale-rich(?) interval. Sandstone is typically in medium to thick beds (minor very thin to thin beds) that are internally horizontal-planar laminated, low angle cross-laminated to trough cross-stratified, or massive. Locally burrows and heavy bioturbation are seen in the sandstone. Sand is white to pale yellow, variably glauconitic, very fine to medium-grained (mostly fine-grained),

subangular to subrounded, and well-sorted. Sand is composed of quartz with 5% feldspar and 3-10% mafics plus lithics. Some pale olive to light yellowish brown (weathered color), calcareous, fine- to medium-grained sandstone beds contain relatively high amounts of lithic grains (>10%) and may be fossiliferous. Base of unit grades into the D-Cross Tongue of the Mancos Shale over several meters. Contact drawn at the lowest thick sandstone bed that can mapped laterally. 120 m-thick.

Kmd **Mancos Shale, D-Cross Tongue (Upper Cretaceous, upper Cenomanian(?) through Turionian Stage) --** Pale yellow to green shale, siltstone, and claystone in laminated to very thin, tabular beds. Slight effervescence in hydrochloric acid. Interbedded, very fine- to fine-grained sandstone beds are present in the top of the unit (locally exhibiting contorted, wavy lamination). Shale is metamorphosed to a black to gray argillite immediately adjacent to laccoliths or dikes. 100-110 m-thick.

Kth **Tres Hermanos Formation (upper Cretaceous, upper Turonian Stage) --** Yellow to olive yellow, very fine- to medium-grained (mostly fine-grained) sandstone in thin to thick, tabular beds that are internally massive, horizontal planar-laminated, or tangential low angle cross-laminated (foresets up to 60 cm-thick). Sand is subrounded to subangular, well-sorted, and composed of quartz, 10-15% feldspar, and 5-15% lithic and mafic grains. Sandstone is locally interbedded with subordinate yellow shale beds. Approximately 60 m-thick.

Kmrs **Mancos Shale, Rio Salado Tongue (upper Cretaceous, upper Cenomanian to lower Turonian Stage) --** Gray, planar-laminated shale that is not exposed. Where inferred in the south-central part of the quadrangle, clasts on the surface have been metamorphosed to an argillite. 40-45 m-thick based on cross-section A-A'.

Km **Undifferentiated Mancos Shale (Upper Cretaceous, upper Cenomanian(?) through Turionian North American Stage) --** Fissile shale that is planar- to wavy-laminated; colors range from gray to light gray to light olive gray to light greenish gray. Mancos shale is not differentiated into the D-cross Tongue or Rio Salado Tongue in the White Sands Missile Range.

Kdu **Dakota Sandstone, upper part (upper Cretaceous) --** Strata near the top of the Dakota Sandstone that may have been deposited in a marine, nearshore environment. Bedding is massive, horizontal planar-laminated, or very low angle cross-laminated. Sand is light gray to white, fine-grained, subrounded, well-sorted, and a quartzose. At least 14 m-thick.

Kdl **Dakota Sandstone, lower part (upper Cretaceous) –** Fine- to medium-grained sandstone. Color ranges from white to light purplish white, weathering to a very pale brown to pink-orangish red to brown. Sandstone is tangential- to planar- cross-stratified or in medium to thick, tabular beds that are internally horizontal planar-laminated or cross-stratified (laminated or very thinly bedded). Foreset thickness is commonly 10 cm or less except near the base, where trough- to tangential foresets are up to 20 cm-thick. Locally the unit is internally massive. Sand is subrounded (mostly)

to subangular, well-sorted, and a quartzose (0.5-3% gray lithic and black mafic grains). Minor (<15%) interbeds of light gray siltstone. Coarse- to very coarse-grained sand is more common near the base of the unit (but still less than 10% of volume). Medium-upper to very coarse-upper sand and pebbles are moderately sorted and composed of rounded quartzite, quartz, chert, and 0.5-1% metarhyolite; largest pebble clast is 4 cm-long; variably abundant clasts of altered, golden-colored argillite. Unit tends to develop a strong purplish black-dark brown desert varnish. Approximately 20-25 m-thick.

Trm **Moenkopi Formation (middle Triassic) –** Interbedded sandstone and pebbly sandstone channel-fills and floodplain deposits. Sandstone channel-fills are thin to thick and tabular, and exhibit a variety of internal bedding: mostly laminations to very thin beds that are horizontal-planar or tangential- to planar- cross-stratified). Foresets are up to 30 cm-thick. In some beds that are typically light gray, sand grains are all composed of intra-formational limestone grains (medium- to very coarse-grained and subrounded to rounded); these beds may have very fine to fine limestone pebbles. Sparse extra-formational channel-fills that are composed of medium- to very coarse-grained sand and very fine to coarse pebbles; pebbles are rounded, moderately sorted, and composed of quartz, chert, quartzite, and metarhyolite(?). Sand is typically light purplish white, red, reddish gray, or light gray (weathering to light brownish gray), fine- to medium-grained, subangular to subrounded, well-sorted, and composed of quartz, 10-25% lithic grains, and ~10% possible feldspar; mica is not common (<1%). Floodplain deposits are composed of weak red to red to reddish brown mudstone, siltstone, and very fine- to fine-grained sandstone that are in fissile, planar-horizontal, laminated to thin beds or else massive. In the southern quadrangle, the floodplain deposits locally display 3-25% light-colored reduction spots (0.1-7.0 mm across), similar to that seen in the Grayburg Formation in the Three Rivers area. At top of unit is 2-3 m-thick, greenish to light gray (i.e., reduced), deeply weathered zone composed of bioturbated, internally massive clay or sand with trace, scattered, very fine to coarse pebbles of chert and quartzite. This is interpreted as a paleosol that likely formed in wet conditions. Base is not exposed so thickness is uncertain. Cross-section A-A' suggests a minimum thickness of 65 m.

PALEOZOIC STRATA

Pag **Grayburg Formation, Artesia Group (upper Permian, middle Guadalupian North American Stage) --** Orange to reddish brown, silty very fine- to fine-grained sandstone; minor clay laminae. Strata are relatively erodible. 3-5% surface coverage by light green reduction spots (0.5-2.0 mm). Bedding not well-exposed. Well data and cross-section on the Three Rivers quadrangle to the south indicate a thickness of 90-110 m. Construction of cross-section A-A' allows a possible thickness of 130 m on this quadrangle.

Psa **San Andres Formation, undifferentiated (lower to upper Permian, Leonardian to Guadalupian North American Stage) --** Light gray limestone and tannish dolomite that grade upward into interbedded carbonate and gypsum beds. Mostly inaccessible because of its location on the White Sands Missile Range. 240-250 m-thick, based on subsurface data for wells used in cross-section A-A' on the Three Rivers Quadrangle to the south. Construction of cross-section A-A' allows a possible thickness of 275 m on this quadrangle.

SUBSURFACE UNITS DEPICTED ONLY IN CROSS-SECTION A-A'

Py **Yeso Formation (lower Permian) --** Yellow and red siltstone, limestone, and gypsum. 630 m-thick.

Pa **Abo Formation (lower Permian) --** Reddish color; consists of overbank deposits of mudstone and clayey fine-grained sandstone that are intercalated with coarse channel-fills of sandstone and pebbly sandstone. Approximately 450 m-thick.

Pb **Bursum Formation (uppermost Pennsylvanian(?) to lowermost Permian) --** Marine strata (shales and limestone beds) interbedded with fluvial sediment of overbank reddish shale together with channel-fill sandstone and pebbly sandstone. Approximately 500 m-thick.

View looking east towards Jackass Mountain. The porphyritic trachyandesite flows and breccias that compose unit Tbr overlie the Palisades Tuff. (unit Tpt). Underlying the Palisades Tuff is a trachyandesite flow, which in turn is underlain by volcaniclastic sandy conglomerate. On the north end of Jackass Mountain, these strata are stratigraphically displaced ~1350-1400 m by the northwest-striking Jackass Mountain fault (southwest side is down-thrown).