NEW MEXICO BUREAU OF GEOLOGY & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY



Map Symbols

approximately located; dotted where concealed

approximately located; dotted where concealed

Anticline – Showing direction of plunge; dashed where approximately located;

mately located; dotted where concealed

mately located: dotted where concealed

Cross bedding-Truncated foresets represent top

Asterisk (*) denotes units shown in cross section only

Magnetic Declination

May 2004

8º 35' East

At Map Center

1:50.000

0.5 0

H H H H H H H

CONTOUR INTERVAL VARIES

NATIONAL GEODETIC VERTICAL DATUM OF 1929

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

0.75

New Mexico

Correlation of Map Units

Description of Map Units

Quaternary–Pliocene Units

The Quaternary units in this map area are grouped into the following categories: artificial fill or excavations, hillslope and mass-wasting deposits, eolian and sheetflood-slopewash deposits, precipitate deposits, alluvial deposits (found on piedmont slopes and alluvial fans), and pediment and terrace deposits. Alluvial fan deposits are generally found west of the mountain-front fault zone, and piedmont slope deposits east of the mountain-front fault zone (the Alamogordo fault). The latter two categories warrant further discussion. Alluvial fans are geomorphic features characterized by depositional lobes that are fan-shaped in plan-view. On topographic maps, alluvial fans are readily noted by the outward curving or bulging of contour lines around the mouths of incised, mountain-front drainages. A good example of this bulging of contour lines is seen west of the mouth of Temporal Creek. Some useful studies that emphasize alluvial fan processes and depositional environments include Hooke (1967), Bull (1972 and 1977), Blair and McPherson (1994a and 1994b), Blair (1999), and Ritter et al. (1993). East of the Alamogordo fault, distinct alluvial fan morphology is lacking for extensive Quaternary deposits under westward-sloping, high-level surfaces. We assign the Quaternary deposits east of the Alamogordo fault as piedmont deposits, which have also been called alluvial slope deposits. Alluvial slope deposits are further discussed in Hawley and Wilson (1965), Smith (2000), and Kuhle and Smith (2001).

For sedimentary units, a brief discussion is warranted on the difference between lithostratigraphic and allostratigraphic units. Most map units presented below are lithostratigraphic: recognized by their geomorphic position or the inferred geomorphic process responsible for deposition. Lithostratigraphic units can be differentiated by lithologic properties (such as texture, color, and composition). Some lithostratigraphic units are subdivided into allostratigraphic units, which are separated by interpreted unconformable contacts or by inset relations (both representing inferred time gaps). Allostratigraphic units have numbers at the end of their map labels. For example, lithostratigraphic unit Qao is subdivided into allostratigraphic units Qao3, Qao2, Qao1; lithostratigraphic unit Qay is subdivided into allostratigraphic units Qay3, Qay2, and Qay1 (listed youngest to oldest). These allostratigraphic units possess different ages, although the sediment looks relatively similar within the overall lithostratigraphic unit (Qao or Qay).

Surface characteristics aid in mapping both lithostratigraphic and allostratigraphic units. Older deposits generally have older surfaces, so surface processes dependent on age-such as desert pavement development, clast varnishing, gypsum and calcium carbonate accumulation, and eradication of original bar-and-swale topography—can be used to differentiate the alluvial fan deposits. Locally, erosion may create a young surface on top of an older deposit, so care must be exercised in using surface characteristics to map Quaternary deposits.

Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). 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 the Munsell Soil Color Charts (Munsell Color, 1994). Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992), Birkeland et al. (1991), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999). Unless otherwise noted below, sand in Quaternary deposits is subrounded to subangular. Medium to very coarse sand has a composition consistent with a litharenite, whereas very fine- to fine-grained sand is more arkosic (as inferred using a hand lens).

Textures in Igneous Rocks

Igneous rocks can have phaneritic, aphanitic, and/or porphyritic textures. In phanertic rocks the individual interlocking crystals are large enough to see with the naked eye or at 10x magnification. In apahanitic rocks, the crystals are too small to see with the naked eye or with 10x magnification. Aphyric is another term used to describe volcanic rocks that have few and/or small crystals. Porphyritic rocks have larger crystals set in an aphanitic matrix. Rocks with crystals smaller than 1 mm are considered fine-grained, 1–5 mm are medium-grained, 0.5–3 cm are coarse-grained, and greater than 3 cm are very coarse-grained.

QUATERNARY-PLIOCENE SEDIMENTARY UNITS

ARTIFICIAL FILL AND EXCAVATIONS

afe Artificial fill or excavations (modern)–Compacted silt, clay, and very fine to very coarse sand (with minor pebbles) under highways and railroads. Very coarse pebbles and cobbles drape compacted fill under railroad tracks. Also found in berms surrounding excavations, which include pits, quarries, or reservoirs. The base of these excavations has generally been filled by >10 cm thick deposits of clay, silt, sand, and gravel transported by arroyo runoff, mass-wasting, or slopewash processes. Human-engineered land.

HILLSLOPE AND MASS-WASTING DEPOSITS

Colluvium (middle to upper Pleistocene and Holocene)—Angular to subangular pebbles, cobbles, and boulders in a matrix of clayey-silty sand. Massive or in steeply inclined, tabular beds. Gravel composed of a variety of lithologic types, but limestone dominates. Common on north-facing slopes. Generally mapped in mountainous areas where it is >2 m thick and obscures underlying geologic formations and geologic structures (such as faults or folds). Also locally mapped adjacent to the Alamogordo fault scarp south-southeast of Three Rivers, where it consists of gypsiferous sand (mostly very fine- to medium-grained) and variable amounts of gravel. Hillslope sediment, generally coarse grained. Societal uses: possibility for aggregate in limited areas.

Ols Landslide deposits (middle to upper Pleistocene?)-Translated, cohesive (but locally internally sheared and brecciated) blocks of rock composed of the Yeso or San Andres formations. Locally, the deposit is rotated. Rock blocks slid down-slope (probably relatively quickly) under the influence aravity. Fast of Crosby **Spring** in the northern map area, deposit consists of bouldery, unstratified debris of Dakota Sandstone, 2–50 m thick Hillslope sediment, generally coarse grained. Societal uses: very limited.

EOLIAN AND SHEETFLOOD-SLOPEWASH DEPOSITS

Ge Eolian deposits, undivided (middle to upper Holocene)–Unit encompasses undifferentiated dunes (other than coppice dunes [Qec], which are mapped separately), and other eolian deposits. It includes eolian sand ramps adjacent to topographic highs (up to several meters thick), NE-SW orientated longitudinal dunes (found near the northern quadrangle boundary east of Highway 54), and eolian sand in mound-like deposits that extend horizontally over several meters. 1-6(?) m thick. Clastic sediment, eolian sediment. Societal uses: low to moderate potential for aggre-

- Qec Coppice dunes (upper Holocene to present)-Mounds of sand accumulated under and in the immediate vicinity of mesquite bushes (and cresosote bushes, to a lesser extent). Mounds range from 20 to 200 cm in height. These dunes also are present on eolian sand ramps adjacent to topographic highs, where the sediment may be several meters thick. Inter-dune surfaces commonly show signs of erosion and may exhibit a lag of pebbles. Color of dune sand ranges from light brown to pale brown to brown (7.5-10YR 5-6/3-4; 7.5YR 5-6/4) or yellowish-brown to light yellowish-brown (10YR 5-6/4). Sand is very fine- to medium-grained, rounded to subangular (mostly subrounded), well- to moderately-sorted, and composed of guartz, with 10-25% estimated lithic + mafic grains and 10-20% estimated potassium feldspar. Within this sand are 1-5%, scattered, coarse to very coarse sand grains. Coppice dunes overlie a bioturbated eolian sand sheet or sheetflood deposits; this underlying deposit is grouped with Qec. The coppice dunes are likely upper Holocene in age, but underlying deposit may possibly be as old as *middle Holocene.* Dunes cover 10-35% of the surface. Loose. Deposit under the dunes is up to ~2 m thick. *Clastic sediment, eolian sediment.* Societal uses: low to moderate potential for aggregate.
- Ose Sheetflood and slopewash deposits, reworking eolian sand (middle Holocene to present)–Very fine- to medium-grained sand and clayey-silty 🚽 fine sand (generally less than 25% fines, but locally as much as 50%). Scattered within this sand may be trace–20% coarse- to very coarse-grained sand and trace-15% pebbles (probably via bioturbation). Unit commonly covers high-level surfaces and mantles slopes at the headwaters of small drainages, where the deposit commonly grades laterally into younger alluvium (Qay). Unit exhibits a wide range of colors: mostly pale brown (10YR 6/3), light brown to brown (7.5YR 5-6/3-4), or pink to very pale brown (7.5-10YR 7/3-4). The sediment is commonly internally massive and bioturbated, with local weak, cumulic soil development characterized by ped development and minor gyspusm + calcium carbonate accumulation, generally as filaments (comparable to a Stage I carbonate morphology). In places, the sediment is highly gypsiferous and may even form a petrogypsic crust on the surface. Locally there are minor coarse channel-fills (generally in very thin to thin lenticular beds) consisting of pebbly sand to sandy pebbles. Sand is subrounded to subangular, moderately- to well-sorted, and composed of quartz, minor feldspar, and 5–15% lithic and mafic grains. Composition varies with local source area. Coppice dunes cover <10% of the surface and are 20-100 cm tall. Surface is sandy, commonly has a sparse erosional lag gravel, and exhibits weak to no desert pavement development. Development of the top soil is relatively weak, with no reddening, no to very minor clay illuviation, and only minor gypsum accumulation (equivalent to a Stage I morphology in a calcic soil). Loose to moderately consolidated. Interpreted to have formed by sheetfloods reworking previously deposited surficial eolian sediment. 0.2–5 m thick. Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: agriculture, residential development, and moderate potential for
- sec/Qao Sheetflood deposits, reworking eolian sand, overlying older alluvium–Only differentiated where Qse is inferred to be >30 cm thick. See descriptions for units Qse (above) and Qao (below). Near Three Rivers, the Qse unit consists of light brown (7.5YR 6/4), clean, very fine- to medium-grained sand, with very minor to minor coarse-very coarse and pebbles. Surface may also have minor coppice dunes in the Three Rivers area. Qse is less than 2 m thick. Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: low potential for aggregate because of

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TERRACE AND PEDIMENT DEPOSITS

- **Pediment gravel, undivided** (upper Pleistocene)—Thin sandy gravel, generally gypsiferous, that overlies pediment surfaces in the lower part of the Sacramento Mountains. Surfaces are relatively smooth and exhibit well-varnished desert pavements. Underlying soil generally marked by gypsum accumulation comparable to a Stage II to III calcium carbonate morphology. Less than 1 m thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate.
- **Qta Terrace gravel** (Pleistocene)—Gravelly terrace deposits found alongside, and paralleling, modern drainages, including the Three Rivers drainage. The bases of the terrace deposits (straths) are greater than 2 m above these drainages. The terrace deposit is generally poorly exposed. Gravel are subrounded to subangular, poorly sorted, and consists of pebbles with subordinate cobbles and 1-10% boulders. Spallation of exposed clasts results in abundant subangular-angular gravel on the surface. The gravel is clast- to matrix-supported and composed predominately of intermediate-mafic igneous rocks, with subordinate Paleozoic-Mesozoic sedimentary clasts (mostly sandstone and limestone). The gravel is interbedded with varying proportions of sand. Sand is very fine- to very coarse-grained, pale brown to very pale brown (10YR 6-8/3; 10YR 7/4), subangular to subrounded, and moderately to poorly sorted. In at least some deposits, a significant proportion of the sand is composed of gypsum grains. Deposit also includes fine-grained sediment that is internally massive, brownish-yellow (10YR 6/6), locally clayey-silty, and dominated by very fine- to fine-grained sand (much of which is gypsum grains); the fine sediment locally contains gypsum-cemented rhizoliths. Surfaces are flat, variably eroded, and commonly exhibit strong gypsum accumulations that obscure the underlying terrace deposit. The gypsum mantle and poor exposure creates local uncertainty about whether a given terrace has a significant deposit or is simply an erosion surface. Some higher surfaces exhibit well-developed desert pavements and well-varnished surface gravel. Weakly to moderately consolidated. Mostly 1–5 m thick, with local paleovalley fills up to 15 m thick.
- Tage High-level gravelly deposits capping ridges (Pliocene to lower Pleistocene)–Gravel, sand, and silty sand deposited on high-level erosional rfaces that are 15–70 m above modern stream grade north of the Rio Tularosa and east of the Alamogordo fault. Extensively mapped on the piedmont south of the Rio Tularosa, but underlying erosional surfaces there are much closer to modern stream grade. Gravel is typically clast-supported, imbricated, subrounded to subangular, poorly to very poorly sorted, and consists of pebbles and cobbles (1–5% boulders) composed of sedimentary (mostly limestone) and igneous clasts. Deposit is well consolidated, and the basal few meters of the unit, where exposed, are commonly cemented by calcite. This calcite cementation is inferred to be related to precipitation of calcium carbonate from ground water. Road cuts reveal Stage III or greater pedogenic carbonate development. Inferred lower Pliocene to lower Pleistocene age is based on comparison of the coarse nature of this deposit to the coarse nature of deposits of that age in the Albuquerque and Española Basins to the north-including the Tuerto Formation (Stearns, 1953), Ancha Formation (Koning et al., 2002a), and Puye Formation (Waresback, 1986; Waresback and Turbeville, 1990). Up to 25 m thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate.

Older alluvium, with subordinate younger alluvium (middle to upper Pleistocene and Holocene)–See descriptions of Qao and Qay above. PLIO-MIOCENE SEDIMENTARY UNITS

Tg Gravel on Coyote Ridge (Pliocene?)-Lag gravel composed of rounded sandstone and limestone clasts sitting in a saddle on Coyote Ridge. < 1

Tbf Older basin fill of the Tularosa Basin, undivided (Miocene to lower Pliocene?) – Exposed east of Three Rivers, this unit consists of clayey-silty, ery fine- to medium-grained sand, locally with minor, scattered, medium- to very coarse-grained sand and 1–10% pebbles. Colors range from very pale brown to light yellowish-brown (10YR 7/3-6/4) to light brown (7.5YR 6/4) to pink (7.5YR 7/3). Thin to thick (mostly thin to medium), tabular beds that are internally massive. Sand is subrounded to subangular, moderately sorted, and composed of quartz and plagioclase, with ~10% estimated potassium feldspar and 10% estimated lithic grains. Paleosols are locally common; these are characterized by calcic horizons (Stage II morphology in limited exposures) underlain by gypsic horizons; locally, the calcic horizons are overlain by thin, yellowish red (5YR 5/6), illuviated clay (argillic?) horizons. Other lithologic types include minor gravelly beds, either as: 1) local, very thin to medium lenses of sandy pebbles and sandstone, locally moderately cemented by calcium carbonate, within the aforementioned, relatively fine-grained sediment, or 2) thin to thick beds of clast-supported, sandy pebbles and cobbles (minor boulders); gravel are subrounded to rounded, imbricated (indicating a westward paleoflow direction), and composed of Tertiary intrusive clasts, andesite, and subordinate Mesozoic sandstone; matrix is fine- to very coarse-grained sand that is subrounded and poorly sorted. Gravel is commonly strongly impregnated by calcium carbonate. Unconformably underlies gravelly Qao1 deposits. Tbf differs from Qao1 by its smaller gravel size and better cementation and consolidation. Unit is inferred to extend well into the subsurface and likely fills paleo-valleys or paleo-embayments on the footwall of the Alamogordo fault near Three Rivers. Greatest exposed thickness is 2 m, but unit is 120 m thick at the Lewelling #1 well (see cross section). On the immediate fault hanging wall, basin-fill is up to ~700 m thick (see cross-section).

NEOGENE INTRUSIVE ROCKS

The ages of the dikes and thin sills in the area are likely 37 to 42 Ma, based on ⁴⁰Ar/³⁹Ar age determinations for dikes and sills in the Three Rivers area to the north and in the Sacramento Mountains to the southeast (McManus and McMillan, 2002). The age of emplacement of the Black Mountain stock just northeast of the quadrangle is middle Eocene based on a biotite 40 Ar/39 Ar age of 37.8 Ma, an 40 Ar/39 Ar plagioclase age of 34.6 Ma, and a hornblende ⁴⁰Ar/³⁹Ar age of 37.3 Ma (Allen and Foord, 1991). Mineralization is generally absent along the dikes and sills. Occasionally, hematite, limonite, barite, calcite, copper, and manganese minerals occur in the vicinity of intrusions. Dikes generally fill fractures and are 1 to 2 m wide. More rarely dikes fill faults, but the dikes are not deformed by subsequent reactivation of the faults. Sills are often out by dikes and sills can be cut by faults. Several new ⁴⁰Ar/³⁹Ar dates are presented below.

Time Dikes and sills, undivided, mapped from air photos.

Tir Rhyodacite (Oligocene)–Light gray, NE-striking dike with phenocrysts of quartz and biotite that cuts a megacrystic sill. Sample at 410715N ^{_____} 3687045E yielded a date of 27.27 ± 0.17 Ma. 2-3 m wide.

- Tite Porphyritic trachydacite (upper Eocene to lower Oligocene)-Dikes and sills of a light gray porphyry. Rock contains 5–15% phenocrysts of gioclase feldspar, biotite ± hornblende, and dark green pyroxene, 1–10 mm long, set in a fine-grained matrix. Unit includes amphibole-rich sills on the south side of Coyote Ridge that are 1–5 m thick. These sills are black to dark green, medium-grained, and contain ~30% dark green, elongated amphibole needles, 5% plagioclase and 5% potassium feldspar. Unit also includes a prominent, 5 km long and 4 m wide, NE-trending dike between Boone Draw and the Three Rivers drainage.
- Tita Porphyritic trachyandesite (middle to upper Eocene)-Dikes, sills, and small laccoliths of a light gray to gray porphyry. 5–15% phenocrysts of lagioclase feldspar, dark green pyroxene, and potassium feldspar, 1–10 mm long, set in a fine-grained matrix. These intrusive bodies may grade into more equigranular textures (Tid). Syenitic and sedimentary xenoliths are locally present. Two cross cutting dikes in the Crawford Windmill area gave low quality dates of 36.41 ± 0.41 and 36.90 ± 0.51 Ma (UTM 411503E 3684169N [NAD 27]). Dikes are 0.5-8 m wide.
- **Trachybasalt** (middle to upper Eocene)-Black to dark green, fine-grained intrusions (generally dikes) with barely discernible needles of plagioclase and pyroxene. No olivine observed in hand lens. This rock type yielded a low quality date of 34.38 ± 0.76 Ma in the Hamm well area (UTM 412704E 3687347N [NAD27]). Dikes are 1-2 m wide.
- Tito Porphyritic trachyte (Eocene)-Dikes of light gray to dark gray porphyry with 15-25% plagioclase laths 10-20 mm long set in an equigranular o fine-grained matrix of dark green pyroxene and feldspar. The plagioclase laths are often distinctly aligned parallel to the margins of the dike. Dikes 1-4 m wide.
- Tid Equigranular, alkali gabbro-diorite or syenogabbro-syenodiorite (middle to upper Eocene)–Light gray to gray, equigranular to slightly prphyritic, fine- to medium-grained, salt-and-pepper colored dikes, sills, and laccoliths. Dikes are 1–7 m wide. Phenocrysts include plagioclase feldspar and pyroxene, ± kspar ± biotite ± amphibole. These intrusive bodies may grade into more porphyritic rocks (Tita), and often contain xenoliths of syenite. Dikes of this composition cut sills of megacrystic trachybasalt (Tim)south of Coyote Peak. Thick sills of this composition in the northeastern parts of the map area have cumulate pyroxene at the base. This unit includes the alkali diorite of Granite Well, which is a greenish-gray, equigranular, fine- to medium-grained, salt-and-pepper colored sill with plagioclase feldspar, pyroxene and biotite phenocrysts exposed south of Granite Well along Temporal Creek near the mountain front. A 4° Ar/ 3° Ar age of 38.07 ± 0.64 Ma was determined for biotite from this intrusion. This sill has pyroxene-rich cumulate phase near the base and is about 30-35 m thick. A thick sill on the north side of Cat Mountain returned a ⁴⁰Ar/³⁹Ar age of 36.21 ± 0.30 Ma on biotite. This unit also includes black to dark green, medium- to coarse-grained, 1–3 m thick sills located on the southwest side of Cat Mountain. Rock contains subequal amounts of black pyroxene and plagioclase, as well as sparse apple-green pyroxene. The coarse gabbro grades upward into a fine- to medium grained, equigranular gabbro. Exposed rock may develop a strong varnish. Tid dikes are 0.5-7 m wide.

Timp Intrusions with megracrystic, aligned plagioclase (middle to upper Eocene) – A distinctive intrusion, generally filling dikes, that contains 5-25%, nedral pl agioclase laths 5–20 mm long. The groundmass is light gray to dark gray, equigranular, and composed of dark green pyroxene and feldspar that are 0.2–0.4 mm long. The plagioclase laths are often distinctly aligned parallel to the margins of the dike. North of Three Rivers, a dike of this composition is crosscut by a Tid dike. Timp dikes are 1-4 m wide.



Preliminary Geologic Map of the Tularosa and Bent Region, northeastern Tularosa Basin, Otero County, New Mexico

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thin nature of Qse. Possible residential development.

Jse/Qao2 Sheetflood deposits, reworking eolian sand, overlying middle subunit of older alluvium–Only differentiated where Qse is inferred to be 30-200 cm thick (it is not more than 200 cm thick). See descriptions for units Qse (above) and **Qao** (below). Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: low potential for aggregate because of thin nature of Qse. Possible residential development.

Ise/Qaof Sheetflood deposits, reworking eolian sand, overlying fine-grained older alluvial fan deposits–See descriptions for units Qse (above) and Qaof (below). Qse is less than 2 m thick. Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: low potential for aggregate because of thin nature of Qse. Possible residential development.

Dise/Qgy Sheetflood deposits, reworking eolian fine-grained sediment, overlying gypsum (Holocene)–See descriptions of Qse (above) and Qgy (below). Sheetflood deposits are probably more than 20 cm thick. Mapped using air photos where surface has a lighter tone and relatively tanner to redder colors (as opposed to darker, grayer colors corresponding to Qgy) and a higher shrub density. Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: very limited.

c Sheetflood and slopewash deposits, reworking eolian sand, with coppice dunes on the surface (middle Holocene to present)–Similar to unit Qse (described above), but with 7-10% or greater surface coverage by coppice dunes (unit Qec, as described above). Clastic sediment, alluvial and eolian sediment. Societal uses: low to moderate potential for aggregate. Possible residential development or agricultural potential.

sectOav Sheetflood deposits, reworking eolian sand, with coppice dunes on the surface, overlying younger alluvium–See descriptions of Qsec (above) and Qay (below). Clastic sediment, alluvial and eolian sediment. Societal uses: low to moderate potential for aggregate. Possible residential development or agricultural potential.

sec/Qao Sheetflood deposits, reworking eolian sand, with coppice dunes on the surface, overlying older alluvium–See descriptions of Qsec (above) and Qao (below). Clastic sediment, alluvial and eolian sediment. Societal uses: low to moderate potential for aggregate. Possible residential development or agricultural potential.

ec/Qao2 Sheetflood deposits, reworking eolian sand, with coppice dunes on the surface, overlying the middle subunit of older alluvium-See descriptions of Qsec (above) and Qao2 (below).

Thick gypsum accumulation (middle to upper Holocene)—Yellowish-white to pink (7.5YR 7/4) to very pale brown (10YR 7/4) gypsum that has een subjected to multiple dissolution and precipitation events. These processes have formed a hard crust >10 cm thick on the surface of this deposit. Underneath, gypsum is generally moderately consolidated, massive or in tabular beds (up to 40 cm thick), and consists of silt and very fine- to coarse-grained sand size, platy crystals (mostly very fine to fine-grained) that are subangular to angular and well-sorted. Locally, this gypsum sand is planar-laminated to low-angle cross-laminated. Very thin cross-beds, with 30 cm thick foresets, locally seen near base of the deposit. Gypsum nd may include subordinate plagioclase and quartz, and when dry has a "fluffy" feel. Surface of unit r exposed on slope shoulders. Interpreted to be a relic of an eastward, eolian-driven expansion of the White Sands dune field in the middle to upper Holocene. Deposit thickens westward and is inferred to interfinger eastward with unit Qay2 (this transitional zone was mapped as Qgyay2). Deposit overlies Qaof, probably over an unconformity. Lower meter of deposit commonly grades into more siliclastic sand that is clean, fine- to coarse-grained, and planar-laminated to very thinly bedded (included in unit Qgy). In the southwestern part of the compilation map, the surface of this unit is marked by minor to abundant sinkholes and similar collapse features, whose locations and extents are shown on the map. These are probably due to dissolution of gypsum beds several meters below the surface (in underlying Qaof). Flat surfaces are commonly overlain by a younger veneer of pale brown (10YR 6/3) silt and very fine- to fine-grained sand a few 10s of centimeters thick (unit Qse). Where this surficial veneer manifests itself on air photos, then this unit is mapped as Qse/Qgy (see above). Unit is also mapped where gypsum forms a hardpan in low areas. 0.5-4 m thick. Precipitate and eolian sediment, gypsum. Societal uses: potential for gypsum mining.

Qgyfy2 Gradation-interfingering between gypsum and younger basin-floor deposits (middle to upper Holocene)–Mapped where unit Qgy transions eastward into unit Qay2. This gradational unit contains about 1/3-2/3 gypsum compared to 2/3-1/3 sediment of Qay2. Surface sediment commonly consists of pinkish, gypsiferous silt and very fine- to medium-grained sand. Probably 1–3 m-thick. Eolian and clastic sediment. Societal uses: possible residential development.

PRECIPITATE DEPOSITS

Our Travertine (lower Pleistocene? to upper Pliocene?) – Laminated to massive calcium carbonate. On Round Mountain, 10–15 m thick travertine sits on 3 m of carbonate cemented gravel. Travertine deposits southwest of Mescalero are associated with faults and consist of 1–2 m thick beds of carbonate overlying the Yeso Formation. Carbonate cemented gravels (with 1 to 2 cm thick CaCO₃ rinds) are exposed north of Mescalero. In this area, the carbonate cemented gravels are covered by younger fans and are being exhumed by down-cutting along the Rio Tularosa. Golden brown travertine at UTM 419746E 3671012N (NAD27) coats bedding planes in the San Andres Limestone on the escarpment north of Tularosa Creek. Calcium carbonate. Societal uses: limited.

Osp Spring deposit (Pleistocene)-Banded barite and goethite deposited along a fault (two deposits, UTM 407146E 3681126N and 406950E ^{__]} 3681195N [NAD 27]) 1-2 m thick.

ALLUVIAL DEPOSITS

ar Recent alluvium (0-200 yrs old)—Well-stratified sand, gravel, and silt deposited by arroyo fluvial activity and sheetflooding in modern or historical times. Sand and gravel characterize this unit in mountain drainages and the proximal portions of alluvial fans, whereas sand, silt, and clay dominate in distal portions of the alluvial fans. In addition to occupying active arroyo bottoms, this unit commonly comprises relatively small (generally less than 500 m across) depositional lobes at the mouths of incised channels and extends downslope from these lobes as thin, tabular bodies. Historical deposits of this unit may be present outside the rim of recently incised arroyos. Color of non-gravel fraction varies according to source area, but generally ranges from reddish-brown in the south to grayish-brown, light grayish-brown, gray, and pale brown in the middle and north. In gravelly sediment, bar and swale topography is present (up to 150 cm relief) and gravel consists of pebbles, cobbles, and boulders. Gravel is subrounded (minor subangular) and very poorly to poorly sorted. Clast composition reflects the source area, and may include sandstone, siltstone, intrusive, or volcanic rock types. Bedding in gravelly sediment is very thin to thick, horizontal-planar to lenticular to ribbon-like, concave-up channel-fills (locally cross-stratified). Sand is very fine- to very coarse-grained; mostly medium- to very coarse-grained and moderately to very poorly sorted on proximate-medial alluvial fans and within the mountains. Sand is mostly very fine- to medium-grained and moderately- to well-sorted on the distal fan. It is on the distal fan that silt (plus clay) can be abundant. Bed forms in sandy sediment are horizontal-planar to cross-stratified and laminated to medium-thick; locally internally massive. Historical alluvium away from rocky topographic highs is generally well-stratified sand and subordinate gravel with a sharp, relatively flat basalt contact. Stratification in sandy or silty sediment is mostly laminated to very thin, horizontal-planar to wavy to cross-stratified (commonly low-angle foresets or ripple-marked). Surface is sparsely to moderately vegetated. No observable soil development, desert pavement, nor clast varnish-but an erosional gravel lag may locally be present. The modern to historic age assignment is based on the presence of post-Native American artifacts in the sediment—including tires, railroad-related coal, and various types of anthrogenic rubbish. This age interpretation is consistent with the youthful surface of the unit and its geomorphic position (i.e., lying in low topographic areas, or adjacent to or in active arroyos or intra-fan lobes). Deposit is loose and less than 3 m thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate at large gully-mouth fan sites.

Qarva Recent alluvium with subordinate youngest subunit of younger alluvium-See descriptions for units Qar (above) and Qay3 (below). Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate.

ave Recent alluvium with subordinate middle subunit of younger alluvium–See descriptions for units Qar (above) and Qay2 (below). Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate.

Qay Younger alluvial fan lithostratigraphic unit (Holocene)-A pale brown (10YR 6/3), light yellowish-brown (10YR 6/4), very pale brown (10YR 7/3-4), pink (7.5YR 7-3/4), grayish (10YR 7/1-2 and 6/1-2), or light brown reddish-yellow (7.5YR 6/4-6) deposit that lacks a well-developed top soil and whose surface is commonly eroded. Although this unit is gravelly near rocky topographic highs, gravel is subequal to subordinate in most areas, including alluvial fans downstream of the fan apex. East of the Alamogordo fault, this unit occupies the floors of valleys. Commonly differentiated into three allostratigraphic subunits that are described below: Qay3, Qay2 (including Qay2u), and Qay1 (from youngest to oldest). Where extensively present south of the Rio Tularosa in the Sacramento Mountains (southeastern map area), this unit generally consists of structureless, pale reddish-brown, fine-grained sediment (silt, sand, and clay) interbedded with thin, discontinuous beds of clast-supported, angular to subrounded gravel composed largely of Permian limestone. On alluvial slopes and footwall valleys near Three Rivers, as well as alluvial fans between Three Rivers and the Rio Tularosa, this unit mostly consists of very fine- to medium-grained sand and clayey-silty fine sand interbedded with coarse channel-fills of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. Much of the non-gravelly sediment (especially the clayey-silty fine sand) is internally massive and weakly modified by pedogenesis (characterized by moderate pedogenic development and Stage I gypsum ± calcium carbonate accumulation). Within the fine sand, there is typically scattered pebbles and minor, scattered medium to very coarser-grained sand. In the northern map area, surface clasts are subangular to subrounded and composed of igneous rocks and subordinate sedimentary rocks. Greater than 80% of this unit is middle to upper Holocene in age. Moderately to well consolidated and 1-6(?) m thick. Clastic sediment, alluvial sediment. Societal uses: agriculture and residential development.

Qava Youngest allostratigraphic subunit of younger alluvium (upper Holocene)–Well-stratified sand, silty fine sand, and variable gravel. Near Temporal Creek and south of the Rio Tularosa, this unit is subsumed into Qay2. Generally occupies arroyo back-fills (generally too small to be mapped) or sheet-like deposits near recent arroyos or channels (most commonly what is mapped). Unconformably overlies, or is inset into, the middle subunit of younger alluvium (Qay2). Gravelly beds are more common on the footwall of the Alamogordo fault and in the proximal alluvial , gravel interbeds are very minor and the **unit is primarily a sand, silty very fine- to fine-**In sandy or silty sediment, stratification is generally horizontal-planar laminated to thinly bedded, with minor wavy laminations or thin cross-bed sets. Sand is pale brown to very pale brown (10YR 6-7/3) or light yellowish-brown (10YR 6/4), very fine- to very coarse-grained, subrounded to subangular (medium to very coarse sand tends to be more subrounded, very fine to fine sand is generally subangular), well to poorly sorted, and composed of quartz, subordinate feldspar, and minor volcanic + lithic grains. Surface has very poor soil development, bar and swale topography less than 50 cm tall, and exhibits no desert pavement development or clast varnishing. This unit may be difficult to differentiated from historic alluvium (Qar), as both appear to have aggraded relatively quickly (at a given location) and lack buried soils (hence the well-developed stratification). However, in aerial imagery the bar and swale topography on this unit's surface is more vague and subdued, compared with that on Qar. This unit was deposited in the late Holocene following the widespread middle Holocene aggradation event associated with Qay2. The landscape in the upper Holocene was characterized by landscape instability, with widespread erosion punctuated by brief, localized back-filling events (Koning, 2009). This unit correlates to the younger Organ alluvium in the Desert Project (Gile et al., 1981). Loose to weakly consolidated. Up to 2 m thick. Clastic sediment, alluvial sediment. Societal uses: agriculture and residential development.

Tim Megacrystic, alkali gabbro-diorite or syenogabbro-syenodiorite (middle to upper Eocene)–Gray to light gray to greenish-gray, porphyritic ls, dikes, and laccoliths. This rock contains 5–25% megacrysts of embayed (tschermakitic), subhedral to euhedral, hornblende or green pyroxene that are up to 2–4 cm long. Locally, biotite phenocrysts are present. The groundmass consists of plagioclase with 15–25% amphibole and/or pyroxene (grain size is 0.2–0.5 mm, less commonly to 1.0 mm). These intrusives locally have xenoliths of pink, coarse-grained syenite porphyry with larger phenocrysts of orthoclase feldspar and hornblende. Exposed rock commonly develops a very strong varnish. Many laccoliths and sills consist of this rock type, including the prominent N–S ridge at the Three Rivers Petroglyph site. This ridge was dated at 36.32 ± 0.35 Ma (Dowe et al., 2002), and was called a trachybasalt sill by McLemore (2002). A sill north of Boone Draw gave a date of 37.95 ± 0.91 Ma (UTM 410998E 3687059N [NAD27]). The intrusion at Kitty Spring is 37.17 ± 0.33 Ma (UTM 405032E 3680799N [NAD27]). Dikes are 1–5 m wide.

Syenite-trachyte (middle Eocene)–Pink, medium-grained, equigranular sills and dikes composed of potassium feldspar, plagioclase feldspar, pyroxene, and biotite. Sills are <3m thick and dikes are less than 4 m wide. This unit includes the syenite of Temporal Creek, which is a tan to pink, equigranular to porphyritic stock exposed in the northeast corner of the map area (Moore et al., 1988), north of Temporal Creek and straddling the western boundary of the Mescalero Apache Indian Reservation. The most common phenocrysts in the stock are potassium feldspar, plagioclase feldspar, and clinopyroxene. Some phases of this stock have amphibole (Moore et al., 1988), while others have sparse phenocrysts of quartz. Dikes with large, aligned, plagioclase phenocrysts (Timp) crosscut this stock.

NEOGENE EXTRUSIVE ROCKS OF THE SIERRA BLANCA VOLCANIC FIELD

GODFREY HILLS GROUP

This unit appears to overlie an unconformity developed at about the stratigraphic level of the Buck Pasture Tuff, which is not exposed in this particular area. Includes the 28.2 to 28.8 Ma Jackass Mountain Formation and the 28.8 to 34.3 Lopez Spring Formation.

Tgivs Volcaniclastic sediment of the Jackass Mountain Formation (lower to upper Oligocene)–Includes an upper unit that is a heterolithic landslide deposit with a white ashy matrix that contains large (1-5 m) angular boulders of porphyritic trachyandesite, Palisades Tuff, and trachyandesite breccia. 5–15 m thick. The lower unit is a sandy, matrix-supported, carbonate-cemented conglomerate that contains upper trachyte lava as the dominate clast. Other clasts include older lavas and flow-banded rhyolite. The clasts are angular and <0.5 m in diameter. Basal conglomerate has large boulders of porphyritic trachyandesite with abundant plagioclase phenocrysts. A thin localized tuff deposit with a basal yellow-brown ash flow tuff containing altered pumice and ~15% phenocrysts of sanidine and quartz underlain by a black, vitric tuff with 35% phenocrysts of sanidine, quartz, and sparse biotite with fine-grained reddish-tan lithic fragments is present at the basal contact at UTM 409692E 3692960N (NAD27). The tuff **yielded an** ⁴⁰**Ar**/³⁹**Ar age of** 28.23 ± 0.06 Ma. The basal vitric tuff is 30 cm thick; upper tuff is 60 cm thick. 30 m thick.

Trachyte to trachyandesite flows of the Jackass Mountain Formation (lower Oligocene)–Light to dark gray fine-grained lava with a trachytic texture and contorted 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. Red to yellow alteration of the flow breaks is common. 4^{0} Ar/ 3^{9} Ar ages of 28.59 ± 0.05 Ma and 28.53 ± 0.03 Ma were obtained from sanidine in a tuff bed in the unit. Base fills paleocanyons, top eroded. 50 m thick.

Tgjb Brecciated, porphyritic trachyte of the Jackass Mountain Formation (lower Oligocene)-Alternating light gray trachyandesite with few nenos (<5%) plagioclase and pyroxene interbedded with monolithologic breccia with subround to angular clasts in a light gray matrix. Base is flat and top is eroded. In Crawford Canyon, trachytic flows bracket the breccia unit. 60–140 m thick.

Tgipt Palisades Tuff Member of the Jackass Mountain Formation (lower Oligocene) – Cliff-forming welded tuff with pronounced eutaxitic foliation and whony weathering. Contains < 2% lithic fragments composed of trachyandesite and trachyte lavas. Phenocrysts include plagioclase, sanidine, pyroxene, magnetite, and sparse biotite and hornblende. The tuff is generally crystal-poor, but the more welded intervals are 15-20% phenocrysts. 40 Ar/ 39 Ar ages of 28.67 ± 0.07 Ma and 28.66 ± 0.08 Ma were obtained from sanidine in the tuff. Geochemically, this tuff is a trachyte. **Both the** top and bottom of this unit is fairly flat. 25-90 m thick.

Lopez Spring Formation, undivided (lower Oligocene)–Interval of thin to thick (1-10 m) discontinuous trachyte, porphyritic trachyandesite, trachydacite, and trachybasalt flows complexly intercalated with volcaniclastic sediments. Some exposures of volcaniclastic sediment are ated by biotite-bearing trachydacite clasts. A trachydacite cobble from this volcaniclastic interval on the Oscura quadrangle to the northeast yielded a biotite 4° Ar/ 3° Ar date of 30.04 ± 0.2 Ma, providing a maximum age for the sediment. Thick individual flows of trachyandesite are shown at Tg/ta. Most of the trachyandesite flows are dark gray to reddish-brown porphyry with phenocrysts of plagioclase and pyroxene. In places the flows are separated by fine-grained red siltstone. The lavas are pervasively altered with zeoloite in the vesicles. One thick flow in this formation is exposed in Crawford Canyon. The Crawford Canyon flow is a fine-grained, sugary textured lava with contorted platy flow foliation. Phenocrysts include pyroxene. The base of the Crawford Canyon flow is covered or fills paleovalleys cut on Tgl sediments and lava flows. The top of the Crawford Canyon flow is irregular and in places paleocanyons filled with sediment cut deeply into the unit. The Crawford Canyon flow unit pinches out to the east. The Lopez Spring Formation is 90-100 m and the Crawford Canyon flow is 30-40 m thick.

WALKER GROUP

Twt Three Rivers Formation, undivided (upper Eocene, possibly lower Oligocene)–From youngest to oldest, includes the Buck Pasture, Double — Diamond, Argentina Spring Tuff, Taylor Well, and Rattlesnake Canyon members. Only the Rattlesnake Canyon Member is preserved in this

Twin Rattlesnake Member of the Three Rivers Formation (upper Eocene) – Dark gray porphyritic trachyandesite with phenocrysts of plagioclase and pyroxene; plagioclase is the dominant phenocryst. The lavas are variably crystal-poor (5%) to crystal-rich (30%). Modest amounts of volcaniclastic material preserved between the flows. Hydromagmatic deposits with scoriaceous andesitic lapilli and bombs are located at UTM 410424E 3692929N and 410256E 3692999N (NAD 27). 30 m of Rattlesnake Member exposed in the quadrangle.

Twh Hog Pen Formation (middle? to upper Eocene)–Green to red volcaniclastic to volcanic unit containing flow breccia and lava flows. The flow accia clasts and lava flows are composed primarily of porphyritic basaltic trachyandesite to trachybasalt with phenocrysts of pyroxene and plagioclase; the pyroxene phenocrysts are usually >5 mm and are noticeable on weathered surfaces. 40 Ar/ 39 Ar hornblende dates of 36.57 ± 0.21 to 37.01 ± 0.10 Ma were determined for this unit in areas north and east of the quadrangle. This unit includes distinctive hornblende trachydacite flows that appear to be within the Hog Pen Formation. These dark gray trachydacite **porphyries** contain phenocrysts of pink albitized feldspar, pyroxene, and hornblende. Two flows separated by a flow break are present on the knob south of the Three Rivers Road. The younger flow directly overlies the older flow; no volcaniclastic sediments are preserved between the flows. The top of the unit is not exposed in this area. The base sits on Sanders Canyon and the lava appears to have interacted with wet sediments at one locality. About 20 m of the unit is exposed.

PALEOGENE SEDIMENTARY ROCKS

Ts Sanders Canyon Formation (middle Eocene)-Includes purplish-maroon volcaniclastic breccia intruded by a NE-striking dike about 2 km southeast of Crawford Windmill. Maroon silt and gray sandstone with black mafic grains are exposed just below the distinctive hornblende trachydacite Hog Pen Formation flows. The lower part of the Sanders Canyon is lumped with the Cub Mountain in this area because of poor exposures and significant interfingering of the units. Volcaniclastic breccia <10 m thick.

Tc Cub Mountain Formation (lower to middle Eocene)-Yellow-tan sandstone intercalated with maroon, brick-red, and dark gray mudstone and rellow-green, green, gray, and red sandstone. Mud clast conglomerates occur higher in the section. Sandstone is medium- to coarse-grained and is poorly- to well-sorted, with angular sand grains of quartz, feldspar (often altered to clay), and black lithic fragments. Bedding is tabular to cross-bedded to ripple-laminated. Nodular limestone was observed at UTM 408650 3688032 (NAD 27) and desiccation cracks were noted at UTM 409507 3688048 (NAD 27). The disconformable base is located just above a mottled paleosol developed on conglomeratic sandstone in the top of the Crevasse Canyon; the top is not exposed. The thickness of the unit is poorly constrained due to poor exposure and complex structure. The Cub Mountain Formation is 370–570 m thick north of this area.

MESOZOIC SEDIMENTARY ROCKS

Kc Crevasse Canyon Formation (Upper Cretaceous, Coniacian North American Stage)–Fluvial strata consisting of interbedded sandstone channel-fills and fine-grained, mudstone-rich floodplain deposits; very minor coal beds. Sandstone channel-fill complexes may be up to 6 m thick, are well-cemented, and form ledges. Colors of the sandstone range from pale yellow, golden, light olive gray, pale olive, very pale brown, and light brownish-gray. Beds are generally tangential to trough cross-stratified (laminated or very thin to thin beds), with subordinate to subequal horizontal-planar bedding (laminated to thin). Sandstone is mostly fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, feldspar, and 5–10% lithic grains; sandstone was classified as sublithic to subarkosic by Arkell (1983). Floodplain deposits consist of mudstone and very fine- to fine-grained sandstone and silty sandstone, with local, very minor coal beds. Mudstone is pale yellow to light gray to gray to light olive gray in color and locally fissile. Carbonaceous shale is dark gray to black in color. Base of unit not well exposed on this quadrangle, but noted to be gradational in Arkell (1983). Near the top of this unit, exposed north of the Three Rivers Petroglyph site, is a ~110 m thick interval consisting of ledge-forming sandstone that is tangential cross-stratified to horizontal-planar bedded (bedding is laminated to thin). The sand in these ledges is white to light gray, medium- to coarse-grained, subrounded to subangular, well-sorted, and composed of quartz with 1–5% mafics and cherty lithic grains. A distinctive, ~5-6 m-thick paleosol has developed on the top of the Crevasse Canyon Formation. It consists of fine- to coarse-grained sandstone that is internally massive (likely bioturbated) and contains ~10% purplish manganese or iron oxide concretions. The contact between Kc and Kclt is conformable. Thickness not well constrained, due to variability in dips, but on the scale of 550-700 m.

wer, transitional part of Crevasse Canyon Formation (Upper Cretaceous, lower Coniacian North Americ and shale interpreted to reflect marginal marine (shoreface, foreshore, lagoonal pond, and deltaic) and fluvial depositional environments (Arkell, 1983). Unit conformably overlies the uppermost shoreface sandstone associated with unit Kgs. One or more coal beds are present near the base of the deposit, interbedded with mudstone and very fine- to fine-grained sandstones; this is assigned to the Dilco Member of the Crevasse Canyon Formation. Above this coal is another coarsening-upward, regressive sequence like those described for Kgs (see below); the nearshore sandstone in this interval is correlated with the Dalton Sandstone of the Crevasse Canyon Formation. The upper contact of this unit is placed at highest, golden brown, highly calcareous, very fine- to fine-grained silty sandstone bed containing marine or brackish water fossils; this bed is generally 30-100 cm thick. This golden brown, fossiliferous sandstone(s) is relatively continuous throughout the study area and commonly forms ledges. Age from Hook (2010) and Hook and Cobban (2012). 50–150 m-thick.



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This and other STATEMAP quadrangles are (or soon will be) available for free download in both PDF and ArcGIS formats at: http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.htm









Qay3r Youngest subunit of younger alluvium with subordinate recent alluvium (upper Holocene to present)–See descriptions for Qay3 and Qar above. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: limited because of higher flooding potential; possible aggregate.

Dave Middle allostratigraphic subunit of younger alluvium (middle to upper Holocene)-This subunit underlies the majority of alluvial fan surfaces in the study area, where it commonly consists of very fine- to medium-grained sand and clayey-silty fine sand—both are interbedded with very thin to thick, lenticular beds of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. The proportion of coarse channel-fills progressively decreases westward away from the mountain front. Qay2 also extends into footwall valleys and mountain drainages. Sediment color is generally pale brown to brown (10YR 5-6/3; 7.5YR 5/4), light yellowish-brown (10YR 6/4), light brown (7.5YR 6/3-4), or pink (7.5YR 7/3-4), with lower strata commonly being redder. Subunit is generally reddish-brown (5YR 4-5/3-4) where it includes notable amounts of Abo Formation detritus. Sediment mostly consists of clay, silt, and very fine- to fine-grained sand in the distal part of alluvial fans. However, sediment contains <10% silt-clay and is dominated by sand and gravel (mostly pebbles and cobbles, with minor boulders) in mountain drainages and the proximal parts of alluvial fans deposited by small to medium, relatively steep mountain-front drainages. Coarse channel-fills are up to 1 m thick (generally in very thin to medium, lenticular to tabular beds) and consist of pebbly sand to sandy pebbles-cobbles. In the medial parts of the alluvial fans, sediment typically consists of a very fine- to medium-grained sand and silty-clayey sand interbedded with pebbly channel-fills. The fine sediment is generally massive or in thick, vague beds that may be bioturbated or horizontal-planar laminated. Fine sand is mostly moderately to well-sorted, subangular to subrounded, and composed of quartz, subordinate feldspar, and minor lithic + mafic grains. The finer-grained sediment commonly includes 1–20%, scattered medium- to very coarse-grained sand and 1–15%, scattered pebbles scattered in a finer-sand matrix (probably via bioturbation). Most fine-grained sediment intervals are overprinted by a weak, cumulic, buried soil(s); these buried soil horizons commonly exhibit moderate ped development, weak (Stage I or less) calcic + gypsic soil horizons (characterized by scattered filaments), and no to very weak clay illuviation (mostly as clay bridges). Minor calcium carbonate nodules may be found in lower strata. Much of the fine sediment was likely blown in and then reworked by sheetflooding during monsoonal thunderstorms. Overall, the finer texture helps in differentiating this subunit from gravelly Qay1 deposits. Subunit may grade laterally up-slope into Qse deposits, but is differentiated from Qse by the presence of local medium to thick, coarse channel-fills.

In the proximal alluvial fans and mountain drainages, gravelly beds are up to 50 cm thick and lenticular to tabular. Gravel is commonly clast-supported and imbricated, and composed of pebbles, cobbles, and minor (1–15%) boulders. Sandy beds are laminated to very thin to medium and horizontal-planar to lenticular. Sand is grayish-brown to light brownish-gray (10YR 5-6/2), very fine- to very coarse-grained, subrounded to subangular, and generally poorly sorted.

The surface of this unit is commonly eroded, resulting in weakly developed topsoils and an erosional lag of unvarnished to weakly varnished pebbles overlying finer-grained deposits. Bar and swale relief is non-existent to very subdued (less than 30 cm relief and likely occurring on late Holocene deposits). Desert pavements do not tend to have well-developed Av peds, and surface clasts exhibit no to slight varnish. Topsoil development is characterized by ped development together with minor gypsum \pm calcium carbonate precipitation. Gypsum and calcium carbonate are present as filaments (1–15% of surface area) or disseminated; clasts are commonly totally covered by a "dusting" of calcium carbonate or have thicker (0.1–0.2 mm-thick), partial calcium carbonate coats—comparable to a Stage I calcium carbonate morphology (Gile et al., 1966). Generally, no reddening is observed. In the Three Rivers area, a thin, quartz-rich, very fine- to fine-grained sand, surficial layer is found on non- or weakly eroded surfaces-probably brought in by eolian processes and then fluvially reworked by sheetflooding. Qay2 unconformably overlies Qao and Qai, and seems to be inset into Qay1. Moderately to well consolidated and 1–6(?) m thick.

Most of this unit aggraded between 6–3 ka (Koning, 2009). This aggradation was followed by widespread erosion punctuated by brief, localized back-filling events (Koning, 2009). Post-3 ka, localized deposits are difficult to distinguish from the sediment associated with the 6-3 ka aggradation; thus, these deposits are generally grouped together in the middle and southern parts of the compilation map. This unit correlates to the Organ alluvium in the Desert Project, which has been assigned an age of 7-1 ka (Gile et al., 1981). Sediment, alluvial sediment, mostly fine-grained. Societal uses: agriculture and residential development.

Qay2u Middle subunit of younger alluvium, consisting of pebbly sand capping subdued topographic highs (middle to upper Holocene)–Sandy upper Qay2 deposits, with minor pebble lenses, underlying subdued topographic highs mantled by an erosional gravel lag. The slightly coarser texture of the sediment has inhibited erosion, creating topographic highs whose surfaces are 20-150 cm higher than surrounding, eroded Qay2 surfaces. To the north, the sand is yellowish-brown to light yellowish-brown (10YR 5-6/4). To the south, the sand is reddish-brown (5YR 5/3-4), pale brown (10YR 6/3), or very pale brown (10YR 7/3-4). Sand is very fine- to very coarse-grained (mostly fine- to medium-grained) and similar to Qay2 sand. Surface gravel consists of very fine to very coarse pebbles and 0–10% cobbles that are subrounded to subangular, generally non- to weakly varnished, and generally lacking coats of calcium carbonate (trace to 10% of clasts exhibit distinctive, thick calcium carbonate coats on their undersides), that form a weak to moderate pavement (generally greater than 10% clast surface cover). Surface lacks original bar and swale relief and generally exhibits no to very sparse (<15%) patches of strong gypsum accumulation. The clast armor of the desert pavement allowed preservation of elongated, slightly higher surfaces that probable coincide with paleo-channels. These highs are generally not as dissected as those underlain by Qfo. Age control for this unit is similar to that discussed for Qay2. Less than 2 m thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: agriculture and residential development.

av1 Older allostratigraphic unit of younger alluvium (lower Holocene)–This unit is only mapped on the proximal alluvial fans, where it is distinguished by a gravelly surface that is generally topographically higher than the surface of Qay2. Clasts on the Qay1 surface are less varnished than the Qao surface. Sediment exposure is limited, but overall seems to be somewhat coarser-grained than Qay2. Only one exposure found of this unit, which shows Qay2 inset into Qay1 and Qay1 composed of fine-grained sand with minor (10–15%), narrow, very thin- to thick-bedded, coarse channel-fills. Sediment is slightly redder than adjoining Qay2 sediment, with colors ranging from reddish-brown to pinkish-white (5YR 5/4 filaments). Sand has 1–30% clay-silt and is very fine- to fine-grained, subangular, well-sorted, and gypsiferous. Sand in channel-fills is reddish-gray to reddish-brown (5YR 5/2-3), subrounded to subangular, and poorly sorted. Surface is mantled (>50% clast density) by very fine to very coarse pebbles and minor fine to coarse cobbles. These clasts are non- to moderately varnished. Surface clasts generally lack thick calcium carbonate coats, are poorly sorted, subangular to subrounded, and composed mostly of limestone. Surface is marked by gypsum accumulation comparable to a Stage II to II+ carbonate morphology. Desert pavement is moderately to well-developed. Less than 10% strong gypsum accumulation is apparent on the surface. Surface lacks bar and swale topography and is undissecteed. The surface of Qay2 is lower (by \sim 1 m) or level with this surface. The aforementioned exposure of Qay1 shows this unit overlying a calcic horizon similar to that seen developed on the Qai deposit. Moderately to well consolidated and 1.5–2.5 m thick.

This unit is inferred to represent limited aggradation close to the mountain-front in the early Holocene. It disconformably or conformably overlies Qai. The best age control for this limited aggradation comes from a radiocarbon date at the mouth of Mule Canyon fan, which returned an age of 8.75 ± 0.07 ka (Koning, 1999; Koning et al., 2002b). Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: agriculture and residential development; limited potential for aggregate.

Qayr Younger alluvium with subordinate recent alluvium (upper Holocene to present) – See descriptions for Qay and Qar above. Clastic sediment, alluvial sediment. Societal uses: limited because of higher flooding potential; possible aggregate or agriculture.

- Qay2r Younger subunit of younger alluvium, with subordinate recent alluvium-See descriptions for units Qay2 and Qar above. This unit is common in the bottom of mountain canyons where Qar is too narrow to differentiate at this map scale. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: limited because of higher flooding potential.
- Qayo Younger alluvium and subordinate older alluvium, undivided (middle to upper Pleistocene and Holocene)—See descriptions of Qay (above) and Qao (below). Clastic sediment, alluvial sediment. Societal uses: possible agricultural potential.
- Qai Intermediate alluvium (uppermost Pleistocene)—Light brown to light reddish-brown (5–7.5YR 6/4), clayey-silty very fine- to fine-grained sand interbedded with lenses of gravel and coarse sand, commonly grading downward into sandy gravel. Variable (but generally minor), scattered coarser sand and pebbles may be present. Lower sandy gravel is in very thin to medium, lenticular to tabular beds; gravel are clast-supported, subrounded, and poorly sorted; matrix is pale brown (10YR 6/3), very fine- to very coarse-grained sand that is subrounded, poorly sorted, and contains abundant lithic grains. A nodular, Stage II to II+ calcic horizon has developed on top of the unit. The calcium carbonate nodules in this horizon are commonly 0.5-2.0 cm. This calcic horizon is about 10-70 cm thick. Unit is inset into Qao2 and Qao1 and generally overlain by unit Qay. It commonly fills topographic lows. Only subaerially exposed in a few places because it is generally overlain by unit Qay. Unit is interpreted to be associated with an interval of limited aggradation and back-filling of arroyos in the latest Pleistocene, which is supported by a radiocarbon age of 22,580 ± 140 ka from an exposure along Salinas Draw. 1–3 m(?) thick.

Qao Older alluvium (lower to upper Pleistocene)–Undifferentiated older alluvium recognized by its relatively red hues and abundant gypsum. Gypsum-cemented rhizoliths are commonly observed. Finer sediment is generally massive or in thick, vague beds, and interbedded with various proportions of gravelly channel-fills. Unit is commonly subdivided into three allostratigraphic units that are described in detail below: Qao3, Qao2, and Qao1. Another allostratigraphic unit (Qaovf) is mapped on modern valley floors west of Tularosa, and a fine-grained lithostratigraphic unit (Qaof) is differentiated on the distal areas of alluvial fans. Moderately to well consolidated and greater than 8 m thick.

This unit is left undivided on alluvial fans, where it commonly underlies slight topographic highs. There, it consists of interbedded sandy gravel, gravelly sand, sand, and clayey very fine- to fine-grained sand. Gravel layers are of variable thickness and consist of clast-supported pebbles with minor cobbles and boulders; clasts are subrounded to subangular and poorly to moderately sorted. Gravel composition varies according to source area, but typically includes variable limestone, sandstone, and igneous rocks. Clast imbrication indicates a westward flow direction. Bedding within a gravel layer is tabular to lenticular and up to ~50 cm thick (mostly very thin to thinly bedded). Some beds have abundant cobbles and boulders (i.e., well-graded pebbles through boulders) in a light brown (7.5YR 6/3-4) to reddish-yellow (7.5YR 6/6), clayey fine sand matrix—these are debris flows. Clayey-silty, very fine- to fine-grained sand on the alluvial fans is light brown to reddish-yellow to reddish-brown (7.5YR 6/3-6), highly gypsiferous, and consists of thick, tabular beds; sediment has 10-20% medium- to very coarse-grained sand and 1-10% scattered pebbles; 1-2% very thin to thin, pebble to cobble lenses are found locally at the base of individual beds. Fine sediment is redder where it contains Abo Formation detritus (2.5YR 5/4). Fine sediment is very well consolidated and has 10–30% gypsum. Sandy beds are reddish-brown to light brown to brown; sand is very fine- to very coarse-grained, subangular to subrounded, and moderately to poorly sorted; up to 50% of sand grains may be composed of gypsum. Fine and sandy beds commonly contain gypsum-cemented rhizoliths or nodules. Sand grains and gravel clasts are commonly covered by clay coats.

Kg Gallup Sandstone (Upper Cretaceous, lower Coniacian North American Stage)—Interbedded nearshore sandstones and deeper-water shales display coarsening-upward, regressive sequences in good exposures to the north (Greg Mack, 2010, personal communication; Koning et al., 2011). These regressive sequences are very likely present in this quadrangle as well, although not well-exposed. Gray to yellow marine shales are found at the base of the regressive sequence. These grade upward into lower shoreface sandstones that are commonly very thinly to thickly, tabular-bedded (mostly very thin to thin beds; beds are internally massive [locally bioturbated and burrowed] to horizontal-planar-laminated to hummocky-laminated). Sand is very fine- to fine-grained, locally silty, calcareous, subrounded to subangular, well-sorted, and composed of quartz with 1-10% lithic grains. Colors range from light gray to olive-yellow to pale olive to light yellowish-brown to pale brown to pale yellow. Upper shoreface sandstones are slightly coarser (mostly fine- to medium-grained) and in very thin to thick, tabular beds that are internally horizontal-planar-laminated or cross-stratified (tangential, low-angle, or trough-cross-laminated to very thinly bedded; foresets are up to 20 cm thick). Sand is pale yellow to light gray to pale brown to white, subrounded to subangular, well-sorted, and composed of quartz with minor feldspar(?) and 1–10% lithic grains. The sandstone commonly weathers to a yellow-golden color. The Gallup Sandstone gradationally overlies the Mancos Shale (Km or Kmd), and is conformably overlain by the Crevasse Canyon Formation (Kclt). Oyster beds are relatively common and include a diagnostic species restricted to the lower Coniacian (Flemingostrea elegans; Hook, 2010). 170-180 m thick.

Mancos Shale, undivided (Upper Cretaceous, middle Cenomanian to lowest Conician North American Stage)–Fissile shale that is planar- to vavy-laminated. Metamorphosed to black to gray argillite adjacent to laccoliths. Strata hosts numerous sills and laccoliths; emplacement of large intrusions has folded and deformed the adjoining Mancos Shale. This undivided unit includes the lower tongue of the Mancos Shale (Kml, see below), the D-Cross Tongue Member of the Mancos Shale (Kmd), and the intervening pale yellow to white, fine-grained, shoreface sands of the Tres Hermanos Formation. Thin limestone and bentonite beds are locally present in the lower tongue of the Mancos Shale (*Kml*). Unit **gradational**ly overlies the Dakota Sandstone and gradationally underlies the Gallup Sandstone. Age assignment is from Hook and Cobban (2012). Cross-section **A–A'** and well data indicate a thickness of 165–270 m.

Kmd Mancos Shale, D-Cross Tongue Member (Upper Cretaceous, middle Turonian to lowest Coniacian Stage)—Dark gray to greenish-gray to pale rellow, fissile shale, silty shale, siltstone and claystone. Slight to no effervescence in hydrochloric acid. Trace to common siderite- and/or calcium carbonate-cemented concretions that are up to 0.5 m in diameter occur about 20 m below the contact with overlying Gallup Sandstone. Unit erodes readily. **Toward** top of unit, green to brown beds of siltstone and very fine- to fine-grained sandstone become progressively more common. Shale is metamorphosed to a black to gray argillite immediately adjacent to laccoliths or dikes, aiding in the preservation of **Inoceramid** fossils. Unit is gradationally overlain by the Gallup Sandstone and underlain by the Tres Hermanos Formation. 70–100 m-thick.

Kth Tres Hermanos Formation (upper Cretaceous, middle Turonian Stage) – A tongue of very fine- to medium-grained (mostly fine-grained) sandstone within the Mancos Shale, locally containing shell debris and chert fragments. Colors range from pale yellow to light gray, weathering to brownish-yellow, very pale brown, or pale yellow. Sandstone is locally interbedded with subordinate yellow shale beds. In places, lenses of bioturbated, yellowish-brown sandstone occur that include oyster, bivalve, and ammonite remnants. Locally, burrows are observed. A plano-convex, medium-sized, ribbed oyster called Cameleolopha bellaplicata confirms lithostratigraphic correlations with the Tres Hermanos Formation (Hook and Cobban, 2011). 10–60 m-thick, thinning to the northeast. Thickness 15–21 m toward the north.

Kmi Mancos Shale, lower tongue (Upper Cretaceous, middle Cenomanian to lower Turonian North American Stage)-Fissile calcareous shale that planar- to wavy-laminated; colors range from gray to light gray to light olive-gray to light greenish-gray. Thin beds of limestone (Bridge Creek Limestone Member) and bentonite are locally exposed. Limestone occurs about 5 m above the base and in the Bridge Creek interval a few 10s of meters higher up section. These marine deposits were mapped as the lower part of the Rio Salado Tongue of the Mancos Shale by Moore et al. (1988) just east of the map area. Unit gradationally overlies the Dakota Sandstone. 85–110 m thick.

Kd Dakota Sandstone (Upper Cretaceous)–White, cross-stratified sandstone that is intercalated with light gray to dark gray shale and light gray siltstone to very fine sandstone in its upper half. Sandstone is tangential- to trough-cross-stratified (laminated to very thin beds) or in medium to thick, tabular beds that are internally cross-stratified or horizontal-planar laminated. Trough cross-stratfication indicates a northeast paleoflow direction. Wood fragments are locally observed. Sand grains are mostly fine- to medium-grained, subrounded to subangular, well-sorted, and a quartz arenite. Locally, coarse to very coarse sand grains are present (composed of chert, quart, or quartzite). Minor beds of pebbly sandstone occur near the base of the unit; clasts include subrounded to rounded quartz, chert, and quartzite. Distinctive, cylindrical Ophiomorpha nodosa burrows are abundant at the top of the Dakota Sandstone. Sandstone is gradationally overlain by the Mancos Shale (*Kml*). The base of the unit is scoured. Locally, the Dakota Sandstone fills paleo-valleys that are up to 6 m deep; these paleo-valley fills consist of subequal sandstone and reddish-brown mudstone. Sandstone weathers to form a purplish brown varnish. Approximately 90 m thick.

Moenkopi Formation (Upper Triassic)–Reddish-brown to weak red to pinkish-gray, cross-stratified, fine- to coarse-grained sandstone (mostly fineto medium-grained). Varying proportions of weak red to reddish-brown shale, claystone, and siltstone (decreasing in abundance to the southeast). Sandstone is commonly trough- to tangential-cross-stratified (laminated to very thinly bedded, 10–15 cm thick foresets) and locally ripple-laminated. The sand grains are subangular to rounded, moderately to well-sorted, and a lithic arenite (including muscovite and lithic fragments). Conglomeratic sandstones with pebbles of chert, quartzite, and quartz are present in a few localities. The upper and lower contacts are disconformable. The fluvial Moenkopi Formation scoured channels into the underlying Grayburg Formation of the Artesia Group. 10–50 m thick; it is **possibly 70 m thick** near Three Rivers but thins to 10 m to the southeast.

PALEOZOIC SEDIMENTARY ROCKS

Pag Grayburg Formation, Artesia Group (Permian)–Orange to reddish-brown to light reddish-brown, very fine- to fine-grained sandstone and silty-clayey very fine- to fine-grained sandstone; only minor siltstone and shale. Bedding is mostly very thin to thick and tabular, but very thin to medium, lenticular beds are locally present. Minor light gray to light greenish-gray reduction spots (0.5–2.0 mm). Sandstone is subangular to rounded (mostly subrounded), well-sorted, and composed predominately of quartz (no lithic grains and feldspar seems to be very minor). Intercalated gypsum beds are more common up-section. The gypsum is absent ~10 m below the top. The gypsum forms medium to thick, tabular beds that are eroded and scoured by the Moenkopi Formation. No fossils preserved. This unit is assigned to the Grayburg Formation because of lithologic characteristics, thickness, and the fact that higher formations of the Artesia Group extend progressively shorter distances from the deepest parts of the Delaware Basin to the south-southeast (Kelley, 1971 and 1972). We did not recognize the Queen Formation of the Artesia Group because we did not note scattered large, rounded, frosted quartz grains indicative of the upper part of this formation (Tait et al., 1962). Orangish color, fine texture, and quartz arenite composition, and reduction spots serve to differentiate this unit from the overlying Moenkopi Formation. 90–110 m based on petroleum well data near Three Rivers.

- San Andres Formation (Permian)–Kelley (1971) recognized three members of the San Andres Formation in south-central New Mexico. The ntercalated limestone and gypsum unit in the upper part of the San Andres Formation belongs to the Fourmile Draw Member of Kelley (1971). The middle part of the unit, the Bonney Canyon Member, is fossiliferous, **thin-thick bedded** dark gray limestone. The lower part of the deposit, the Rio Bonito Member, is composed of medium- to thick-bedded dark gray, fossiliferous limestone, golden tan dolomite, and thin beds of yellow siltstone and gypsum. Harbour (1971) described a sandstone bed within the Rio Bonito Member approximately 30 m above the base of the limestone that he named the Hondo Sandstone Member of the San Andres Formation. In this area, only the Fourmile Draw, the Hondo Sandstone, and the Rio Bonito members are present. The San Andres Formation is 240-250 m thick, based on petroleum well data north of the map boundary.
- Psf Fourmile Draw Member-The Fourmile Draw Member is composed of interbedded light gray dolomite, dark gray limestone, and laminatd gypsum. The carbonates contain fossils, but fossils are not as common as they are in the Rio Bonito Member. The relative ratio of gypsum to carbonate increases upsection through the member. The thickness of this unit is uncertain because the top is not exposed this unit is quite deformed. The contact between the Fourmile Draw and Rio Bonito members is very gradational and is here defined to be at the base of a distinctive limestone bed present across the map area. The marker limestone is dark gray, fossiliferous, and has a gypsum bed that is about 6 m thick below it. The carbonates above the marker limestone become progressively more dolomitic up section. The marker limestone is generally the thickest succession of limestone above cliffs of the Rio Bonito Member, but the marker does vary in thickness (6-24 m; average is 12 m). The marker limestone forms an easily traceable unit on poorly exposed, gypsum-mantled hills. The 6 m thick gypsum bed is continuous across the area, but thin, discontinuous gypsum and intercalated limestone beds often occur in the uppermost Rio Bonito Member as much as 25 m below the mappable marker limestone. Similarly, thin sequences of dark gray, fossiliferous limestone that grade up into dolomite and thick beds of gypsum are present above the marker limestone. **Estimated thickness is approximately 300 m.**
- Hondo Sandstone–The Hondo Sandstone is a gold-brown to tan, well-sorted, medium to fine-grained quartz arenite with well-rounded and grains. Bedding is commonly tabular, cross-bedding is rare. The sandstone is discontinuous and ranges from 0–10 m thick. The sandstone, where present, is only 0.7 m thick on Cat Mountain (UTM 415916E 3670526N [NAD27]) and is 5-10 m thick on the west end of Coyote Ridge. The unit consists of a single sandstone bed that is 0.5-4 m thick in the hills just north of Temporal Creek. An outcrop of Hondo Sandstone at UTM 406593E 3675665N (NAD27) that is in proximity to a fault contains nodules of barite near the top of the exposure. The sandstone unit thickens to 10 m thick toward the northwest just south of Salinas Draw, where two sandstone beds are separated by a medial dolomite that is 1 m thick. Here, the lower sandstone is massive, and the upper sandstone has tabular bedding. The Hondo Sandsone is about 2 m thick north of the Salinas Draw fault.
- Per Rio Bonito Member–Dark gray, thin- to thick-bedded, fossiliferous limestone with thin to medium-bedded gypsum near the top of the unit. possils include productid brachiopods, crinoids, echinoderm spines, and bryozoa fragments. The contact with the underlying Yeso Group is generally quite sharp; however, thin (<0.5 m) gypsum beds can persist a few meters above the contact. The Rio Bonito Member is 60-75 m thick.

Py Yeso Formation (Permian)-Red and yellow siltstone, thin beds of gray limestone, and laminated to thin-bedded gypsum dominate the asal part of the section. A 30 m thick medium-bedded limestone forms a prominent bed in the middle portion of the unit. The upper part of the Yeso Formation on Cat Mountain is gypsum with yellow and red siltstone and thin-bedded limestone. Red siltstone often occurs near the top of the unit. In contrast, the upper Yeso Formation to the north of Cat Mountain is primarily gypsum and limestone. The limestones are sparsely fossiliferous, containing brachiopods. A solitary nautiloid 15 cm across was found in limestone near the base of the unit. Sea star fossils are at the Yeso/San Andres contact in the northeastern part of the map area. Oncolites are preserved in the limestone at UTM 416913E 3670824N (NAD 27). The Yeso Formation has a gradational contact with the underlying Abo Formation that is particularly well exposed south and southwest of Cat Mountain. The red arkosic sandstone and red and green mudstone of the Abo Formation grade upward into thin beds of black and green shale, fine-grained green and yellow sandstone, and thin beds of gypsum and limestone. The upper contact is gradational with the San Andres Formation. Kelley (1971) measured a complete section of Yeso Formation on the Cat Mountain quadrangle in the vicinity of Coyote Peak in T13S, R10E, Sec. 21 and 22. Maximum thickness is 372 m.





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Unit underlies topographically high surfaces dissected by gullies (0.5–1.0 m-deep) that have been partly back-filled by Qay deposits. The surface is smooth and lacks original bar and swale topography. Much of the surface is covered by thin (generally less than 30 cm thick), younger sheetflood deposits (Qse). A thin mantle of younger eolian deposits (Qec and Qsec) is common in the Three Rivers area. Where not mantled by these younger deposits, the surface manifests a weak to well-developed desert pavement—with moderately to strongly varnished surface clasts exhibiting calcium carbonate rinds (up to 65% clast coverage). Surface gravel include very fine to very coarse pebbles and 8-10% fine cobbles. A Stage II+ to III calcic horizon has locally developed on this unit on the Temporal Creek alluvial fan, but generally the unit exhibits a top soil with strong gypsic + calcic horizon(s) (comparable to a Stage II+ to III morphology in a calcic soil). In areas where the deposit has been stripped, pedogenic gypsum horizons have been exposed and weathered to form a hard gypsum crust at the surface. In areas of poor exposure on the alluvial fans, Qao assignment was based on the observation of 10% or greater strong gypsum indications (such as gypsum crusts) on the surface. Base of unit not defined, but alluvial fan sediment filling the basin here is generally several hundred meters thick.

This unit correlates to the Jornada II alluvium in the Desert Project, which is inferred to be upper middle to upper Pleistocene in age (Gile et al., 1981, Table 9). Radiocarbon dates presented in Koning et al. (2002b) support a Pleistocene age for Qao. Unit almost certainly represents more than one episode of alluvial aggradation. Clastic sediment, alluvial sediment. Societal uses: residential development; high gypsic content of top soil impedes agriculture; buried soils and variable gravel and clay content reduces aggregate quality.

Dani Fine-grained, older alluvial fan deposits of intercalated gypsiferous clay, sand, silt, and gypsum on the distal alluvial fans (lower? to upper Pleistocene)—Intercalated clayey fine sand, clay, silt, very fine- to fine-grained sand, and gypsum. Colors range from reddish-brown to light reddish-brown (5YR 4–6/4) to pink (5YR 7/3 to 7.5YR 7/4) to reddish-yellow (7.5YR 6/6) and yellowish-red (5YR 4/6). Very thin to thick, tabular beds that are internally massive and commonly hard; locally planar-laminated. Local calcium carbonate in nodules or thin to thick beds. Sand is very fine- to coarse-grained (mostly very fine- to medium-grained), moderately to well-sorted, and consists of various proportions of quartz, calcite, gypsum, feldspar, and minor lithic grains (including granite). Locally, there are minor, meter-scale-thick, sandy pebble to cobble beds interbedded n the typically tine sediment of this unit Radiocarbon age of $2/010 \pm 160$ obtained from agest pod shells from the upper part of this deposit (s and clay beds), 1.1–1.3 below Qgy. Base of unit not defined. West of Tularosa, unit is exposed or underlies units Qgy or Qay2. Surface of unit is comparable to that of Qao. Total basin-floor sediment is several hundred meters thick before Paleozoic bedrock is encountered. Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: residential development; high gypsic content of top soil impedes agriculture; buried soils and variable gravel and clay content reduces aggregate quality.

Qapyr Older alluvial fan deposits occupying the floors of modern valleys on the distal parts of the alluvial fans, locally capped by a veneer of recent alluvium (middle to upper Pleistocene to uppermost Holocene)—This unit was applied to valley floors incised below unit Qgy in the southwestern map area. There, lack of exposure commonly presented difficulty in recognizing thin, discontinuous, recent deposits (Qar) versus fine-grained, older alluvial fan deposits (Qaof). Thus, these units were generally combined on these valley floors. Latest Holocene sediment is light yellowish-brown (2.5Y 6/3), internally massive, well-sorted, and consists of silty sand composed of gypsum, calcite, quartz(?), and plagioclase). Clastic sediment, alluvial sediment, mostly fine-grained. Societal uses: very limited because of high flooding potential.

Qao3 Younger allostratigraphic subunit of older alluvium inset into older deposits (probably upper Pleistocene)–Generally a sandy gravel and pebbly sand with variable (but commonly subordinate) interbeds of strong brown to reddish-yellow to light brown (7.5YR 5-6/6; 7.5YR 6/4), gypsiferous sand. The sand is mostly very fine- to fine-grained and contains variable amounts of scattered pebbles (pebbles may also be in thin lenses) and coarser sand. Differentiated east of the Alamogordo fault, this unit generally occupies paleo-valleys that are inset into older alluvium (Qao2). Unit locally fines upward from a sandy gravel at its base to clayey very fine- to fine-grained sand at its top. The gravelly sediment exhibits very thin to medium, horizontal-planar to lenticular beds. Gravel is clast-supported, rounded to subangular (mostly subrounded), poorly sorted, and includes pebbles with lesser cobbles and boulders. Matrix in gravelly sediment is pale brown to light brownish-gray (10YR 6/2-3), highly gypsiterous, and composed of very fine- to very coarse-grained sand (mostly coarse- to very coarse-grained) that is subrounded, poorly sorted, and contains abundant lithic grains; beds are very thin to thick and lenticular to tabular. Fine-grained sediment is internally massive and has gypsum filaments. Locally, sediment extends hundreds of meters away from paleovalleys as a tabular deposit up to a few meters thick. Where unit is not covered by younger, surficial deposits (e.g. Qse), a strong gypsic-calcic horizon is developed on the surface of the unit (comparable to a Stage II+ or III morphology in a strictly calcic soil), surface clast varnish is relatively well-developed, and there is a well-developed desert pavement. Where this unit has been buried or recently exhumed, a nodular, Stage II to II+ calcic horizon may be developed on top of the unit (10-70 cm thick). Unit partially correlates with Qao on the alluvial fans. No direct age control but inferred to be late Pleistocene. Weakly to moderately consolidated. South of the Three Rivers drainage, this unit is notably gravelly and 4-14 m-thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: aggregate.

Dad Middle allostratigraphic subunit of older alluvium (middle to upper Pleistocene)—Reddish, gypsiferous, relatively fine-grained sediment interbedded with coarse channel-fills of sand and gravel. Only differentiated east of the Alamogordo fault. Scoured base of deposit appears to lie several meters below the base of unit Qao1. Unit locally occupies discrete paleovalleys whose tops are at the same height as adjoining Qao2; sediment in these paleovalleys generally consists of clast-supported, sandy gravel in very thin to thin, horizontal-planar beds. Unit includes relatively coarse sediment on the immediate footwall of the Alamogordo fault north of Three Rivers. Color of fine sediment is pink to light brown (7.5YR 6-7/3-4), brown to reddish-yellow (7.5YR 5/4-6/6), light reddish-brown (5YR 6/4), yellowish-red to reddish-yellow (5YR 5-6/6), or brown to dark grayish-brown (10YR 5/3-4/2). The fine sediment is composed of very fine- to medium-grained sand and clayey-silty fine sand, with minor medium- to very coarse-grained sand and pebbles (as scattered grains/clasts or in very thin to medium lenses). Very fine- to medium-grained sand is subangular to subrounded and consists of quartz, 5–15%? feldspar, and 15% volcanic grains. Coarse to very coarse sand is subrounded to angular (mostly subrounded to subangular) and consist of lithic fragments (mostly igneous fragments to the north and mostly Paleozoic sedimentary detritus to the south). The fine-grained sediment is internally massive, well consolidated, commonly bioturbated, and variably affected by pedogenesis (i.e., illuviated clay and ped development), with common rhizoliths cemented by gypsum and local calcium carbonate nodules. Less commonly, the fine sediment is in medium to thick, tabular beds. Between Rio Tularosa and Temporal Creek, fine-grained sediment dominates the unit near the mountain-front, where it is interpreted to have been brought in by eolian processes before being fluvially reworked. Intercalated gravelly channel-fills are up to 1 m thick and contain pebbles with minor cobbles and local boulders. These channel-fills are clast- to matrix-supported (mostly clast-supported) and in thin to thick, tabular to lenticular beds. Gravel is commonly imbricated, subrounded to subangular, poorly to moderately sorted, and composed of limestone, sandstone, and igneous clasts (the latter dominating to the north). Sand in the coarse channel fills is generally horizontal-planar laminated to very thinly bedded, light brown to reddish-yellow (7.5YR 6/4-6) to light yellowish-brown (2.5Y 6/3) to light gray-grayish-brown (10YR 6/3-5/2 and 10YR 6-7/2), very fine to very coarse-grained (mostly medium- to very coarse-grained), subrounded to subangular, and moderately to poorly sorted. This channel-fill sand contains up to 3% clay (as sand-size rains or as clay films) and gypsum crystals may occupy up to 2% of the volume. Near rocky topographic highs, matrix-supported debris flows are interbedded in clast-supported, stream-flow sediment. The matrix of these gravelly debris flows consist of pink (7.5 YR 7/3-4), very fine- to medium-grained sand with subordinate coarser sand. Where not covered by Qse or Qsec, the surface of Qao2 is characterized by a moderately to well developed desert pavement (containing well-varnished clasts) and strong gypsum accumulations (comparable to a Stage III morphology in a calcic soil or else a petrogypsic horizon). Several different erosion surfaces have developed on this unit, which are most obvious immediately adjacent to the Alamogordo fault. Unit probably correlates with much of the older alluvial fan deposits west of the Alamogordo fault (Qao). No direct age control but inferred to be middle to late Pleistocene. Well consolidated and locally cemented. 3 m to greater than 15 m thick. Clastic sediment, alluvial sediment. Societal uses: residential development. Low to moderate aggregate potential because of high content of gypsum and fine-grained sediment–moderate to high aggregate potential in Three Rivers area because of coarser texture there. Low agricultural potential because of gypsic top soil.

Qao1 Older allostratigraphic subunit of older alluvium (lower to middle Pleistocene)–Generally a sandy gravel with subordinate to subequal interbeds of clayey-silty, gypsiferous, very fine- to fine-grained sand containing minor medium to very coarse sand. Finer-grained sediment increases progressively south of the Three Rivers drainage. Gravel contains pebbles with variable cobbles, locally with minor boulders. Gravel are subrounded to subangular, poorly to moderately sorted, and composed of limestone, intermediate to mafic intrusive rocks, and subordinate sandstone (limestone clasts dominate to the south and igneous clasts dominate to the north). Color of sand ranges from pale brown to very pale brown (10YR 6-8/3), pink (5-7.5YR 7/3), or light yellowish-brown to light brown (10-7.5YR 6/4). Sand is very fine to very coarse-grained, subrounded to subangular, and moderately to poorly sorted. Very fine- to medium-grained sand is composed mostly of subangular to angular gypsum grains, whereas coarser sand is composed of lithic grains. Base of deposit generally lies several meters above the base of unit Qao2. Surface of unit typically lies >3 m above the Qao2 surface. **Prevalent petrogypsic horizon developed on its surface and very strongly varnished surface** clasts. Moderately consolidated, highly gypsiferous, and variably cemented. Unit is locally strongly cemented near Salinas Draw. 5–25 m-thick. Clastic sediment, alluvial sediment, mostly coarse-grained. Societal uses: residential development, aggregate potential, low agricultural potential because of gypsic top soil and gravelly texture.

Abo Formation (Permian)—Brick red sandstone, mudstone, siltstone, and conglomerate. The Abo Formation is dominated by mudstone (50%) and arkosic sandstone and conglomerate (40%). Fossiliferous limestone and pedogenic carbonate, which are primarily found in the basal 150 m, make up the rest of the unit (Otte, 1959). Sandstones are cross-bedded to tabular, coarse to medium-grained, and poorly to moderately sorted. Angular to subround quartz, orthoclase feldspar, and muscovite are common sand grains. Conglomerates contain well-rounded clasts of Proterozoic quartzite, Proterozoic rhyolite porphyry, chert of uncertain age, and sandstone. Thin fossiliferous limestone beds that are 0.2-0.7 m thick occur locally near the transitional base of the unit. Thin (4-20 cm) chert beds **are found** just above the contact with the Bursum Formation and above a thin (0.2 m) limestone bed at UTM 408507E 3666281N (NAD 27). Petrified wood is preserved in the Abo Formation at UTM 408658E 3664679N (NAD27). Malachite and hematite mineralization is associated with the Abo Formation. 427-550 m thick (Otte, 1959; Speer, 1983). Thickness of Abo is 530-630 m farther north.

Pb Bursum Formation (Late Pennsylvanian to Early Permian)-Fluvial sandstone and mudstone interbedded with fossiliferous marine limestone and plack shale. Fine-grained fluvial deposits in the Bursum Formation consist of reddish-gray and dark reddish-gray mudstone and sandy claystone, where the minor sand is very fine- to coarse-grained and arkosic. Sandstone and pebbly sandstone occupy medium to thick, lenticular to tabular channel-fills; internal bedding is massive to planar-laminated or in very thin to medium, planar to lenticular beds. Channel-fill sediment is pinkish-gray to reddish-gray to pinkish-gray. Sand is fine- to very coarse-grained (mostly medium- to very coarse-grained), angular to (mostly) subangular to subrounded, moderately sorted, and is arkosic to lithic arkosic. Limestone is composed of medium to thick (mostly thick), tabular micritic to bioclastic beds that are gray to light gray. Marine shales are gray and planar- to slightly wavy-laminated. Strata are typically strongly cemented, although the shales are friable. In addition, the Bursum Formation contains beds of poorly sorted conglomerate, up to several meters thick, with pebble- to cobble-sized rounded to subrounded guartzite and angular to subrounded rhyolitic porphyry clasts, as well as conglomeratic beds dominated by limestone clasts. The unit represents the transition from predominantly marine conditions that existed during deposition of the underlying Pennsylvanian Holder Formation, to a terrestrial environment during deposition of the overlying Permian Abo Formation. Algal bioherms with abundant crinoid stems preserved at the top that are located just northeast of Tularosa have been studied in some detail (e.g., Scholle et al., 2007). Bryozoans and brachipods are other common fossils on the mounds. This unit is equivalent to the Labrocita Formation of Otte (1959). Lucas and Krainer (2004) based on regional study of these transition beds, have concluded that the deposits below "Laborcita" may be retained as a member of the Bursum Formation in the northern Sacramento Mountains). The age assignment for the Bursum Formation is also undergoing continued discussion (S.G. Lucas, personal communication, 2009). Based on North American fusulinid biostratigraphy, the bulk of the Bursum Formation in the Sacramento Mountains is Wolfcampian, traditionally considered to be Lower Permian. Recent biostratigraphic studies based on conodonts, however, suggest that lowermost Wolfcampian strata in North America may ultimately be considered Upper Carboniferous in the global scheme. At any rate, the lithostratigraphic base of the formation in the map area is gradational with the underlying Holder Formation, and is chosen at the top of a laterally continuous, comparatively thick bed of marine limestone (assigned to the top of the Pennsylvanian Holder Formation), the basal Bursum deposits consisting of a succession of reddish and greenish siltstone and sandstone with interbeds of limestone and locally a bed of limestone conglomerate near the base of the formation. We followed Otte (1959) by using a continuous limestone bed (Otte's bed 55) to mark the gradational top contact between the Bursum and the Abo formations. Estimated thickness east of Tularosa is 170-300 m, thickening from south to north across the map area (Otte, 1959). King and Harder (1985) interpret the Bursum Formation to be 280-328 m thick in Houston Fed A 1 and Hodges Houston 1, respectively.

Ph Holder Formation (Upper Pennsylvanian)-Interbedded dark-colored marine shale and fossiliferous limestone containing beds of sandstone, eddish to maroon mudstone, and occasional beds of limestone conglomerate near the top and marine carbonate, dark-colored shale, and algal bioherms in the lower portion of the formation. The base of the formation is not exposed in the map area. As discussed above, the top of the Holder Formation is gradational with the overlying Bursum Formation in the map area. Estimated to be about 275 m thick just south of the map area (Otte, 1959) **and interpreted** to be 121 m in Houston Oil and Minerals 1 State.

Pb Beeman Formation (Pennsylvanian) [subsurface only]-Thin beds of argillaceous limestone interbedded with calcareous shale with dolomite and continuous arkosic sandstone near the base (Koning et al., 2007). Estimated to be 110–150 m thick and interpreted to be 265 m thick in Houston Oil and Minerals 1 State.

Gobbler Formation (Pennsylvanian) [subsurface only]-Shale and quartz sandstone form the top of the unit; the underlying medial Bug Scuffle estone grades upward into the upper unit. The lower Gobbler Formation is composed of shale and cherty limestone, with minor coarse-grained sandstone, fine pebbly sandstone, and sandy, chert-cobble conglomerate (Koning et al., 2007). ~400-500 m thick.

M Lake Valley Formation (Mississippian) [subsurface only]-The Lake Valley Formation includes calcareous shale, mudstones, thin-bedded estone, and minor quartzose siltstone. Crinoid-bearing bioherm mounds are common in the middle of the formation. Thickness varies from a maximum of nearly 80 m to a more usual 50 m in areas near mounds. The formation is considerably thinner (15–20 m) away from the bioherm mounds (Koning et al., 2007). Interpreted to be 146 m thick in Houston Oil and Minerals 1 State.

Diate, Sly Gap, and Percha Shale Formations (Devonian) [subsurface only]—Dark gray to brownish-gray silty dolomite, dolomitic siltstones, and rery fine-grained quartz sandstones. Light gray calcareous shales are common **toward** the base and black, non-calcareous shales are common at the top of the section. Pebbly sandstones occurring locally along the base are in layers not very resistant to erosion. Unit is poorly exposed and commonly covered by colluvium. The upper contact is a disconformity (Koning et al., 2007). 15-30 meters thick (mostly ~30 m

S-O Fusselman Formation (Silurian), Valmont Dolomite, Montoya Formation, El Paso Formation (Ordovician) [subsurface only]–Lower Paleozoic dolomite and chert with minor shale. Sandy dolomite and thin to medium beds of quartz sandstone are present near the base of this combined unit (Koning et al., 2007). 225–288 m thick.

ECOB Bliss Sandstone (Cambro-Ordovician)-Exposed on the Bent dome. Fine- to coarse-grained, well-sorted quartz sandstone. Sand grains are vell-rounded to subrounded quartz, chert, and trace feldspar that are, in places, cemented by carbonate, and in others, by quartz overgrowths (Bauer and Lozinsky, 1991). Bedding is tabular to cross-bedded and ripple-marks are present. The sandstone is generally tan in color, but contains glauconite that locally causes the sandstone to be green near the base (Bauer and Lozinsky, 1991). 27-34 meters thick.

Diorite (Proterozoic?)–Exposed on the Bent dome. Gray, porphyritic plutonic rock with a medium-grained matrix of alkali feldspar, plagioclase, and altered hornblende, pyroxene, and biotite (Bauer and Lozinsky, 1991).

Granite (Proterozoic?)−Exposed on the Bent dome. Red, coarse-grained plutonic rock with alkali feldspar, plagioclase, quartz, biotite, and ppaque minerals (Bauer and Lozinsky, 1991).

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