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NMBGMR Open File Report 563
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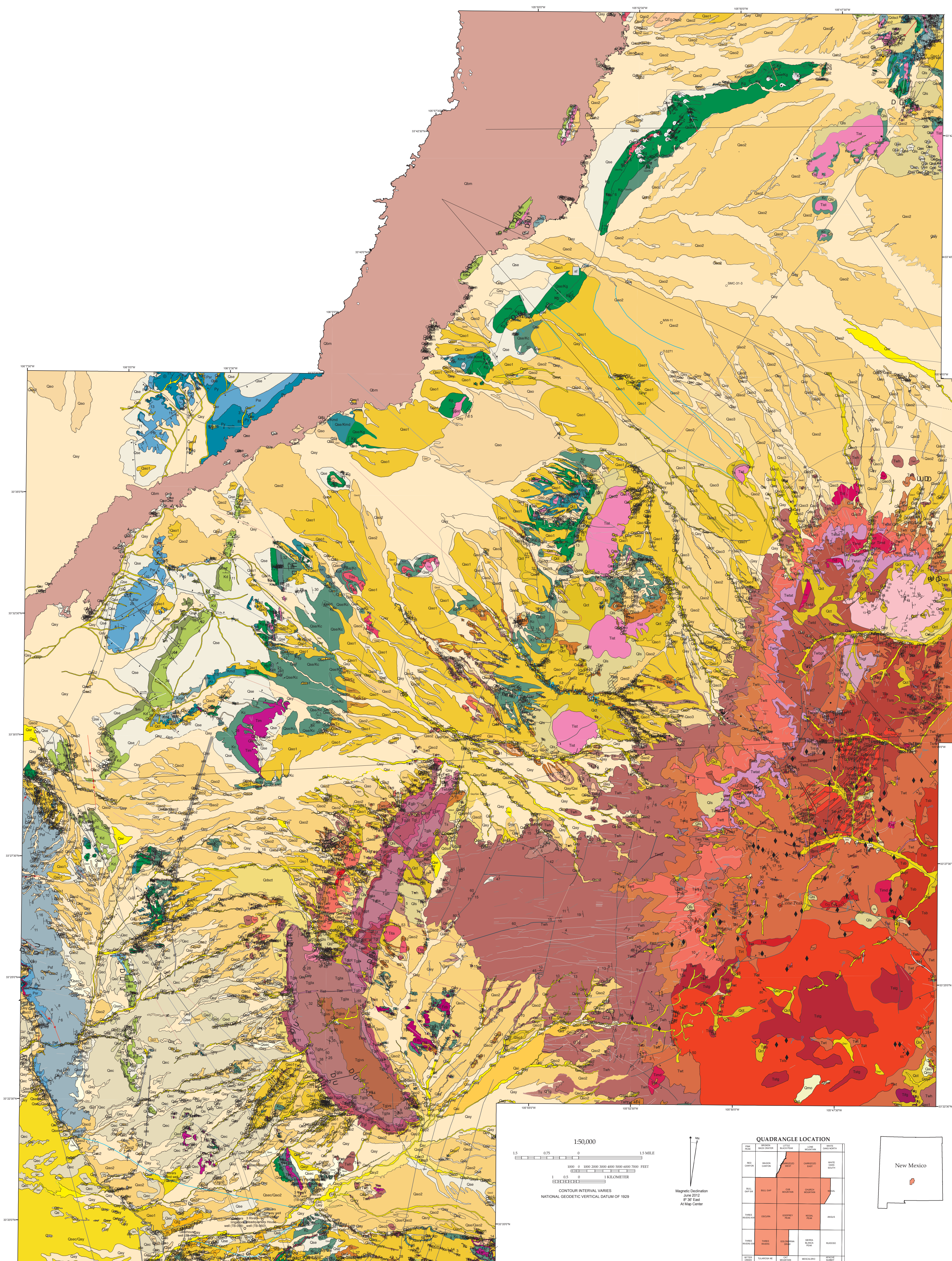
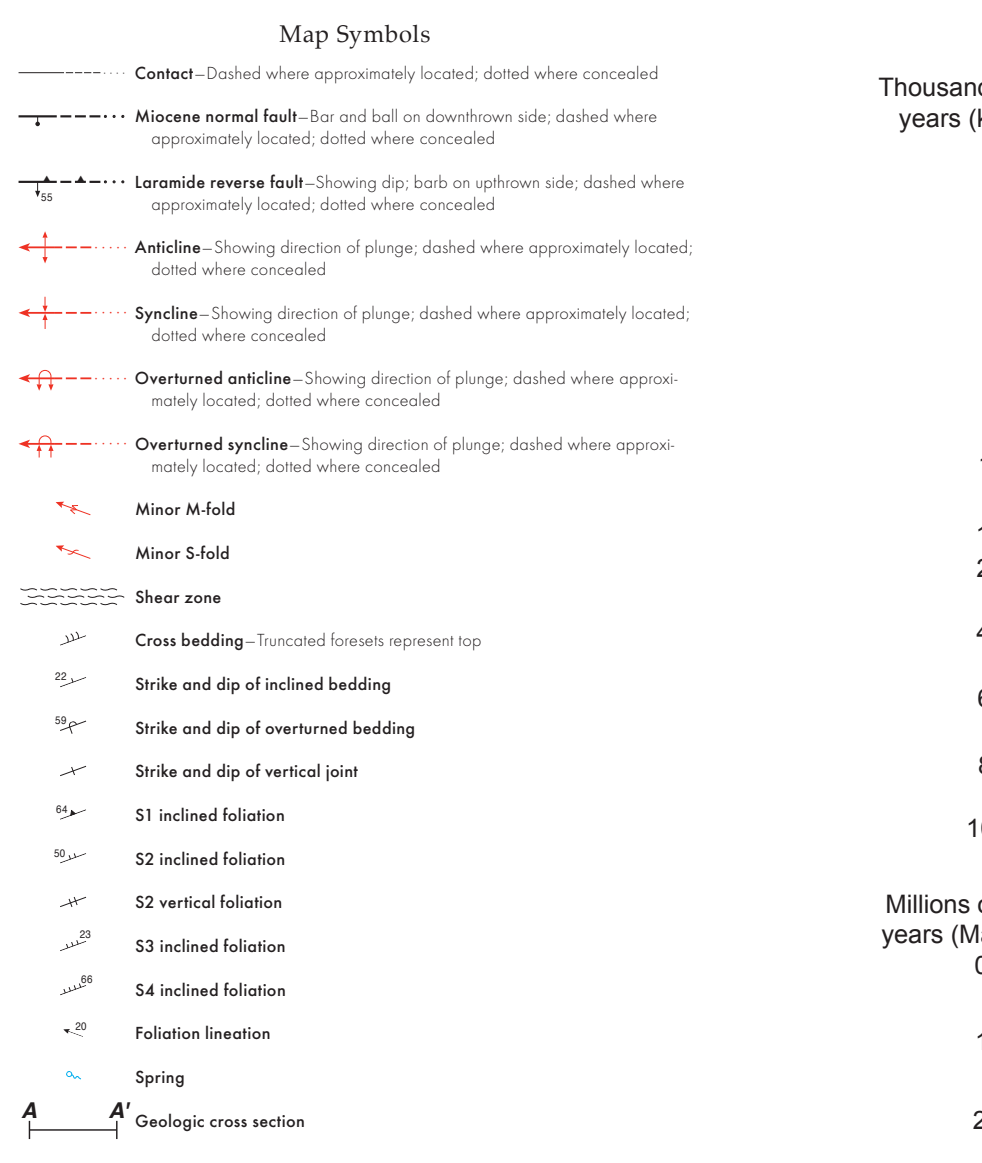


Map Symbols



Contact—Dashed where approximately located; dotted where concealed

Miocene normal fault—Bar and ball on downthrown side; dashed where approximately located; dotted where concealed

Laramide reverse fault—Showing dip; barb on upthrown side; dashed where approximately located; dotted where concealed

Anticline—Showing direction of plunge; dashed where approximately located; dotted where concealed

Syncline—Showing direction of plunge; dashed where approximately located; dotted where concealed

Overturned anticline—Showing direction of plunge; dashed where approximately located; dotted where concealed

Overturned syncline—Showing direction of plunge; dashed where approximately located; dotted where concealed

Minor M-fold

Minor S-fold

Shear zone

Cross bedding—Truncated foresets represent top

Strike and dip of inclined bedding

Strike and dip of overturned bedding

Strike and dip of vertical joint

S1 inclined foliation

S2 inclined foliation

S2 vertical foliation

S3 inclined foliation

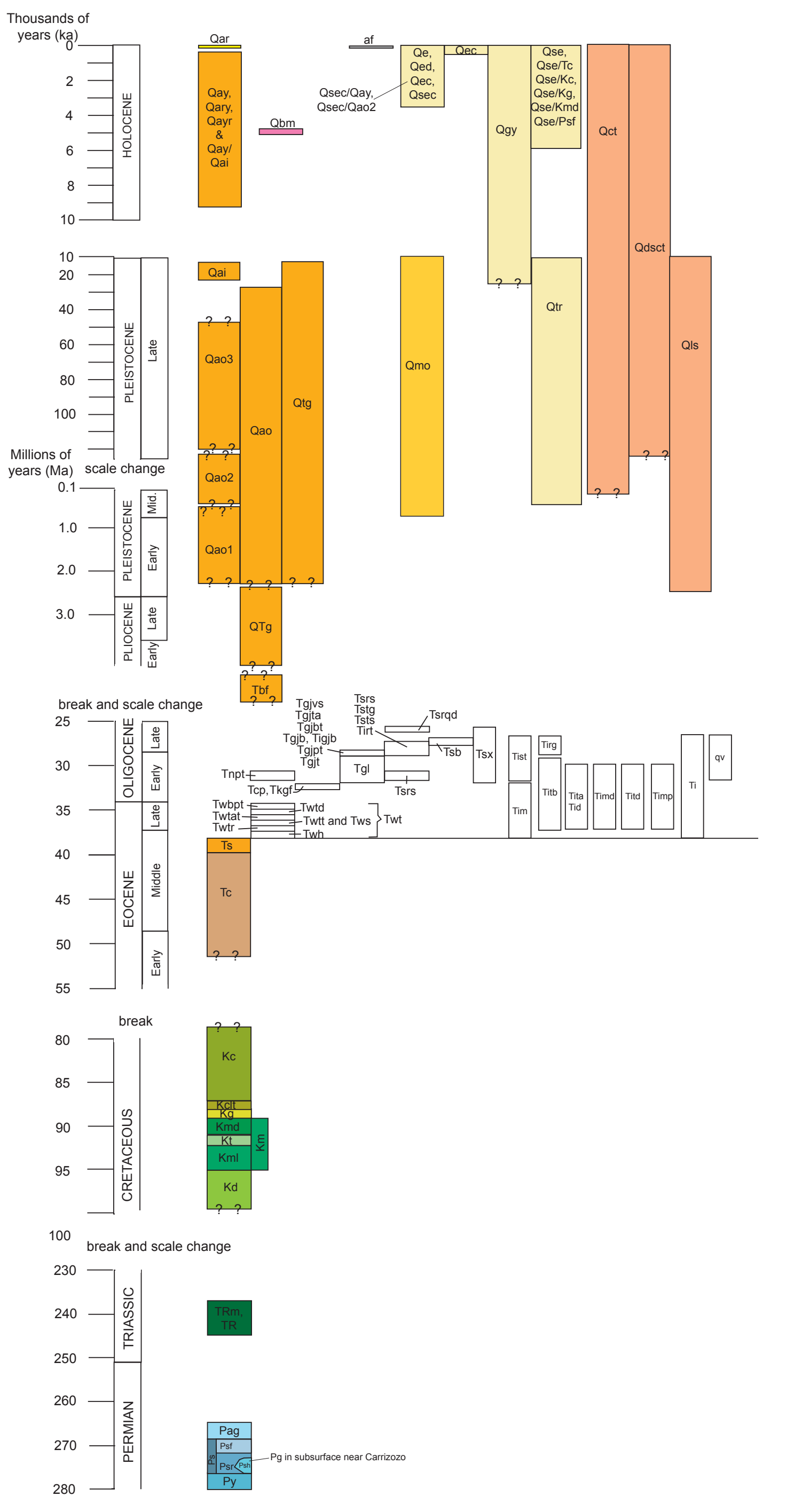
S4 inclined foliation

Foliation lineation

Spring

Geologic cross section

Time correlation chart for map units in the northernTularosa Basin compilation map



Preliminary Geologic Map of the northeastern Tularosa Basin and western Sierra Blanca Basin, Lincoln and Otero Counties, New Mexico

June 2014

by

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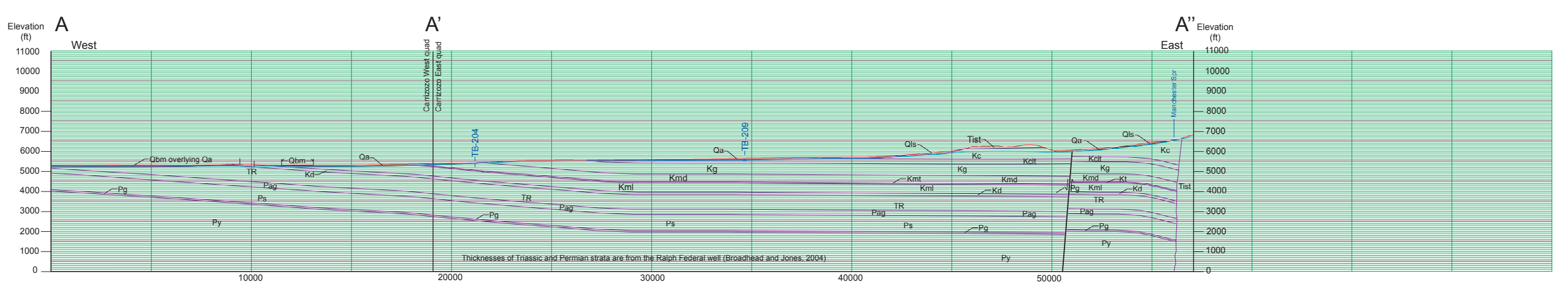
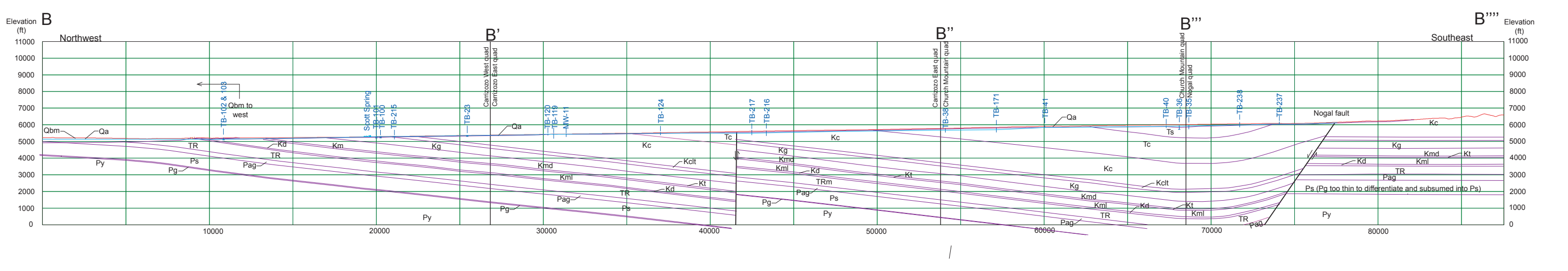
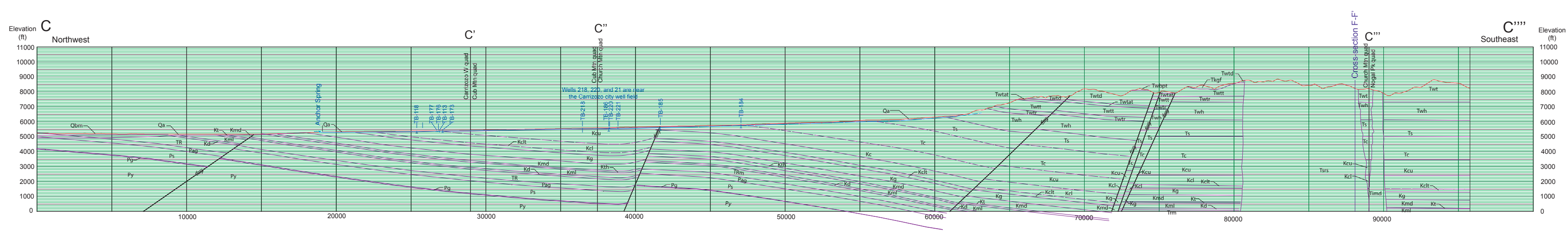
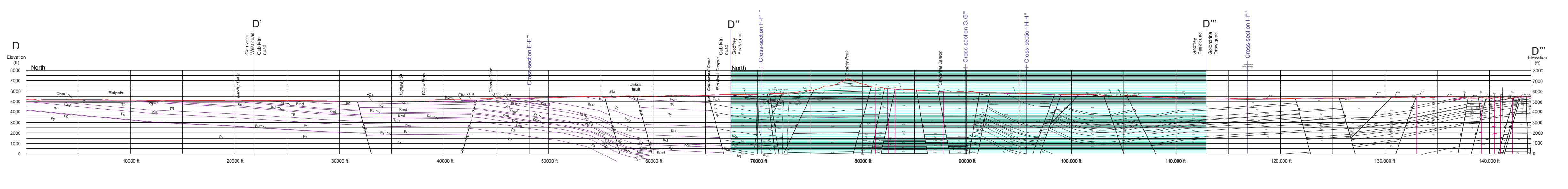
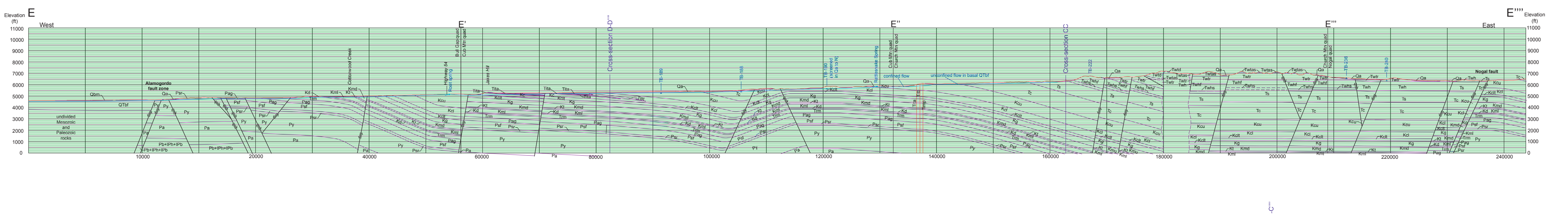
http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.html

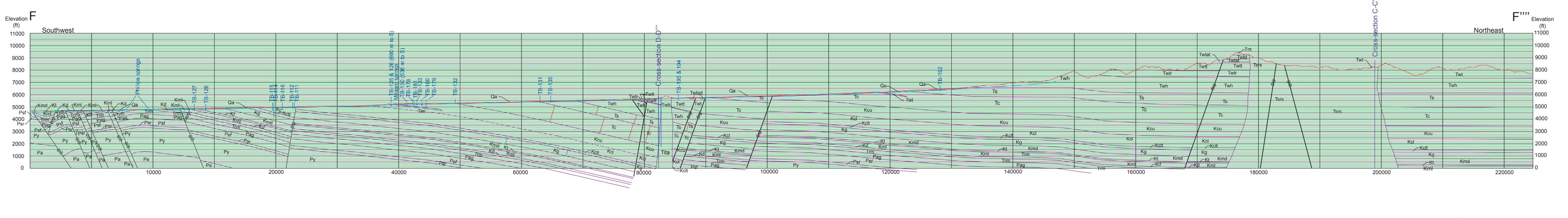


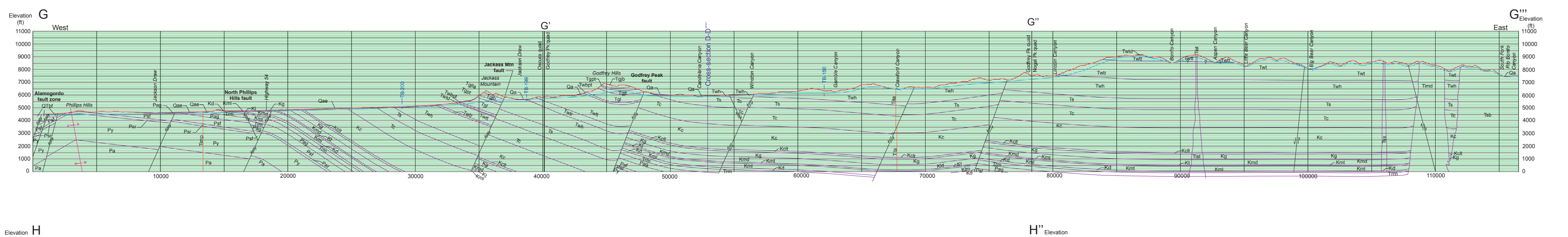


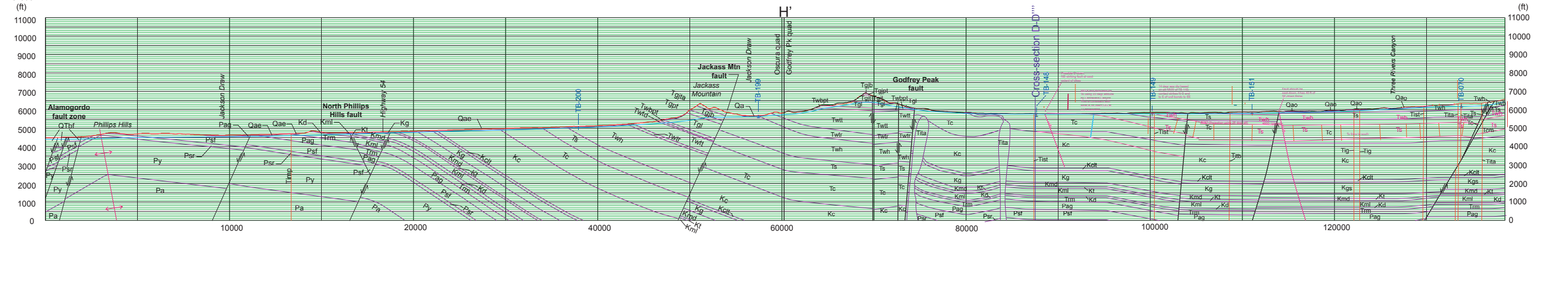


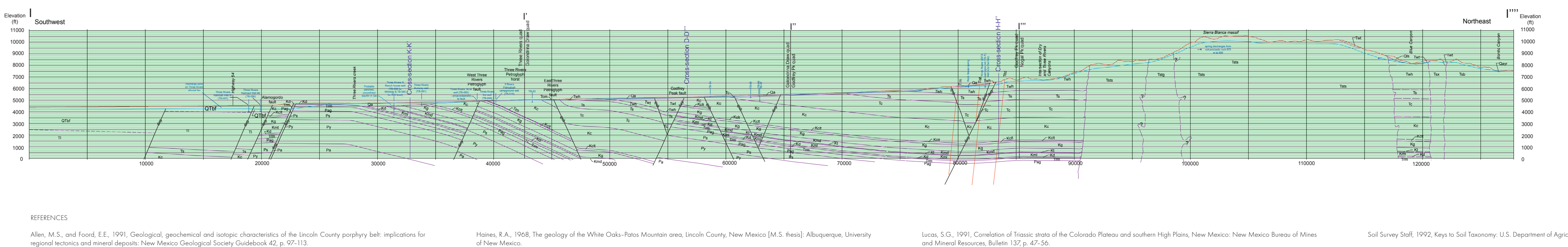












Description of Map Units

The units described below were mapped by field traverses and inspection of aerial photography. 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). Except where noted, description of sedimentary and igneous rocks was based on inspection using a hand lens. More detailed descriptions of lithology, presentation of age-related data, and discussion of depositional environments are found in the accompanying report.

For sedimentary units, a brief discussion is warranted on the difference between lithostratigraphic and allostratigraphic units. Most map units presented below are lithostratigraphic, or are 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 Quaternary lithostratigraphic units are subdivided into allostratigraphic units, which are separated by interpreted unconformable contacts or by inset relations (both representing inferred time gaps), as well as geomorphic position. Allostratigraphic units have numbers at the end of their map labels. For example, lithostratigraphic unit *Qao* is subdivided into allostratigraphic units *Qao3, Qao2, Qao1*. These allostratigraphic units possess different ages, although the sediment looks relatively similar within the overall lithostratigraphic unit (such as in *Qao*).

Surface characteristics aid in mapping Quaternary 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.

QUATERNARY–PLIOCENE SEDIMENTARY UNITS

ARTIFICIAL FILL AND EXCAVATIONS

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

HILLSLOPE AND MASS-WASTING DEPOSITS

Qct **Colluvium and talus** (middle to upper Pleistocene and Holocene)—Angular gravel and sand deposited on or adjacent to steep slopes. Sediment lacks distinctive bedding and is very poorly sorted. Gravel consists of pebbles, cobbles, and boulders. Matrix consists of sand, minor clay–silt, and is notably gypsiferous to the south. Weak to absent soil development. 1–6(?) m thick.

Qls **Landslide deposits** (upper to middle Pleistocene)—Two types of landslide deposits are present: 1) weakly consolidated, very poorly sorted, angular cobbles and boulders (minor pebbles) in a light brown matrix of very fine- to fine-grained sand (5–10% silt–clay) and minor coarser sand, up to 60 m thick; 2) large, semi-cohesive blocks derived from uphill escarpments of competent rock, 1–6 m thick.

Qdsct **Debris flows, slopewash, colluvium, and talus on steep hillslopes** (upper Pleistocene to Holocene)—Gravelly sediment on steep slopes inferred to have been deposited by debris flows or processes associated with colluvium or talus. Commonly matrix-supported. Gravel is angular and mostly consists of medium to very coarse pebbles and cobbles, but includes minor finer pebbles and boulders. Unit is commonly overlain by finer-grained slopewash deposits of clayey-silty, gravelly sand. Weakly to non consolidated. 1–10(?) m thick.

EOLIAN AND SHEETFLOOD–SLOPEWASH DEPOSITS

Qe ***Eolian sand deposits, undivided*** (middle to upper Holocene—Undivided eolian sand that is mostly brown to light brown, very fine- to medium-grained (minor coarser sand). Includes eolian sand ramps that slope away from topographic highs. Loose and several meters thick.

Qec **Coppice dunes** (upper Holocene)—Mounds of brown sand accumulated around shrubs, where dunes exceed 5% surface cover. Mounds range from 10–200 cm in height. Sand is very fine- to medium-grained (mostly fine-grained), with 1–5% coarse to very coarse, scattered sand grains. Coppice dunes overlie a bioturbated eolian sand sheet or sheetflood deposits (with a sparse pebble lag). Loose. Deposit under the dunes is up to ~2 m thick. Unit includes coppice dunes developed on sand ramps, where the entire eolian deposit may be several meters thick.

Qed **Eolian sand in dune forms other than coppice dunes** (middle to upper Holocene)—Eolian sand in mound-like deposits that extend over several meters. Dunes are 30–100 cm tall, commonly elongated NE–SW (3–30 m in length), and overlie sheetflood deposits or eolian sand sheets correlative to Qse (included with this unit). Sand is light brown to reddish-yellow and fine- to medium-grained. Loose and up to 3 m thick.

Qse **Sheetflood and slopewash deposits, commonly reworking eolian sand sheets** (middle to upper Holocene)—Light brown to brown to reddish yellow, very fine- to medium-grained sand (minor coarser-grained sand). May be composed of pale brown, clayey–silty, very fine- to fine-grained sand at the base of steep slopes. Both deposits contain minor (1–5%), scattered, very fine to coarse pebbles. A very thin pebble bed may be present at base of deposit. Internally massive with weak cumulic soil development characterized by ped development and minor gypsum accumulation. Local, very thin to thin sandy pebble lenses. Unit locally grades laterally into *Qay*. Surface commonly has a sparse lag gravel and no to weak desert pavement development. Loose to moderately consolidated. 0.2–3 m thick.

Qse/Tc **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, overlying the Cub Mountain Formation**—See descriptions for units *Qse* (above) and *Tc* (below),

Qse/Kc **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, overlying the Crevasse Canyon Formation**—See descriptions for units *Qse* (above) and *Kc* (below).

Qse/Kg **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, overlying the Gallup Sandstone**—See descriptions for units *Qse* (above) and *Kg* (below).

Qse/Kmd **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, overlying the D-Cross Member of the Mancos Shale**—See descriptions for units *Qse* (above) and *Kmd* (below).

Qse/Psf **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, overlying the Four Mile Draw Member of the San Andres Formation**—See descriptions for units *Qse* (above) and *Kmd* (below).

Qsec **Sheetflood and slopewash deposits, probably reworking a notable component of eolian sediment, with coppice dunes on the surface** (middle to upper Holocene)—Similar to unit *Qse*, but with 5% or greater surface coverage by coppice dunes. See descriptions of *Qse* and *Qec* (above).

Qsec/Qay ***Sheetflood–slopewash deposits and coppice dunes, undivided, overlying younger alluvium***—See descriptions for units *Qsec* (above) and *Qay* (below).

Qsec/Qao2 ***Sheetflood–slopewash deposits and coppice dunes, undivided, overlying the middle subunit of older alluvium***—See descriptions for units *Qsec* (above) and *Qao2* (below).

PRECIPITATE DEPOSITS

Qgy **Gypsum at the base of steep slopes west of Oscura** (upper Pleistocene to Holocene)—Gypsum in a tabular layer or possibly in an eolian sand sheet. Inferred to have been deposited by wind and then later experienced dissolution-precipitation events. 1 m thick?

Qtr **Travertine** (middle to upper Pleistocene?)—Thin to medium, tabular beds of gray to tan calcium carbonate near the western quadrangle border. Microkarst topography common on the travertine surface. Probably deposited in a series of seeps or springs during paleoclimates with higher precipitation rates than today.

qv **Quartz veins** (Oligocene)—Milky quartz precipitated in veins.

GLACIAL MORAINE AND OUTWASH DEPOSITS

Qmo **Moraine and outwash deposits near Sierra Blanca** (middle to upper Pleistocene)—Glacial moraine deposits noted by Moore et al. (1988) but not accessible for description. Outwash deposits consist of very poorly sorted boulders, cobbles, and pebbles of crystalline rocks eroded from the Three Rivers stock (Moore et al., 1988).

ALLUVIAL DEPOSITS

Qar **Recent alluvium** (0–200 years old)—Well-stratified sand and gravel (primarily pebbles and cobbles) in active drainages, where the surface has fresh bar and swale topography up to ~60 cm. Also commonly observed as small fan lobes at the mouths of recently incised arroyos, and as a veneer of laminated sand overlying *Qay* near active drainages. Occupies shallow valleys in the medial Three Rivers fan, where the sediment is primarily clay, silt, and very fine- to fine-grained sand. Soil development is very weak to non-existent. 1–3 m thick.

Qary **Recent alluvium, with subordinate younger alluvium** (Holocene)—See descriptions for units *Qar* and *Qay*. Mapped near modern drainages where *Qar* and *Qay* could not be differentiated at this map scale.

Qay **Younger alluvium** (lower to upper Holocene)—This lithostratigraphic unit includes three allostratigraphic subunits that were not differentiated at this map scale. The oldest allostratigraphic subunit, mapped adjacent to steep mountain fronts (where it disconformably overlies *Qai* or *Qao*), consists of brown pebbles and sands that are well-stratified to massive and typically fine upwards. Its topsoil is characterized by weak clay illuviation textures and a Stage II to II+ carbonate morphology underlain by Stage I gypsum accumulations.

The second-oldest allostratigraphic unit is the most laterally extensive and locally inset into the oldest allostratigraphic unit. It commonly is brownish-gray to pale brown to light yellowish-brown to light brown. Redder hues are more prevalent on the Three Rivers fan and near the base of the deposit. Sediment consists of clayey-silty very fine- to medium-grained sand interbedded with very thin to medium lenticular beds of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. Most of the clayey to silty fine sand is internally massive and pedogenically modified (marked by moderate ped development and Stage I gypsum accumulation); locally, there are minor laminations to thin beds. Scattered, minor pebbles and medium to very coarse sand are present. Top soil characterized by a calcic horizon with Stage I to II carbonate morphology.

The youngest allostratigraphic unit back-fills narrow paleovalleys cut in the second-oldest unit, and consists of pale brown to very pale brown to light brownish-gray, well-stratified sand with minor beds of pebbles. The top soil of the youngest allostratigraphic unit is marked by slight calcium and gypsum accumulation (comparable to a Stage I calcium carbonate morphology). Age control from Koning, 2009). 1–4 m thick.

Qayr **Younger alluvium, with subordinate recent alluvium** (Holocene)—See descriptions for units *Qay* and *Qar*. Mapped near modern drainages where *Qay* and *Qar* could not be differentiated at this map scale.

Qay/Qai **Younger alluvium overlying intermediate alluvium**—Generally mapped in the west–east valley north of the Godfrey Hills. See descriptions for units *Qay* and *Qai*.

Qai **Intermediate alluvium** (uppermost Pleistocene)—Unit locally seen in arroyo cuts disconformably between units *Qao* below and *Qay1* above. Sediment consists of reddish-brown, commonly clay-rich, very fine- to very coarse-grained sand and pebbly sand that is massive; pebbles occur as isolated, matrix-supported clasts and in thin, discontinuous lenses. Larger dimension gravel beds are laterally continuous, well-bedded, and clast-supported but matrix-rich; these may contain up to 10% cobbles. Locally contains gypsum rhizoliths or filaments. Topsoil marked by common, macroscopic clay illuviation textures, rare disintegrating clasts, and Stage I+ to II+ carbonate morphology underlain by Stage I gypsum accumulation. Weakly to well consolidated 1–3(?) m thick.

Qtg **Terrace gravel, undivided** (Pleistocene)—Undifferentiated terrace deposits flanking major drainages. Composed primarily of sandy pebbles–cobbles and lesser boulders. Straths located 3 to 15 m above local base level. In the southwest compilation map area, this unit was applied to thin(?), highly gypsiferous deposits overlying erosional surfaces greater than 10 m above active drainages. Generally 0.5–2.0 m thick, but locally as thick as 5 m.

Qao **Older alluvium, undivided** (Pleistocene)—Undifferentiated older alluvium recognized by its red hues, abundant gypsum, and locally well-developed, buried soils. ***To the south, rhizoliths commonly seen that are cemented by gypsum.*** There are varying proportions of gravelly channel-fills, in which gravel content decreases and sand content increases in a downstream direction; gravel dominates within 1–2 km of mountain fronts. Gravel consists of pebbles, cobbles, and minor boulders. Top soil characterized by a reddish Bw or Bt horizon (where preserved), underlain by horizons of Stage III to IV calcium carbonate and/or gypsum accumulation, with gypsum content increasing to the south. Base of unit generally not exposed. Unit is commonly overlain by younger, finer-grained sheetflood deposits, correlative to *Qse*. Well consolidated and up to 25 m thick.

Qao3 **Younger allostratigraphic subunit of older alluvium** (upper Pleistocene)—Sand and gravel inset into the middle subunit of older alluvium (*Qao2*), locally occupying paleo-valleys. Contains interfingering coarse channel-fills and finer-grained deposits that locally exhibit a coarsening-upward trend. Gravel is clast-supported, locally imbricated, gypsiferous (***but seemingly less gypsum than in units Qao2 and Qao1***), and consists of very fine to very coarse pebbles with subordinate to subequal cobbles and 1–25% boulders. Debris flow sediment is locally observed (<10% of sediment volume away from bedrock highs) and commonly has matrix-supported cobbles. Sand is mostly medium- to very coarse-grained. Coarse beds are weakly to moderately consolidated and non-cemented. Thick clay colloids commonly coat sand grains and clasts.

Finer-grained sediment is light brown (7.5 YR 6/4) to reddish-yellow (7.5 YR 6/6) to reddish-brown (5 YR 5/4), hard, gypsiferous, and composed of silty-clayey very-fine to fine-grained sand (locally with medium to very coarse sand) in thin to thick, tabular beds (also internally massive). Within the floodplain sediment are 20–25% interbeds of fine- to very coarse-grained sand and sandy pebbles; these coarse beds are very thin to thin and lenticular to tabular. There may also be up to 5–15% scattered pebbles and up to 15% scattered medium- to very coarse-grained volcanic sand. The tread of this unit lies as much as 6 m below adjacent *Qao2* surfaces.

On the surface, clast varnishing is relatively strong, and there is a well-developed desert pavement where unit is not covered by slopewash or sheetflood deposits (*Qse*). A strong gypsum horizon (comparable to a Stage III calcium carbonate morphology) is developed on top of this unit to the south, with strong Stage III to IV calcic horizons more common to the north. Locally, a reddish-yellow Bw or Bt soil horizon overlies calcic horizons. In places, such as along Willow Draw and Harkey Draw, surface erosion has resulted in a general lack of a notable calcic horizon. Weakly to well consolidated. 3–12 m-thick.

Qao2 **Middle allostratigraphic subunit of older alluvium** (middle to upper Pleistocene)—The extensive *Qao2* probably represents multiple aggradational events that were amalgamated into seemingly one deposit. Unit consists of interbedded fine-grained sediment and sandy gravel and pebbly sand, and locally exhibits a coarsening-upward trend (where the upper part consists of amalgamated or stacked channel-fills). Finer sediment consists of gypsiferous, reddish to very pale brown, very fine- to medium sand and clayey fine sand, with minor coarse- to very coarse-grained sand and pebbles (scattered or in very thin to medium lenses). Buried soils commonly have a relatively thin, slightly reddened horizon (locally with illuviated clay) underlain by a calcic horizon (Stage I to II carbonate morphology) underlain by a gypsic horizon. Locally, rhizoliths are present that are cemented by gypsum.

In coarse channel fills, gravel is dominated by pebbles but cobbles and boulders are abundant close to the mountain front. Gravel is commonly clast-supported and imbricated, but cobbly, massive debris flow beds locally fill paleochannels. Sand is mostly medium- to very coarse-grained.

Base of unit lies several meters below the base of unit *Qao1*, and its surface contains strong gypsum or calcic/gypsic horizon(s) with Stage III-IV apparent carbonate morphology. Strong clast varnish and a well-developed desert pavement where unit is not covered by slopewash or sheetflood deposits (*Qse*). Several non-differentiated erosion surfaces. Weakly to well consolidated, non-cemented. Unit grades downward into Santa Fe Group deposits west of the Alamogordo fault. Exposures are 3–15 m thick.

Qao1 **Older allostratigraphic subunit of older alluvium** (lower to middle Pleistocene)—Sandy gravel under topographic highs, locally overlying exposed bedrock, that grades westward into intercalated sandy pebbles, pebbly sand, sand, and clayey-silty sand. Finer-grained sediment appears to dominate progressively south of the Three Rivers drainage. Unit lacks the buried soils that are commonly observed in *Qao2*, typically contains coarser gravels, and is locally very gypsiferous. The unit contains a basal sandy gravel, 1–3 m thick and commonly strongly cemented, which is overlain by a coarsening-upward sequence. Sandy gravel is dominated by stream-flow facies, with lesser amounts of debris-flow facies. Gravel is mostly clast-supported, locally imbricated, and consists of pebbles with subequal to subordinate cobbles and boulders. About 1–3% of clasts disintegrate readily. Sand is mostly medium- to very coarse-grained. Debris flow sediment contains abundant cobbles and boulders that are commonly matrix-supported. Fine-grained sediment ranges from reddish to very pale brown. Clay, silt, and very fine- to fine-grained sand become increasingly common away from the mountain front. Sand in fine-grained deposits is mostly very fine- to fine-grained, with subordinate medium to very coarse grains that are commonly scattered. Base of deposit is typically >6 meters above the base of unit *Qao2*. In the south, a prevalent petrogypsic horizon developed on its surface with very strongly varnished surface clasts. In the north, top soil is characterized by strong calcium carbonate + gypsum accumulations (Stage III to IV calcium carbonate morphology). Weakly to moderately consolidated. 1–35 m thick.

QTg **High-level sandy gravels** (Pliocene to lower Pleistocene)—Sandy gravel whose base is >15 m above present drainage bottoms and above straths associated with *Qao1*. Unit not exposed, but surface gravel consist of pebbles and cobbles with 1–10% boulders. Where present, an eroded horizon of relatively large clasts is used to map the base of this terrace deposit. 1–10 m-thick.

Tbf ***Older basin fill of the Tularosa Basin, undivided*** (Miocene to lower Pliocene?)—Clayey-silty, very fine- to medium-grained sand interbedded with minor conglomerate beds, locally with minor scattered medium- to very coarse-grained sand and 1–10% pebbles. Mapped south of the Three Rivers drainage on the footwall of the Alamogordo fault. Unconformably lies beneath unit *Qao1*, and is distinguished from younger deposits by smaller gravel sizes, common calcium carbonate-impregnation of gravel beds, strong consolidation, and steeper dips. Base is not exposed. Colors of non-gravelly beds range from very pale brown to light yellowish-brown to light brown to pink. Paleosols 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, illuviated clay horizons. 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).

IGNEOUS AND VOLCANICLASTIC ROCKS

QUATERNARY

Qbm **Basalt of the Malpais** (middle Holocene)—Gray, vesicular basalt that contains 5% phenocrysts of pyroxene (0.5–2.0 mm long). Groundmass is 0.1–0.3 mm and a mix of plagioclase and pyroxene(?). Up to several meters thick.

SIERRA BLANCA AND CAPITAN INTRUSIVE ROCKS

Ti ***Intrusive rocks, undivided*** (Eocene to Oligocene)

Tirg **Rhyolite to granite** (Oligocene)—White to pale orange, aphanitic and typically aphyric, igneous rocks forming dikes, sills, and irregular igneous masses north of Nogal. Where present, phenocrysts consist of <10% quartz. Unit includes intrusion of Vera Cruz Mountain of Rawling (2011). This intrusion exhibits a core of biotite-phyric granite or syenite surrounded by aphyric trachyte and quartz-phyric trachyte. Commonly associated with faults.

Tigjb **Intrusion of brecciated, porphyritic trachyte of the Jackass Mountain Formation** (lower Oligocene)—Similar to unit *Tgjb* but in sills, dikes, or small plugs.

Timd **Monzonite to diorite** (Oligocene?)—Light gray to gray to greenish-gray, weathering tan to brown, aphanetic to medium-grained (less commonly, coarse-grained) phaneritic igneous rocks forming dikes, sills, and irregular intrusive masses. Composed of feldspar and mafic minerals, but sparse quartz may be present north of Nogal. Feldspar consists of varying proportions of plagioclase and lesser potassium feldspar. Mafic minerals may include pyroxene, amphibole and biotite.

Tirt **Rhyolite to trachyte** (Oligocene)—White to gray, aphyric to porphyritic, felsic intrusions interpreted to be of rhyolite or trachyte composition. Intrusions consist of dikes and small plugs associated with the Three Rivers stock. ***Phenocrysts include Kspar, quartz, biotite, and plagioclase. Locally, flows of aphyric rhyolite are included in this unit; these are typically flow-banded and folded and contain microphenocrysts of quartz). are included in this unit (i.e., Oak Grove rhyolite of Goff et al., 2011).*** Unit also includes fine- to coarse-grained, pale pink to pale tan dikes containing Kspar, quartz, minor plagioclase, minor biotite, and arfvedsonite (these cut the Walker Group and various syenite units).

Tid **Alkali diorite and syenodiorite** (Eocene to lower Oligocene)—Equigranular, fine- to medium-grained, salt-and-pepper textured dikes and sills with variable plagioclase feldspar and pyroxene phenocrysts. These intrusive bodies may grade into more porphyritic textures (*Tita*). Alkali diorite may contain amphibole and biotite (Moore et al., 1988).

Tist **Syenite and trachyte** (upper Eocene and lower to upper Oligocene)—This inclusive unit is applied to light-colored, intrusive rocks dominated by plagioclase and potassium feldspar. Unit occurs as stocks, sills, and dikes. Color ranges from creamy tan to creamy white to light pink to light gray to gray. Stocks and many other intrusions are commonly porphyritic, with phenocrysts composed of orthoclase and plagioclase that are 1–20 mm long. Locally, phenocrysts include hornblende and/or pyroxene. Groundmass feldspar probably includes albite, microline, and orthoclase. These feldspar grains are commonly <1 mm long, platy and stacked, producing a foliated texture. 1–25% mafic minerals 0.1–0.5 mm long, which locally include biotite and pyroxene ± amphibole. Up to 1% quartz and 1–5% possible sanidine.

Titd **Trachydacite dikes** (upper Eocene to lower Oligocene)—Light gray to light grayish-white to light reddish-gray to tan, biotite-bearing intrusions. Variably non-porphyritic to porphyritic. Phenocrysts are composed of potassium feldspar, plagioclase, and biotite. Locally, hornblende and quartz phenocrysts are observed. Equigranular varieties are common in the northwest part of the compilation map, west of Cub Mountain, where grains are 0.5–2.0 mm, subhedral, and composed of plagioclase and potassium feldspar(?), with about 25% biotite and hornblende. Unit also assigned to a prominent, ENE orientated dike south of the Three Rivers drainage, containing phenocrysts of feldspar, pyroxene, and subordinate biotite; the groundmass is aphanitic.

Timp **Dikes and other intrusions with megacrystic, aligned plagioclase** (upper Eocene)—A distinctive, light gray to dark gray intrusive rock containing about 15–20% large phenocrysts (0.1–2.0 cm long) of tabular plagioclase in an equigranular to fine-grained matrix of plagioclase and pyroxene (0.1–0.5, mostly 0.1–0.3 mm). The plagioclase laths are often distinctively aligned parallel to the margins of the dikes. Probable intrusive equivalent of megacrystic plagioclase-bearing lavas in the Rattlesnake Member of the Three Rivers Formation, which is the basis of the upper Eocene age interpretation.

Tita **Trachyandesite intrusions, including minor trachybasalt** (upper Eocene)—Porphyritic intrusive rocks that are common throughout the map area, commonly occurring as dikes or sills. These rocks are typically light gray to dark gray, locally weathering to reddish-brown to brownish-gray. Exposed rocks generally do not develop as strong a varnish as that on *Tim*. Up to 35% phenocrysts of pyroxene (0.5–10 mm-long) and feldspar (probably plagioclase, 0.5–11 mm long); locally, hornblende phenocrysts are observed. Feldspars are commonly aligned. Groundmass is composed of feldspar that ranges from 0.1–0.5 mm together with 10–35% pyroxene(?) ± biotite (0.1–0.5 mm long).

Titb **Trachybasalt intrusions** (upper Eocene)—Gray to dark gray, ***aphanetic to sparsely finely porphyritic dikes.*** Locally, these dikes are spotted. Phenocrysts, where present, consist of plagioclase. Groundmass is composed of plagioclase, olivine, clinopyroxene ± phlogopite.

Tim **Megacrystic, alkali gabbro–diorite or syenogabbro–diorite intrusions** (middle? to upper Eocene)—Dark gray to gray to greenish-gray, porphyritic hypabyssal rocks occupying sills, dikes, and laccoliths. ***Groundmass is 0.2–0.5 mm, less commonly to 1.0 mm, and consists of plagioclase with 15–25% pyroxene and local hornblende. Rock has 2–25% phenocrysts composed of hornblende ± pyroxene (up to 20–60 mm long) and 5–20% smaller plagioclase. Groundmass consists of plagioclase with subordinate, but variable, amounts of mafic minerals and plagioclase (mostly 0.1–0.5 mm in size). Near Sierra Blanca, the groundmass contains hornblende ± biotite and xenolithos of pink, coarse-grained syenite may be present.*** Exposed rock commonly develops a strong to very strong varnish.

STOCKS

Tsb **Bonito Lake syenite to syenodiorite** (lower Oligocene)—Gray to salt-and-pepper, medium- to coarse-grained syenite in northeast map area; contains plagioclase, Kspar, minor quartz (≤2%), biotite, hornblende and clinopyroxene (Thompson, 1972; Black, 1978; Constantopoulos, 2007). Margins of intrusive body are generally dioritic containing more plagioclase and mafic minerals than core syenite; commonly contains aplite dikes about 0.1–0.5 m wide. K-Ar date on biotite is 26.6 ± 1.4 Ma (Thompson, 1972); U/Pb date is 27.3 ± 0.04 Ma; maximum exposed thickness [illegible]

Tstg **Three Rivers alkali granite** (lower Oligocene)—Fine- to medium-grained, equigranular to slightly porphyritic, pale gray to salt-and-pepper granite composed of Kspar, quartz, and minor plagioclase. Mafic minerals consist of biotite ± arfvedsonite ± aegirine. Some areas contain sparse larger crystals of alkali feldspar. Some zones contain essentially no mafic minerals. Rb–Sr age (whole rock) from unknown site is 26.7 ± 1.2 Ma (Moore et al., 1991); preliminary ^{40}Ar/^{39}Ar date on arfvedsonite from body at top of eastern chair lift, Ski Apache is 27 ± 2 Ma. Maximum exposed thickness is ≥ 700 m.

Tsts **Three Rivers syenite** (lower Oligocene)—Light gray, very coarse-grained syenite consisting primarily of large gray Kspar (anorthoclase) surrounded by small interstial Kspar and quartz, aegirine, arfvedsonite, no apparent plagioclase; a zone of more quartz-rich syenite is found on the east margin of the unit; sporadically contains ≤10 cm enclaves of fine-grained rock; intruded by thin porphyritic dikes of containing Kspar and clinopyroxene phenocrysts and unidentified blue and purple minerals (fluorite?); various units not dated; maximum exposed thickness about 650 m.

Tstag **Three Rivers quartz syenite to alkali granite** (lower Oligocene)—Highly variable, but voluminous unit of medium-grained, light gray to bluish-gray, equigranular to porphyritic, quartz syenite to granite; syenite is dominant; contains Kspar (often large and distinctly blue–gray) partly rimmed by other feldspar; blue–gray phenocrysts are most plentiful at higher elevations and western margin in the unit; plagioclase sparse to absent; quartz sparse, minor arfvedsonite, aegirine, and/or biotite; K-Ar date on biotite is 28.1 ± 1.7 Ma (Moore et al., 1988); preliminary ^{40}Ar/^{39}Ar date on Kspar from west contact in Three Rivers canyon is 28.24 ± 0.19 Ma; maximum exposed thickness is ≥ 850 m.

Tsrqd **Rialto monzonite** (lower Oligocene)—Secondary intrusive phase of Rialto stock consisting of white to gray, weakly porphyritic, fine-grained quartz diorite having phenocrysts of plagioclase in groundmass of plagioclase, minor Kspar, euhedral biotite, hornblende, and small quartz. Occurs as NE-trending dikes and possible sills that intrude Rialto syenite and Walker Group volcanic rocks. U/Pb date of 31.8 ± 0.5 Ma; maximum exposed thickness about 280 m.

Tsrs **Rialto syenite** (lower Oligocene)—Initial intrusive phase of Rialto stock; greenish-gray, medium- to coarse-grained syenite containing plagioclase, Kspar, and sparse anhedral quartz; mafic minerals consist of clinopyroxene, hornblende and biotite. K–Ar date on hornblende is 31.4 ± 1.3 Ma (Thompson, 1973); maximum exposed thickness is 300 m.

Tsx **Breccia associated with stocks** (lower Oligocene)—Angular to subrounded blocks of fine-grained syenite and Walker Group porphyritic to aphanitic lavas and tuff included within the intrusive rocks near the margins of the stock. The breccia is particularly common in the Rialto stock. Up to 15 m thick.

Tifg **Feldspathoidal gabbro (essexite) with nepheline** (lower Oligocene)—Plug of dark gray to splotchy black and white, feldspathoidal gabbro (essexite; Williams et al., 1954; Moore et al., 1988), Contains large (≤3 cm) phenocrysts of potassium feldspar and plagioclase in an altered, medium-grained groundmass of nepheline, clinopyroxene, olivine, biotite, and magnetite. Intrudes Walker Group lavas and breccias. Maximum exposed thickness is 185 m.

SIERRA BLANCA VOLCANIC FIELD EXTRUSIVE AND VOLCANICLASTIC ROCKS

The stratigraphy developed by Thompson (1964, 1972) was revised during this project. A full description of the revised stratigraphy is presented in the report that accompanies this map.

GODFREY HILLS GROUP

This unit appears to overlie an unconformity developed at about the stratigraphic level of the Bucky Pasture Tuff. Includes the 28.2 to 28.8 Ma Jackass Mountain Formation and the 28.8 to 34.3 Ma Lopez Spring Formation.

Tgjvs **Volcaniclastic sediment of the upper Jackass Mountain Formation** (lower to upper Oligocene)—Consists of a lower and an upper unit. The upper unit is a heterolithic landslide deposit with a white ashy matrix that contains large (1–5 m) angular boulders of porphyritic trachyandesite, Palisades Tuff, and trachyte 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. Locally preserved vitric, lithic tuff interbedded with the lower sediment has an ^{40}Ar/^{39}Ar date of 28.23 ± 0.06 Ma. 30 m thick.

Tgjta **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. 50 m thick.

Tgjbt **Biotite trachyte within trachyte to trachyandesite flows of the Jackass Mountain Formation** (lower Oligocene)—Flow of trachydacite with biotite set in a sugary matrix interbedded with *Tgjta*. At one locality on the east side of Jackass Mountain, this unit consists of altered tephra (< 1 cm) overlain by an ignimbrite with feldspar, altered mafics, and granular-sized rock fragments. ^{40}Ar/^{39}Ar date is 28.60 ± 0.05 Ma. 1–10 m thick.

Tgjb **Brecciated, porphyritic trachyte of the Jackass Mountain Formation** (lower Oligocene)—Light gray trachyte lava flows with phenocrysts of sanidine and pyroxene interbedded with monolithologic breccia with subround to angular clasts in a light gray matrix. ^{40}Ar/^{39}Ar ages of 28.59 ± 0.05 Ma and 28.53 ± 0.03 Ma were obtained from sanidine in the unit. Trachyte lava flows that are similar to *Tgjb* flows are present between Godfrey Peak and Maverick Spring, but this lava contains biotite in addition to sanidine and pyroxene. This lava is separated from the overlying *Tgjb* flows by a distinct, mappable flow break. 60–140 m thick.

Tgjpt **Palisades Tuff Member of the Jackass Mountain Formation** (lower Oligocene)—Cliff-forming welded tuff with pronounced eutaxitic foliation and taphony weathering texture. 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. 25–90 m thick.

Tgjt **Biotite trachydacite flow of the Jackass Mountain Formation** (lower Oligocene)—Cliff-forming succession of light gray flow-banded lava flows and flow breccias of trachydacite with ~10% phenocrysts of plagioclase, biotite, and pyroxene. ^{40}Ar/^{39}Ar date is 28.78 ± 0.04 Ma. 60–70 m thick.

Tgl **Lopez Spring Formation, undivided** (lower Oligocene)—Interval of thin to thick (1–10 m) discontinuous trachyte, porphyritic trachyandesite, biotite trachydacite, and trachybasalt flows complexly intercalated with volcaniclastic sediments. Some exposures of volcaniclastic sediment are dominated by biotite-bearing trachydacite clasts. Unit includes a thick (up to 85 m) flow of fine-grained trachyandesite in the southeastern Godfrey Hills, containing small phenocrysts of hornblende, pyroxene, and clusters of potassium feldspar. Irregular base fills in paleovalleys. Radiometric dating returned ^{40}Ar/^{39}Ar ages of 31.05 ± 0.76 Ma and 30.04 ± 0.2 Ma (the latter is from a trachydacite cobble in volcaniclastic sediments). 200–220(?) m thick.

Tkgf **Kountz Canyon and Gaylord Peak flows** (lower Oligocene?)—The Kountz Canyon flow is a crystal-rich (15–20%) porphyritic flow with distinctive zoned, blocky potassium feldspar phenocrysts that are dark gray at the center and white on the rim. This flow was deposited on a rugged paleotopography. Up to 25 m thick. The Gaylord Peak flows are porphyritic lavas with potassium feldspar and green pyroxene; the pyroxene commonly forms in clusters. The feldspar phenocrysts have a bimodal range of grain sizes. Maximum thickness of the flows is 200 m.

Tnpt **Nogal Peak trachyte** (lower Oligocene)—Gray, slightly porphyritic to aphyric lavas with intercalated flow breccia, as well as minor volcaniclastic sediment. Includes an aphanitic to sparsely porphyritic (<2%) lava capping a hill with a spot elevation of 8,594 ft along the Pennsylvania trail. West and southwest of Nogal Peak, the unit consists of a single flow of gray, slightly porphyritic, medium- to fine-grained lava containing phenocrysts of plagioclase in a trachytic matrix. ^{40}Ar/^{39}Ar date of 31.41 ± 0.38 Ma was determined from a trachydacite that overlies the "high country" tuff on a ridge north of Nogal Peak in the headwaters of Norman Canyon. Maximum exposed thickness of flow is ≤35 m.

Tcp **Church Mountain phonolite** (lower Oligocene)—Gray crystal-rich flows containing variable lithic content and sparse pumice. Phenocrysts are dominantly potassium and plagioclase feldspar with minor biotite and amphibole. Lithics are generally pebble-sized and sparse to absent, but locally constitute up to 10% of outcrops. Pumice is sparse to absent, fine pebble in size, and flattened. Included in this unit are interbedded volcaniclastic sediments and fine grained lava flows. Samples submitted for radiometric analyses from bottom and top of unit returned ^{40}Ar/^{39}Ar ages of 32.70 ± 0.10 Ma and 32.72 ± 0.16 Ma, respectively. Biotite from the lower sample returned a ^{40}Ar/^{39}Ar age of 32.95 ± 0.12 Ma.

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.***

Twbpt **Buck Pasture Tuff Member of Three Rivers Formation** (upper Eocene)—Welded to unwelded lithic-rich tuff. The lithic fragments are angular pieces of trachytic lavas. The phenocrysts are sanidine, plagioclase, biotite, and pyroxene. The tuff contains mafic clots that are flattened near the base and that are rounded to embayed, but more equant, upsection. In places a thin bed of lithic-bearing tuff similar to the Buck Pasture Tuff is preserved about 15–20 m below the main exposures. ^{40}Ar/^{39}Ar sanidine date is 34.28 ± 0.05 Ma on exposures in the Godfrey Hills. The "high country" tuff overlain by Nogal Peak Trachyte on Nogal Peak is similar to the exposures in the Godfrey Hills and is interbedded in the Double Diamond Formation. 0–60 m thick.

Twtd **Double Diamond Member of Three Rivers Formation** (upper Eocene, possibly lower Oligocene)—Intercalated plagioclase-phyric porphyry lavas, plagioclase- and amphibole-phyric porphyry lavas, and pebble to locally boulder conglomerates. A trachyandesite at Spring Point that is just above Argentina Spring Tuff gave a ^{40}Ar/^{39}Ar date of 35.32 ± 0.16 Ma. Up to ~280 m thick in the area of Diamond Peak.

Twtat **Argentina Springs Tuff Member of the Three Rivers Formation** (upper Eocene)—A lithic-rich, plagioclase-phyric, flow-foliated (rheomorphic) ignimbrite. The ignimbrite intervals are black to gray to yellowish-tan, slightly welded to densely welded, and lithic-rich, with flattened pumice (fiamme) with a maximum aspect ratio of ≥25:1. Lithic fragments consist of white chert to fine-grained sandstone and a variety of light to dark-colored volcanic rocks, including syenitic rocks. There appears to be a volcaniclastic sedimentary interval between two zones of strongly foliated lithic-rich ignimbrite. ^{40}Ar/^{39}Ar date is 36.06 ± 0.70 Ma. Unit is 40–120 m thick.

Tws **Spring Canyon trachydacite** (upper Eocene)–Thick, cliff-forming lava of aphyric, flow-banded trachydacite. Contains very sparse, small phenocrysts of plagioclase in a felty groundmass of tiny plagioclase, clinopyroxene, biotite, and magnetite; some specimans are spotted with clots of tiny plagioclase. Formerly called "trachyandesite of Spring Canyon" by Thompson (1972, 1973). Maximum exposed thickness near vent is 110 m.

Twtt **Taylor Well Member of the Three Rivers Formation** (upper Eocene)—Dark gray fine-grained 1–4 m thick lava flows characterized by a silvery sheen and splotches on weathered surfaces. Flows are discontinuous and are intercalated with red, altered volcaniclastic sedimentary rocks. A trachybasalt in this unit has an imprecise ^{40}Ar/^{39}Ar date of 37.84 ± 0.48 Ma. The top of the Taylor Well Member on the Sierra Blanca massif contains a thick, extensive flow, the Spring Canyon trachydacite (^{40}Ar/^{39}Ar 36.87 ± 0.13 Ma), that is petrologically and chemically distinct from underlying strata. Total thickness up to 365 m.

Twtr **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%). The basal contact with the underlying Hog Pen Formation volcanic breccia is gradational. The contact between the plagioclase-phyric trachyandesite and the trachybasalt units is locally marked by a distinctive crystal-rich lava flow with large (1–2 cm) elongate plagioclase laths. 150 m thick.

Twh **Hog Pen Formation** (middle? to upper Eocene)—Green to red volcaniclastic to volcanic unit containing flow breccia, debris flows, mudflows, lava flows, and red sandstone to sandy conglomerate. The flow breccia 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. Typical debris flow clasts are 5 to 20 cm in diameter, although some are >1 m across. ^{40}Ar/^{39}Ar hornblende dates from near the base of the unit are 36.57 ± 0.21 to 37.01 ± 0.10 Ma. 120–180 m.

SEDIMENTARY ROCKS THAT PRE-DATE THE SIERRA BLANCA VOLCANIC FIELD

Ts **Sanders Canyon Formation** (middle Eocene)—Interbedded, reddish-gray to reddish-brown floodplain deposits and light gray, sandy channel-fills. The average sandstone/mudstone ratio of this fluvial unit is about 30:70 (Cather, 1991) and decreases up-section. ***The unit appears to be finer-grained west of Cub Mountain than it is to the southeast.*** Although tongues of this formation are interbedded in the Cub Mountain Formation, this unit is only mapped where it overlies the entire Cub Mountain Formation. Channel-fills occupy vague, tabular beds <35 cm thick and contain up to 1% pebbles and lesser cobbles-boulders of plagioclase-phyric andesite. Sandstone petrologic study by Cather (1991) gives ranges of: 31–65% volcanic rock fragments (including 0.5–2% biotite grains), 8–41% twinned plagioclase, 7–31% quartz (decreasing up-section), 0–7% microline and orthoclase, 0–4% granite and gneiss rock fragments, 0–3% chert, 0–2% metamorphic rock fragments, and 0–2% sandstone rock fragments. Floodplain sediment consists of claystone, siltstone, mudstone, and very fine- to fine-grained sandstone. Generally, the basal mapped contact is probably conformable. North of Barber Ridge, the upper 50–100 m of this unit consists of light gray to maroon, generally massive mudstone and clayey-silty very fine to fine-grained sandstone. Unit is sharply and irregularly overlain by volcanic conglomerates of the Hog Pen Formation (*Twh*). Well to moderately consolidated and weakly cemented by calcium carbonate; generally a slope-former. About 120 m of this unit is exposed northwest of Nogal Peak, but the total thickness there may possibly be as much as 400 m. Unit thins to the south, and is not observed south of the Three Rivers drainage.

Tc **Cub Mountain Formation** (lower to middle Eocene)—White to pale yellow to light reddish-gray, arkosic channel-fill sandstones interbedded with red, reddish-brown, or reddish-pinkish-gray floodplain deposits of mudstone and very fine- to fine-grained sandstone. Sandstone petrologic study by Cather (1991) gives ranges of: 50–70% quartz, 3–15% microline and orthoclase, 2–16% granite and gneiss rock fragments, 5–11% volcanic rock fragments, 1–9% chert, 0–9% metamorphic rock fragments, 0.5–6% twinned plagioclase, and 0–3% sandstone rock fragments. Locally, very coarse sand and pebbles are present in the channel-fills, composed of quartz + quartzite, rhyolite, and chert. Floodplain deposits consist of claystone, mudstone, siltstone, and very fine- to fine-grained sandstone. The slightly coarser texture of the sand (mostly medium-grained), more "pockety" outcrop appearance, and reddish fine-grained sandstone beds serve to distinguish this fluvial unit from the underlying Crevasse Canyon Formation. The unit differs from the overlying Sanders Canyon Formation by its general lack of light gray channel-fills and lesser amounts of volcanic detritus in its sand fraction (less than 20%). Locally, there are undifferentiated tongues of Sanders Canyon Formation in the middle to upper part of the Cub Mountain Formation. These tongues are typically composed of light gray, fine- to medium-grained sandstone that have 20% lithic fragments + mafic grains (including abundant biotite). Base of unit defined at the top of the paleosol developed on the underlying Crevasse Canyon Formation (described below). Thickness range of 370–570 m.

Kc **Crevasse Canyon Formation** (Upper Cretaceous)—Intercalated channel-fill sandstones and floodplain deposits. This fluvial sediment differs from the overlying Cub Mountain Formation by its yellowish-greenish floodplain deposits and slightly finer sand in channel-fills. Unit coarsens up-section. Upper 250–270 m of unit contains ~subequal (±20%) sandstone–mudstone. Sandstone is white to pale yellow to olive-yellow to light gray, commonly weathering to yellow-orange, and fine- to coarse-grained (mostly fine- to medium-grained, except in the upper part of the unit). Channel-fill pebbles occur near top of unit. Coarse channel-fills are mostly cemented by calcium carbonate (Cather, 1991). Floodplain sediment consists of mudstone, siltstone, and very fine-to fine-grained sandstone; coal seams are locally common and generally up to 30 cm thick. Upper contact mapped at the top of a distinctive, 3–8 m thick paleosol(s) composed of a light gray to light grayish-green, massive (bioturbated) sandstone with 10–15% irregular, dark purple to purplish-black concretions of manganese oxide(?).

Mudstone and shale floodplain deposits dominate in the lower 280–300 m of this unit. Floodplain deposits consist of gray to dark gray to greenish-gray, fissile to blocky shale and mudstone. Estimate 1–5% coal beds or organic-rich mudstone beds that are generally less than 1 m thick. Locally, iron oxide (siderite?) concretions are present. Sandstone channel-fills are 1–5 m thick and pale yellow to yellow. Basal contact is drawn at the uppermost, shell-bearing bed of unit *Kclt*. Total thickness 550 m.

Kclt **Transitional terrestrial–marine unit in the lower Crevasse Canyon Formation** (Upper Cretaceous, Coniacian Stage)—Lower 18–28 m consists of interbedded gray shale and minor yellow sandstone and coal beds; this is correlated to the Dilco Member (Crevasse Canyon Formation). Upper 24–45 m is correlated to the Dalton Sandstone (Crevasse Canyon Formation); it is composed primarily of pale yellow, fine- to medium-grained sandstone that locally contains marine invertebrate fossils (including oysters). Base of Dalton Sandstone contains hummocky cross-stratification (1 m thick or less) underlain by ~1 m of bioturbated sandstone. Top contact is drawn at the uppermost thick, calcareous, orangish, fine-grained sandstone to sandy limestone bed containing shell fossils (including oysters). Lower contact is drawn at the lowermost occurrence of coal. Coal is seldom exposed, so base is commonly drawn just above the topmost ledge of Gallup Sandstone. 40–70 m-thick.

Kg **Gallup Sandstone** (Upper Cretaceous, lower Coniacian Stage)—Nearshore sandstone tongues interbedded with light gray to gray, fissile, marine shale intervals. In a given sandstone tongue, strata progress upwards from 1–2 m of bioturbated sand to 1–2 m of hummocky cross-stratified sand to several meters of tangential cross-stratified (up to 60 cm thick foresets) and horizontal-planar laminated sand. Sand is white to pale yellow to yellow and very fine- to medium-grained (mostly fine- to medium-grained). Top of sandstone beds locally contain paleo-burrows. Oyster shells are abundant locally. The top bed of the upper sandstone tongue, underlying the coal-bearing Dilco Member of the Crevasse Canyon Formation, is generally thick, tabular, and composed of a distinctive fine- to medium-grained, bioturbated, quartzose sandstone. Base of unit grades downward into the D-Cross Tongue of the Mancos Shale; basal contact drawn at the bottom of the lowest 2 m thick (or greater) sandstone tongue displaying the aforementioned shallowing upward cycle. Degree of cementation is highly variable. An oyster called *Flemingostrea elegans* is unique to the Gallup Sandstone and confirms lithostratigraphic correlations to this formation (Hook, 2010). 100–130 m thick.

Km ***Mancos Shale, undivided*** (Upper Cretaceous, middle Cenomanian(?) to lowest Coniacian Stage)—Gray to light gray to light olive-gray, fissile shale. Metamorphosed to a black to gray argillite adjacent to laccoliths.

Kmd ***Mancos Shale, D-Cross Tongue Member*** (Upper Cretaceous, middle Turonian to lowest Coniacian Stage)—Dark gray to greenish-gray to pale yellow, 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. 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. Unit is gradationally overlain by the Gallup Sandstone and underlain by the Tres Hermanos Formation. 100–120 m thick.

Kml **Lower tongue of Mancos Shale** (upper Cretaceous, middle Cenomanian to middle Turonian Stage)—Hard, calcareous shale; gray to very dark gray, weathering to gray to light gray to light yellowish-brown. Lower part of unit includes several bentonite layers. Up-section is an interval of three closely spaced, medium- to thick-bedded (<50 cm thick), tabular limestones that are dark gray, weathering to light gray, and micritic. These limestones are separated by less than 1 m of shale and correlated with the ***Bridge Creek Limestone beds***. Unit is gradationally overlain by the Tres Hermanos Formation. The basal Mancos Shale contains thin sandstone beds and grades downward into the Dakota Sandstone. 100 m(?) thick.

Kt **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, and Hook, in press). 10–60 m thick, thinning to the northeast.

Kd **Dakota Sandstone** (upper Cretaceous, Cenomanian(?) Stage)—Ledge-forming, fine- to coarse-grained, quartz arenite sandstone. Fresh colors range from white to light purplish-white. Exposed sandstone tends to develop a strong purplish-black to dark brown desert varnish. Minor (<15%) interbeds of light gray siltstone. Very fine to very coarse pebble-conglomerate beds occur near the base of unit (~1% estimated volume) as very thin to medium lenses. Coarse- to very coarse-grained sand is more common near the base of the unit (but still less than 10% of volume). Coarse sand grains and pebbles are composed of rounded quartzite, quartz, chert, and 0.5–1% metarhyolite. Interbeds of light gray siltstone, very fine-grained sandstone, and light to dark gray shale become increasingly common up-section. Uppermost sandstone beds are extensively burrowed and include ***Ophiomorpha***. The lower contact is a scoured unconformity locally filling paleovalleys, and the upper contact grades conformably into the lower tongue of the Mancos Shale. Top contact placed at top of upper quartz arenite sandstone with ***Ophiomorpha*** burrows. Sandstone beds are well-cemented. Mostly 35–50 m thick, but thickness values of 60 m reported by Smith (1964) and Haines (1968).

Ꞧ ***Triassic, undivided***—Mapped in the subsurface in the Carrizozo area, where Triassic formations younger than the Moenkopi may be present.

Ꞧm **Moenkopi Formation** (middle Triassic, lower Anisian Stage)—Chocolate brown to reddish-brown, fluvial, interbedded sandstone and pebbly sandstone channel-fills and floodplain deposits. Extra-formational clasts are composed of quartz, chert, quartzite, and metarhyolite(?); sparse intra-formational clasts are composed of limestone. Sand is generally a litharenite with variable mica content. Both sandstone and conglomerate beds frequently contain mud rip-up clasts. Floodplain deposits are composed of mudstone, siltstone, and very fine- to fine-grained sandstone. Lower contact is a planar to scoured unconformity over the Artesia Group (scour relief of 1–3 m). Unconformably overlain by the Dakota Sandstone. Approximately 30–70 m thick.

Pag **Grayburg Formation, Artesia Group** (upper Permian, upper Guadalupian North American Stage)—Very fine- to fine-grained, quartz arenite sandstone and silty to clayey very fine- to fine-grained sandstone; subordinate siltstone and shale. Colors range from orange to red to light red to reddish-brown (most to least common). Commonly bioturbated, although very locally laminations and ripple-marks can be observed. Reduction (bleached) spots 0.5–2 mm in diameter cover 1–15% of rock area, with higher coverage along bedding and fault planes (where they are decimeter-scale and irregular). No fossils observed. Thick gypsum or anhydrite beds are absent to the north but increase to the south (to about 5–10% of the unit; more common toward the top). Orangish color, fine texture, and quartz arenite composition serve to differentiate this unit from the overlying Moenkopi Formation. Lower contact with San Andres Formation is a disconformity (***Figure 3***). Wells near Three Rivers indicate a thickness of 90–110 m, although to the north the unit may be 130 m thick.

Ps ***San Andres Formation, undivided*** (lower to upper Permian, Leonardian to Guadalupian North American Stage)—Undivided limestone, dolomite, and anhydrite strata. Dolomite and anhydrite are more common up-section. Unit deposited in a shallow-marine setting. The San Andres Formation was ***generally subdivided into the Fourmile Draw Member, the Hondo Sandstone, and the Rio Bonito Member;*** these units are described below. 240–250 m thick, based on subsurface data for wells in the Three Rivers area.

Psf **Fourmile Draw Member** (upper Permian, Guadalupian North American Stage)—Micritic, dark gray limestone, grayish-tan to light gray dolomite, and gypsum or anhydrite. Beds are medium to thick and tabular. Carbonates become more dolomitic up-section, and the proportion of evaporite beds increases up-section. Base of member drawn at the lowest anhydrite bed. Local paleokarst breccias. Approximately 100–120 m thick.

Psh **Hondo Member** (upper Permian, Guadalupian North American Stage)—Tannish-white to yellowish-tan, fine- to medium-grained, quartzose sandstone. Less than 5 m thick.

Psr **Rio Bonito Member** (upper Permian, Guadalupian North American Stage)—Medium to dark gray, generally micritic limestone and minor dolomite. Bedding is thin to thick and tabular. Thick bed(s)of tannish-white to yellowish-tan, fine- to medium-grained, quartzose sandstone up to 2 m thick is present near top (3–10 m below upper contact) and base of unit, correlated to the Hondo Sandstone. Unit deposited in a shallow marine setting. ~60 m thick.

Py **Yeso Formation** (lower Permian)—Very pale reddish-brown to light brown and composed predominantly of gypsum with minor limestone/dolomite. Gypsum is faintly laminated in places, though bedding is usually contorted. Limestone beds are less than 0.3 m thick, are dark brown-gray in color and appear to be intensely bioturbated. No fossils were observed. Thickness not well constrained, but possibly up to 300 m.

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