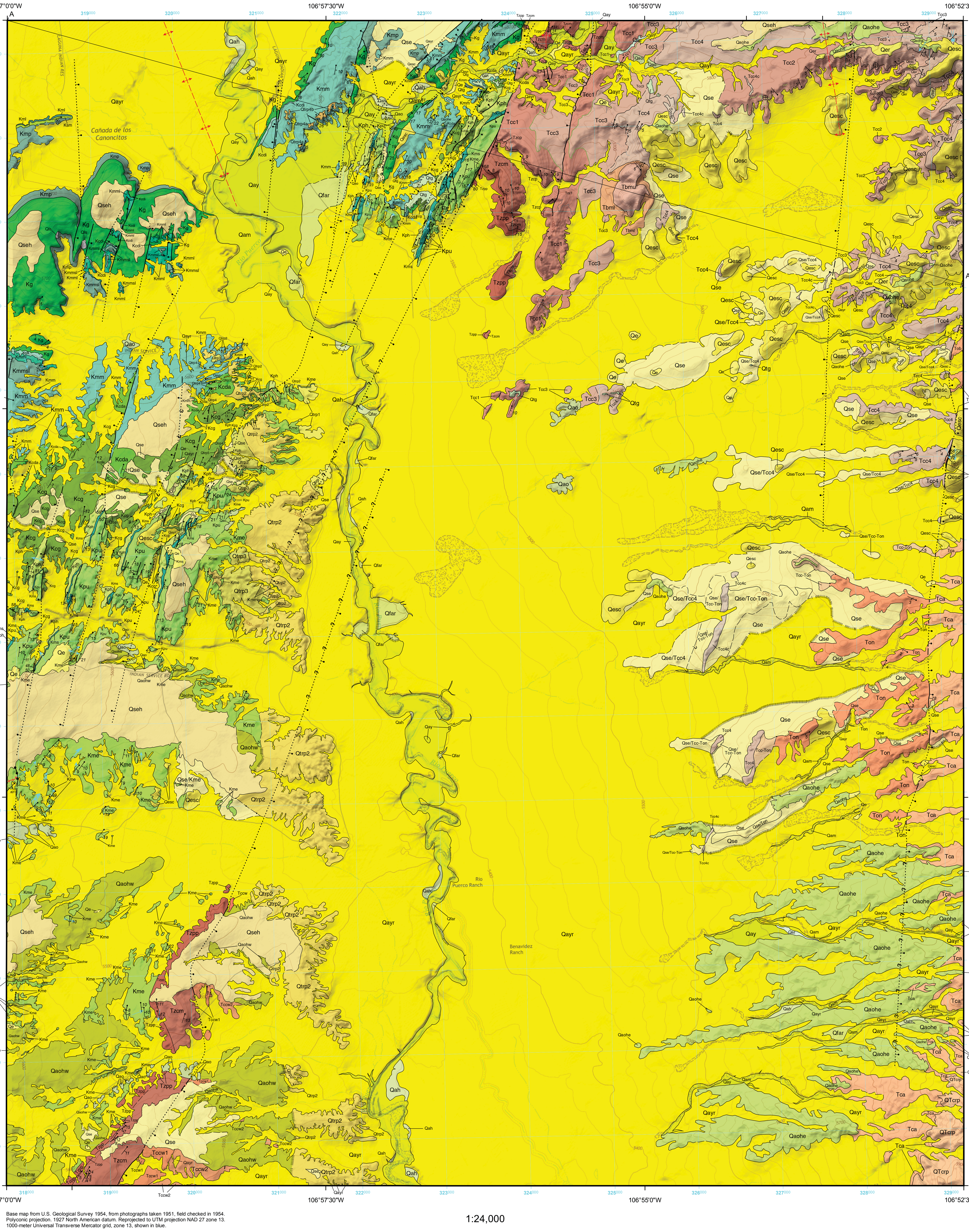

Base map from U.S. Geological Survey 1954, from photographs taken 1951, field checked in 1954. Polyconic projection. 1927 North American datum. Reprojected to UTM projection NAD 27 zone 13. 1000-meter Universal Transverse Mercator grid, zone 13, shown in blue.

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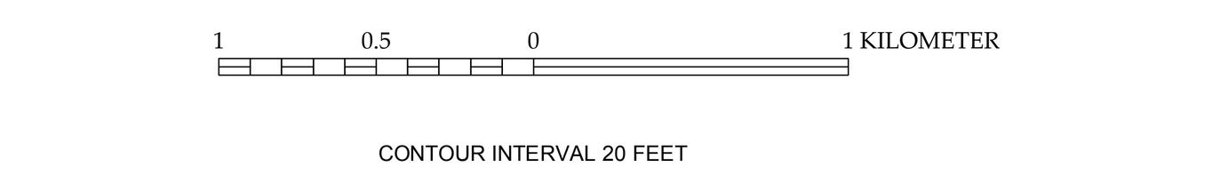
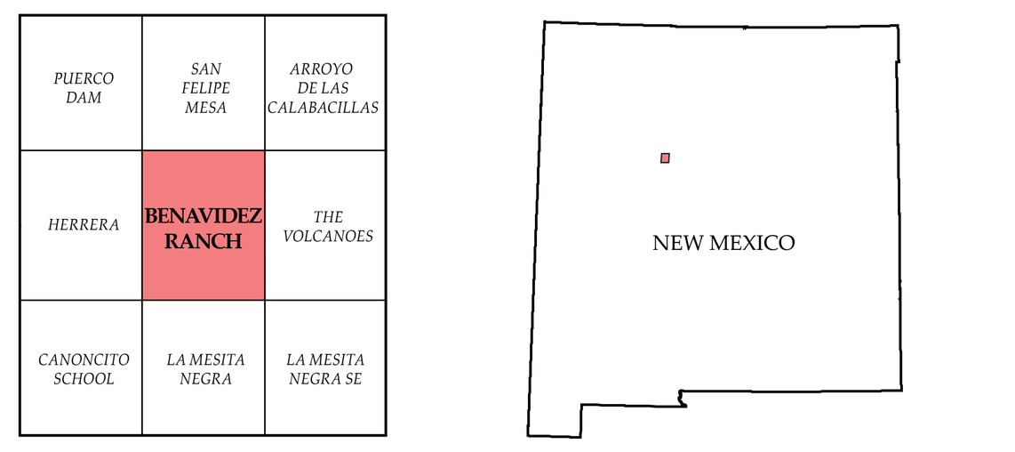
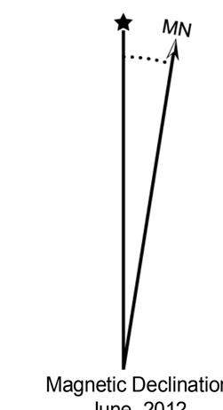


CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



Quadrangle Location



Magnetic Declination
June, 2012
9.24655° East
At Map Center

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
801 Leroy Place
Socorro, New Mexico
87801-4796

[575] 835-5490

This and other STATEMAP quadrangles are available for free download in both PDF and ArcGIS formats at:

http://geoinfo.nmt.edu

New Mexico Bureau of Geology and Mineral Resources
Open-file Geologic Map 234

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Geologic Map of the Benavidez Ranch 7.5-minute Quadrangle, Bernalillo and Sandoval Counties, New Mexico

June, 2014

by
Daniel J. Koning and Andrew P. Jochems

New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801

This draft geologic map is preliminary and will undergo revision. It was produced from either scans of hand-drafted originals or from digitally drafted original maps and figures using a wide variety of software, and is currently in cartographic production. It is being distributed in this draft form as part of the bureau's Open-file map series (OFGM), due to high demand for current geologic map data in these areas where STATEMAP quadrangles are located, and it is the bureau's policy to disseminate geologic data to the public as soon as possible.

After this map has undergone scientific peer review, editing, and final cartographic production adhering to bureau map standards, it will be released in our Geologic Map (GM) series. This final version will receive a new GM number and will supercede this preliminary open-file geologic map.

DRAFT

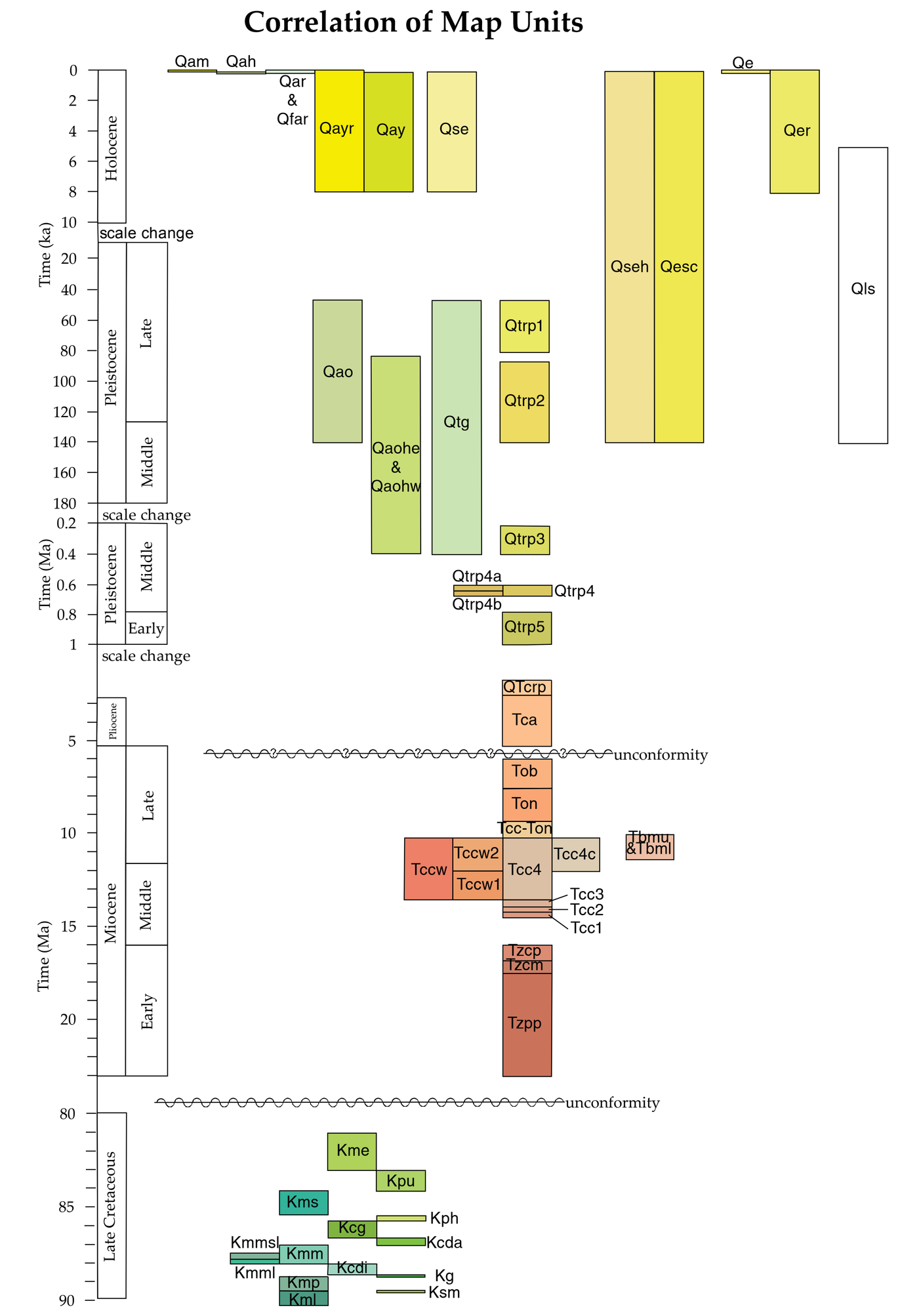
Comments To Map Users

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

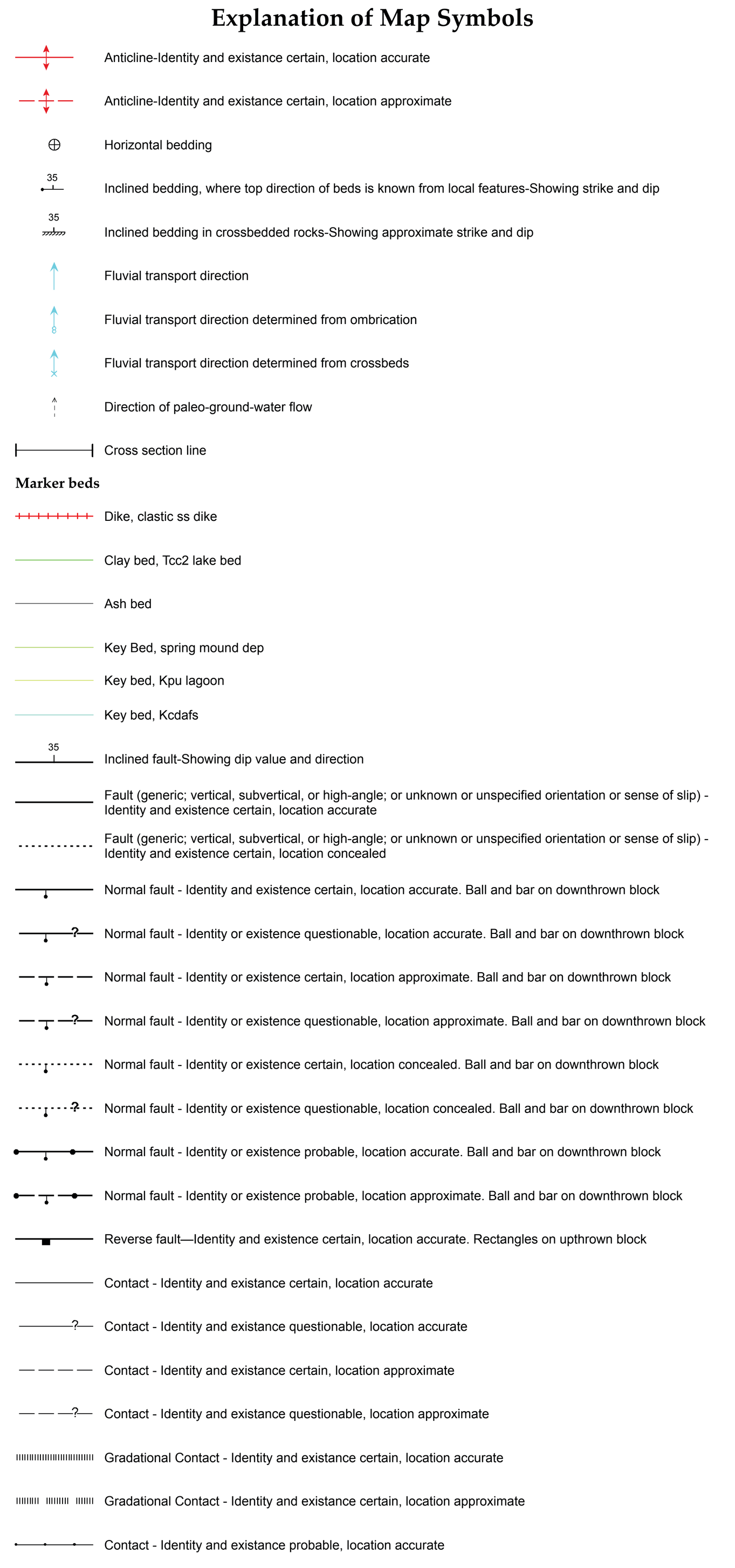
Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

Correlation of Map Units



Explanation of Map Symbols



Map Unit Descriptions

Quaternary hillslope and landslide unit

Qls — **Landslide deposits (middle(?) to upper Pleistocene or Holocene)** — Large bodies of fractured Gallup Sandstone (**Kg**) that have slid downward, via the influence of gravity, over the Mancos Shale (**Kmp**) along a basal shear zone. Up to 6-8 m thick.

Quaternary eolian and sheetflood deposits

Qe — **Eolian sand (modern to historic)** — Fine- to medium-grained sand that is pale brown to very pale-brown (10YR 6-7/3). Unit is preserved on east-facing lee slopes (where it is 1-3 m thick), along the east side of wide arroyo bottoms in the north-central part of the quadrangle (where it is 1-2 m thick), and near the northeast sides of mesa-tops (where it is ~1 m thick). Locally overlies reddish soils associated with unit **Qseh** and locally grades laterally into the younger, upper sediment of **Qse**.

Qer — **Eolian sand lying on ridge tops (Holocene)** — Fine- to coarse-grained (mostly fine- to medium-grained) sand that is light brown to reddish yellow to pink (7.5YR 6/3-6; 7/3). Deposited on the tops of ridges by eolian processes. Low-angle cross-stratified to massive. Loose and non-cemented. 1-5 m thick.

Qse — **Slopewash deposits reworking eolian material (Holocene)** — Unit underlies relatively steep slopes (1-3°) adjacent to hillslopes; sediment is probably similar to nearby **Qay** sediment except that channel-fill sand bed forms are overall thinner. Sediment is locally derived from uphill lithologic units. Laterally grades into adjoining **Qay** and **Qayr**. 1-10 m thick.

Qse/Ton — **Slopewash deposits reworking eolian material, overlying the Navajo Draw Member of the Arroyo Ojito Formation (Holocene)** — Slopewash deposits, as described in unit **Qse**, that overlies sandy sediment of the Navajo Draw Member of the Arroyo Ojito Formation (**Ton**).

Qse/Tcc-Ton — **Slopewash deposits reworking eolian material, overlying interbedded Navajo Draw Member (Arroyo Ojito Formation) and the Cerro Conejo Formation (Holocene)** — Slopewash deposits, as described in unit **Qse**, that overlies the gradational and interbedded unit between the Navajo Draw Member of the Arroyo Ojito Formation and the Cerro Conejo Formation (**Tcc-Ton**).

Qse/Tcc4 — **Slopewash deposits reworking eolian material, overlying subunit 4 of the Cerro Conejo Formation (Holocene)** — Slopewash deposits, as described in unit **Qse**, that overlies subunit 4 of the Cerro Conejo Formation (**Tcc4**).

Qse/Tcc3 — **Slopewash deposits reworking eolian material, overlying subunit 3 of the Cerro Conejo Formation (Holocene)** — Slopewash deposits, as described in unit **Qse**, that overlies subunit 3 of the Cerro Conejo Formation (**Tcc3**).

Qse/Kme — **Slopewash deposits reworking eolian material, overlying the Menefee Formation (Holocene)** — Slopewash deposits, as described in unit **Qse**, that overlies the Menefee Formation (**Kme**).

Qesc — **Eolian deposits on hill slopes and hilltops, locally reworked as sheetwash or colluvium (middle-upper Pleistocene to Holocene)** — Eolian sand under steep slopes (> 5°) and inferred to be derived from local slopewash or colluvial deposits. The eolian sand is itself subjected to slopewash and colluviual action. Unit mantles underlying Santa Fe Group deposits, commonly the Cerro Conejo Formation. Sand is massive to low-angle, cross-laminated to horizontal-planar laminated; usually well-bedded sand is found in the uppermost part of the deposit and is likely historical to modern. Sand is fine- to coarse-grained and strong brown to reddish yellow (7.5YR 5-6/6) to light brown to light-yellowish brown (10-7.5YR 6/4). A winnowed lag of cU-vcU sand grains is commonly observed on the surface. Coppice dunes and other mound-like features, up to 1.5 m tall and 5 m long, are also common. Loose. Estimated thickness of 0.2-7(?) m.

Qseh — **High-level sheetflood deposits reworking eolian material (middle-upper Pleistocene and Holocene)** — Sand locally interbedded with slightly clayey-silty (est 5-15% fines) sand and thin pebbly beds. Sand is commonly massive (locally containing scattered, very minor pebbles) and has experienced cumulic soil development manifested by reddening, ped development, clay illuviation, and calcium carbonate accumulation. Sand is very fine- to very coarse-grained (mostly fine- to medium-grained) and strong brown to reddish yellow (7.5YR 5-6/6) or light brown to light yellowish brown (7.5-10YR 6/4).Generally 0.5-2.0 m thick.

Quaternary alluvium

Qam — **Modern alluvium** — Sand and gravelly sand that underlies the floors of active arroyo bottoms; generally well-bedded. Sand is very fine- to very coarse-grained and laminated to very thin beds that are horizontal-planar to cross-stratified. On air photos, the surface exhibits notable bar and swale relief. 1-2 m thick.

Qah — **Historical alluvium** — Sand and gravelly sand that underlies low terraces adjacent to active arroyo bottoms; generally well-bedded. Sand is very fine- to very coarse-grained and in laminated to very thin beds that are horizontal-planar to cross-stratified. On air photos, the surface is relatively smooth. 1-3 m thick.

Qar — **Recent alluvium (Modern and historical)** — A combination of units **Qam** and **Qah**. 1-3 m thick.

Qfar — **Recent alluvium associated with gully-mouth fans (modern to historical)** — Sand and gravelly sand, similar to that described for units **Qam** and **Qah**, that form large lobes at the mouths of arroyos. 1-2 m thick.

Qay — **Younger alluvium (Holocene)** — Sand, pebbly sand, and subordinate clayey-silty sand and sandy silt-clay. Sediment is massive or in very thin to medium, lenticular to tabular beds that are locally internally cross-laminated; locally cross-stratification (foresets are thin to laminated). 0-3% pebbly beds. Sand is mostly very fine- to medium-grained (minor coarse and very coarse sand) and commonly pale brown to light-yellowish brown to brown (10YR-2.5Y 6/3-4; 10YR 5-6/4) to light brown (7.5YR 6/4). Locally, two allostratigraphic units are seen, with the younger inset into the older. The older unit is massive, may exhibit cumuli soil development, and may contain 1-5% scattered pebbles. The younger unit is slightly coarser and exhibits well-defined beds. Along the Rio Puerco, this unit consists of interbedded sand and fine-grained floodplain deposits. Weakly consolidated and non-cemented (weak to moderate HCl effervescence). Up to 10 m exposed thickness.

Qayr — **Younger and recent alluvium, undivided (Holocene to modern)** — Unit **Qay**, as described above, but this unit includes minor modern and historical alluvium that is in or near active channels or deposited as gully mouth fans. Up to several meters thick.

Qao — **Older alluvium (middle(?) to upper Pleistocene)** — Sandy pebbles, pebbly sand, and sand deposited by tributaries to the Rio Puerco. Gravel includes minor cobbles and is composed of chert with lesser volcanic rocks, sandstone, quartzite, granite, and quartz.. Sand is very fine- to very coarse-grained and light yellowish brown (2.5Y 6/4). Mapped where the strath lies within 6 m of modern grade. 2-12 m thick.

Qaohw — **High-level, older alluvium found in the western part of the quadrangle (middle to upper Pleistocene)** — Sand interbedded with minor pebbly lenses (locally containing as much as 10% cobbles). Found in the western quadrangle, where it commonly interfingers westward with terrace deposit Qtrp2. Gravel is very thin- to thin-bedded, with local thick channel-fills; clast composition is dominated by chert with 0-20% quartzite, 0.5-10% red granite, 5-35% Mesozoic sandstone, 0-1% Pedernal chert, 0-1% vesicular basalt, and 0% trace felsic hypabyssal intrusive clasts. Sand is very fine- to very coarse-grained (mostly fine- to medium-grained) and light gray to light brownish gray to pale brown to white (2.5Y-10YR 6-7/2 and 6/3; 2.5Y 7/2-8/1). Lower contact has several meters of paleotopographic relief. 2-6(?) m thick.

Qaohe — **High-level, older alluvium found in the eastern part of the quadrangle (middle Pleistocene)** — Sand interbedded with minor sandy gravel dominated by pebbles. Sand is massive, horizontal-planar laminated, or in very thin to thin, tabular to lenticular beds. Gravelly beds are very thin to medium and lenticular to tabular to U-shaped. Gravel composition is dominated by Mesozoic sandstone, chert, and granite; there is minor felsic to mafic volcanic rocks, Pedernal chert, quartzite, and quartz. Sand is mostly medium- to coarse-grained and light yellowish brown (10YR 6/4) to very pale brown (10YR 7/3-4) to pale brown (2.5Y-10YR 6/3). Scoured lower contact displaying up to 3 m of paleotopographic relief. Loose to weakly consolidated and non-cemented. 18-25 m thick.

Qtg — **Gravelly terrace deposit associated with tributaries of the Rio Puerco alluvium, gravelly (middle(?) to upper Pleistocene)** — Interbedded sandy pebbles-cobbles and fine sand. The gravel are composed of pebbles and minor (< 10%) cobbles. Clasts are subangular to rounded, poorly to moderately sorted, and dominated by sandstone rock types in the western quadrangle; in the eastern quadrangle, there is minor and variable amounts of vesicular basalt, red granite, Pedernal chert, chert, and quartzite. Sand is fine- to very coarse-grained, contains as much as 10% clay-silt, and pale brown (10YR 6/3) to light gray to pale brown (2.5Y 7/2-3). Base of deposit lies greater than 6 m above modern grade. 1-3 m thick.

Qtrp1 — **Lowest terrace deposit associated with the Rio Puerco (upper Pleistocene)** — Fill terrace composed of sand and gravel deposited by the Rio Puerco. Gravel contains pebbles and minor cobbles; clast composition dominated by andesite-basalt with subordinate Mesozoic sandstone, red granite, chert,and quartzite. Sand is fine- to very coarse-grained and olive brown (2.5Y 4/4). Loose. Strath is commonly buried by Holocene alluvium. 2-6 m exposed thickness.

Qtrp2 — **Lower terrace deposit associated with the Rio Puerco (middle to upper Pleistocene)** — Fill terrace transitioning northward to a thinner strath terrace. Consists of sand and gravel channel-fills with minor floodplain deposits of silty-clayey, fine-grained sand. Channel-fills are commonly cross-stratified. Gravel consist of pebbles with 10% cobbles; clasts composed of gray andesite to basalt (about 5% of volcanic clasts are vesicular basalt) with 30-35% tan Mesozoic sandstone, 15% red granite, 5% chert and FeO concretions, trace to 0.5% quartzite. Sand is mostly fine- to very coarse-grained and pale brown (10YR6/3). Loose. Strath is generally buried by Holocene alluvium. 12-14 m thick.

Qtrp3 — **Middle terrace deposit associated with the Rio Puerco (middle Pleistocene)** — Fill terrace whose base lies 12-18 m above the modern floor of the Rio Puerco valley; base locally buried by aggradation associated with terrace deposit **Qtrp2**. Sediment consists of intercalated gravel (pebbles with 10-20% cobbles) and sand. Gravel composed of gray andesite-basaltic andesite, 25-30% tan Mesozoic sandstone, 10-20% chert and reworked FeO concretions, 3% basalt, 3-5% red granite, and 1% quartzite. Sand is invery thin to thin beds, fine- to very coarse-grained, and pale brown to very pale brown (2.5Y-10YR 6-7/3). Lower part of unit may include several meters of locally derived sand that is in semi-horizontal beds (very thin to medium and tabular). The locally derived sand is more yellow (2.5Y-10YR 6-7/4), very fine- to fine-grained, and contains 5-10% medium, tabular beds of light gray (2.5-5Y 7/1) clay-silt. 10-18 m thick.

Qtrp4 — **Higher terrace deposit associated with the Rio Puerco (middle Pleistocene)** — Poorly exposed sand and gravel (pebbles with 1-10% cobbles) occupying a strath terrace whose base lies 30-38 m above the modern floor of the Rio Puerco valley. Gravel composed of gray to light gray andesite-basaltic andesite, 1-3% vesicular basalt, about 10-25% chert, about 10-30% Mesozoic sandstone, 5-10% red granite,and 1-5% quartzite. Sand is mostly fine- to medium-grained and light yellowish brown to pale brown (2.5Y-10YR 6/3-4). Deposit is locally cemented at its base but is otherwise loose. 1-2 meters thick. Subdivided into two terraces near the north boundary of the quadrangle, whose treads and straths are separated by a few meters.

- **Qtrp4a** — The lower of the two **Qtrp4** strath terraces near the northern quadrangle boundary.
- **Qtrp4b** — The higher of the two **Qtrp4** strath terraces near the northern quadrangle boundary.

Qtrp5 — **Very high terrace deposit associated with the Rio Puerco (middle Pleistocene)** — Poorly exposed gravelly sand. Gravel consists of pebbles with 5-10% cobbles and composed of andesite-basaltic andesite, 3-5% vesicular basalt, 15-20% tan Mesozoic sandstone, and 7-8% red granite. Sand is mostly medium to coarse-grained and light olive brown to light yellowish brown (2.5Y 5-6/4). Occupies a strath terrace whose base lies ~55 m above the modern floor of the Rio Puerco valley. 1-1.5 m thick.

Tertiary Basin-fill of the Santa Fe Group

QTcrp — **Rio Puerco Member of the Ceja Formation (lower Pleistocene)** — Very pale-brown, amalgamated channel-fills of sand and pebbly to cobbly sand. Unit occupies the upper part of the bluffs east of the Rio Puerco. Sand and gravelly sand are in laminated to very thin beds that are planar cross-stratified to horizontal-planar. Minor sandy pebbles-cobbles in very thin to thin, lenticular beds. Gravel are composed of chert (including Pedernal chert) with 20-30% quartzite, ~10% gray, intermediate to mafic volcanic clasts, ~10% sandstone clasts, and 3-10% granite. Unit contains scattered cobbles and boulders up to 1 m in maximum diameter. Sand is mostly medium- to very coarse-grained. Channels have scoured bases, otherwise the unit has a gradational to interfingering contact with underlying Atrisco Member. Weakly consolidated and non-cemented. 34-45 m thick. [description taken from Cikoski et al., 2012].

Tca — **Atrisco Member of the Ceja Formation (Pliocene)** — Well-bedded sand and minor clayey mudstone. Sand beds are typically thin to medium and tabular. Mudstones are horizontal-planar laminated or in very thin to thin, tabular beds. Sand is very fine- to medium-grained and pink to reddish yellow to light brown (7.5 YR 6-7/4 to 6/6). Mudstone is light-reddish brown to reddish brown to yellowish red (5YR 6/4 and 5YR 5/4-6). ~3% strong to moderate cementation. The reddish hue, well-bedded nature, and fine-grained nature of this unit serve to differentiate it from the Loma Barbon Member of the Arroyo Ojito Formation. Lower contact overlies a paleosol immediately east of the central eastern quadrangle boundary. 49-50 m thick.

Tob — **Loma Barbon Member of the Arroyo Ojito Formation (Upper Miocene)** — Tan sand interbedded with minor pebble-conglomerate beds and 1-5% mudstone beds. Pebble-conglomerate channel-fills are thin to thick and lenticular. Estimated clast composition: 30-50% tan and fine-grained Mesozoic sandstone, 15-30% dark gray to black to brown chert, 10-40% Pedernal chert, 10%red granite, 1-5% quartzite, 1% gray intermediate volcanic rocks, trace lithic-rich sandstone, and 0.5% mudstone rip-up clasts. Sand is tangential cross-laminated (up to 50 cm-thick foresets) to horizontal planar laminated. Sand is mostly fine- to coarse-grained and very pale brown to light gray to pinkish gray (7.5-10YR 7/2-3). Moderately to well consolidated and overall poorly cemented. Base of deposit is not exposed. At least 60 m thick.

Ton — **Navajo Draw Member (Upper Miocene)** — Pale brown sand with minor mudstone and conglomeratic interbeds. Conglomeratic beds are 30-100 cm thick; gravel are clast- to matrix-supported and consist of pebbles (locally with cobbles) composed of tan sandstone (intraformational or older Santa Fe Group sandstone) and chert; other clast types include: 0-50% intraformational calcium carbonate nodules, 1-7% quartzite, 5-7% quartz, 1-5% light gray dacite or andesite, and 1% petrified wood; Pedernal chert increases upsection, from 0% to 15%; granite increases up section, from 0-3%. Sand is in medium to thick, tabular beds that display internal laminations to thin beds that are horizontal-planar, wavy, or low-angle cross-stratified. Sand is mostly fine- to medium-grained and verypale brown to pale brown to light yellowish brown (10YR-2.5Y 7/3; 10YR 6/4). Mudstone interbeds are tabular and laminated to thin; the mudstone is clay-rich and light brown (7.5YR 6/4). Weakly to moderately consolidated and non-cemented (1-3% weak calcium carbonate cementation). Top of unit is not preserved; unit thickness is at least 50 m.

Tcc-Ton — **Interbedded Cerro Conejo Formation and Navajo Draw Member of Arroyo Ojito Formation (Upper Miocene)** — Unit encompasses a ~30 m thick transitional zone between the Cerro Conejo Formation and the Navajo Draw Member of the Arroyo Ojito Formation.

Tbmu — **Upper unit of Benavidez maar (Upper Miocene)** — Light-colored and well-bedded sandstone, pebbly sandstone, and siltstone. These strata are distinctly and parallel-bedded, ranging from cross-stratified to tabular to contorted, very thin to medium beds and laminations. Pebbles are generally intraformational siltstone and sandstone. Sandstone is mostly very fine- to medium-grained and pale brown (2.5Y 7/3 and 8/2-3). Sand composition is generally non-basaltic and similar to that of the Cerro Conejo Formation. ~1% of beds contain coarse to very coarse sand with very fine to fine pebbles composed of chert and local quartz. ~15% of the beds are well-cemented by calcium carbonate. Local intervals, up to 3 m-thick, of massive, greenish gray, pebbly medium- to very coarse-grained sandstone dominated by basalt. Local bombs of very fine- to fine-grained sandstone, up to 80 cm long, have caused underlying sediment to sag downward. Dips decrease up section. 15-45 m thick.

Tbml — **Lower unit of Benavidez maar (Upper Miocene)** — Dark-colored (gray to greenish gray), well-bedded to massive, basaltic + quartz sand interbedded with very fine to very coarse basaltic lapilli. Generally well-bedded only at its base and in its upper 6 m; in these places, sediment is laminated to very thin, tabular and parallel-bedded, and steeply inward dipping. Sand is very fine- to very coarse-grained and a mix of basalt and sand (the latter similar to that seen in the Cerro Conejo Formation). Coarse to very coarse sand is generally basaltic. Near top of unit are minor beds similar to those in unit **Tbmu**. Dips decrease up section. Where exposed on the north side of the maar, the lower contact is relatively sharp and planar (but steeply dipping), and parallels bedding in the underlying Cerro Conejo Formation. 40-50m thick.

Tccw2 — **Cerro Conejo Formation, upper exposed unit in western part of the quadrangle (Middle to Upper Miocene)** — Sandstone interpreted to reflect a mix of fluvial and eolian depositional processes, interbedded with minor light reddish brown mudstone. Eolian strata contain thick cross-stratification (tangentially cross-laminated foresets up to 3 m-thick) and lenticular grain-flow beds (20-100 cm wide). Sand is mostly fine- to medium-grained and very pale brown (10YR 7/4). Locally, reddish paleosols are present, up to 40 cm thick, that exhibit evidence of clay illuviation and calcium carbonate accumulation. Weakly to well consolidated; non to weakly cemented by calcium carbonate (except locally near faults). 70-80 m thick [description taken from Cikoski et al., 2012, where the unit is better exposed].

Tccw1 — **Cerro Conejo Formation, lower exposed unit in western part of quadrangle (Middle to Upper(?) Miocene)** — Mapped in the western quadrangle, where it lies on the west side of the Sedillo fault. There, the unit is distinctly orange-colored and composed of sandstone, with minor gravelly sandstone and clayey sandstone beds. The sandstone is in thick to very thick, tabular beds separated by thin to medium, tabular beds composed of light reddish brown to reddish yellow (5YR 6/4-6) clay mixed with very fine- to fine-grained sand. The sandstone is fine- to medium-grained and light brown to reddish yellow (7.5YR 6/4-6). 1-5% gravelly sandstone beds that are laterally extensive and thick; the pebbles are composed of felsic-intermediate volcanic clasts up to 7 cm long. Sediment in unit is mostly weakly consolidated and non-cemented. At least 250 m thick (based on Cikoski et al., 2012).

Tccw — **Cerro Conejo Formation in western part of the quadrangle, undivided (Middle to Upper Miocene)** — Strata that are similar to that seen in either **Tccw1** or **Tccw2**.

Tcc4c — **Conglomeratic subunit 4 of Cerro Conejo Formation (Middle to Upper Miocene)** — Sandy-pebble conglomerate to pebbly sandstone whose pebbles are very fine to very coarse and composed of chert, 1-10% metavolcanics (felsic, including flow-banded metarhyolite), 1-7% quartz, 1-5% quartzite, and 1% petrified wood; 0% to trace granite and no Pedernal Chert. Generally about 1 m-thick and occur as tongues within unit **Tcc4**.

Tcc4 — **Subunit 4 of Cerro Conejo Formation (Middle to Upper Miocene)** — Reddish sandstone with subordinate (~10-20%) mudstone and clayey sandstone and very minor pebble-conglomerate beds. Lower part of unit is a ledge-former in the northeastern part of the quadrangle. Sand occurs in thin to thick, tabular beds that are internally horizontal-planar laminated to massive to low-angle cross-laminated. Sand is mostly fine- to coarse-grained and reddish yellow to pink to light brown (5-7.5YR 6/6-7/3; 7.5YR 6-7/4). Mudstone occurs in reddish intervals as thick as 10 m, where mudstone is interbedded with very thin to thin, tabular beds of very fine- to medium-grained sand and clayey sand; mudstone beds are mostly very thin to medium, tabular, dominated by clay, and reddish brown to light brown (2.5-5YR 4-5/4; 7.5YR 4-6/4). 1-15% strong cementation of the sandstone by calcium. Weakly developed paleosols are locally developed in this unit, particular the middle part. Unit contains trace, very thin to thin beds of coarse to very coarse sand and pebbles. Upper half of unit locally contains intervals of pronounced tangential cross-stratification, up to several meters thick, as well as minor sand and pebble-conglomerate beds up to 1 m thick (**Tcc4c**). Mostly non-cemented and weakly to well consolidated. Where exposed, the lower contact is relatively sharp and planar. Poorly constrained thickness of ~120 m.

Tcc3 — **Subunit 3 of Cerro Conejo Formation (Middle Miocene)** — Tan sandstone in poorly defined, thin to very thick, tabular beds (up to 5-6 m thick); also massive. Within the beds, the sand is horizontal-planar laminated to very thinly bedded, with very minor cross-lamination. Trace amounts of very thin to thin beds (lenticular to tabular) containing very coarse sand and fine pebbles composed of mainly of rhyolite-dacite; these beds are more abundant in the upper 6 m of the unit. Sand is mostly fine- to medium-grained and light brown to pink (7.5YR 6-7/4) (lower part) to very pale brown (10YR 7/3) (upper ~15 m). 1-15% strong cementation; otherwise, moderately to well consolidated and non-cemented. Base is mapped at the top of the highest greenish mudstone bed found in unit **Tcc2**. Upper contact is sharp and planar. 30-45 m thick.

Tcc2 — **Subunit 2 of Cerro Conejo Formation (Middle Miocene)** — Fine-grained, pastel-colored unit (light-greenish to grayish-green to pink) composed of very fine- to medium-grained sandstone, commonly in channel-fills that fine-upwards, together with 5-10% interbeds of claystone, mudstone, and clayey sandstone beds. The sand is horizontal-planar laminated or very thinly bedded; cross-laminations also are present (with foresets up to 20 cm thick). Sand is very fine- to medium-grained and commonly pink (7.5YR 7/4) to pale brown (2.5Y 7/3) to light gray to white (2.5-5Y 7/2-8/1). Clay is in thick beds (up to 1 m) and either reduced and greenish or reddish brown to light reddish brown (5YR 6/3-5/4). Clay beds may contain altered ash interbeds as well as pebble-size calcium carbonate nodules. Clayey sand beds are very thin to thin, tabular, and reddish brown to reddish yellow (5YR 6/4-6). Unit thickens eastward, from 2 to 30 m. Mapped as a line where less than 5 m thick.

Tcc1 — **Subunit 1 of Cerro Conejo Formation (Middle Miocene)** — Ledge-forming, well-bedded, and reddish sandstone. Strata are mostly in mostly medium to thick, tabular beds. These exhibit internal horizontal planar-laminations, cross-laminations (foresets are tangential and up to 20 cm thick), or are massive. Sand is mostly very fine- to medium-grained and pink to light-brown (7.5YR 6-7/3; 5-7.5YR 7/4) to reddish-yellow (5-7.5YR 6/6). Minor (~10%) light-reddish-brown to reddish-yellow (5YR 6/4-6/6) beds of clay, silt, and very fine- to fine-grained sandstone. The degree of cementation increases up section in the unit, from 1-2% to 20-35%. Lower contact is sharp and locally exhibits angular discordance near the northern quadrangle boundary. It has been interpreted as a disconformity, where strata of 15-16 Ma age are missing (Tedford and Barghoorn, 1999). 45-50 m thick.

Tzcp — **Canada Pilares Member of the Zia Formation (Lower Miocene)** — Slope-forming, reddish, interbedded fine-grained sandstone and mudstone. Very thin to medium, tabular (minor lenticular) beds. These are internally horizontal planar-laminated to cross-laminated (foresets are tangential and up to 20cm thick). Sandstone is mostly very fine- to medium-grained and pink to light brown (7.5YR 6-7/3-4; 8/2) to light-reddish brown (5YR 6/4). Mudstone is clay-rich, light-reddish brown to light brown (5-7.5YR 6/4; 2.5YR 4/4), and in very thin to medium, tabular beds. Lower contact not exposed. 30 m thick according to Tedford and Barghoorn (1999).

Tzcm — **Chamisa Mesa Member of the Zia Formation (Lower Miocene)** — A sandstone unit that is slightly redder, finer-grained, and displays better bedding than the underlying Piedra Parada Member. Typical texture of very fine- to medium-grained sand and silty very fine- to fine-grained sand. Mostly in medium to thick, tabular beds that are internally horizontal-planar bedded (laminated to thin), tangentially cross-laminated, or massive. 10-20% of beds are well-cemented by calcium carbonate. Non-cemented sand is mostly very fine- to medium-grained and pink to light brown (7.5YR 6-7/3-4) to very pale brown (10YR 7/3-4), Evidence of bioturbation is relatively common and includes massive textures, rhizoliths, and paleo-burrows. Sparse (up to 10%), reddish, medium to thick tabular beds of mixed clay, silt, and very fine- to medium-grained sandstone. Lower contact is conformable and gradational over ~4 m. 30-35 m thick.

Tzpp — **Piedra Parada Member of the Zia Formation (Lower Miocene)** — White to light gray to very pale brown (10YR 8/1-7/2-7/3) sandstone that is mostly in horizontal-planar beds, with lesser cross-lamination exhibiting tangential foresets up to 40 cm thick. Beds are mostly laminated to very thin. These thicker beds are less distinct and not as laterally extensive as those in the Chamisa Member Member of the Zia Formation. Sand is mostly medium- to coarse-grained and contains more volcanic (felsic-intermediate) lithic grains (15-30% of total) than overlying Santa Fe Group units. In the southwestern part of the quadrangle, there are local chert and lesser rhyolite pebbles. Weakly to moderately consolidated, with ~5-25% strong cementation by calcium carbonate. Base unconformably overlies the Menefee Formation, where there is meter-scale paleo-topographic relief. At the contact lies ventifacted pebbles and cobbles of volcanic rock. 14-30 m thick in the southwest and about 100m thick in the northeast.

Upper Cretaceous rocks

Kme — **Menefee Formation (Upper Cretaceous)** — Fine-grained floodplain deposits interbedded with 15-30% sandstone channel-fills. Floodplain sediment consists of mudstone, siltstone, and very fine- to fine-grained sandstone. Mudstone is mostly light gray to dark grayish brown; in contrast to unit **Kcg**, the mudstones of this unit are locally greenish gray (~5% of unit). The mudstone is laminated to very thin, tabular to wavy bedded within medium to very thick, tabular beds. Interbedded in the mudstone are minor, thinly bedded, very fine- to fine-grained sandstones that likely represent crevasse splay deposition; these are lenticular to broadly lenticular (1:10 height : width ratio) and commonly white. Also interbedded in the floodplain deposits are coal beds, commonly 10-50 cm thick; these decrease in abundance up section (1-5% in lower ~60 m, trace-0.5% higher in the section). The sandstone in the flood plain deposits are commonly horizontal-planar laminated. Local petrified wood, iron oxide concretions, and white ashes up to 15 cm thick. Sandstone channel fills range in size from ribbon forms (0.2-1.5 m-thick and <= 5 m wide) to broadly lenticular amalgamated bodies (1-6 m thick and up to ~60 m wide). Channel-fills display trough cross-lamination (up to 30 cm thick) to tangential cross-lamination to horizontal-planar laminations. The sandstone is white to light gray to very pale brown, weathering to yellow to light yellowish brown. Sand grains are very fine- to medium-grained. Variably cemented by calcium carbonate and possibly clay. Interpreted as a fluvial deposit. Gradational and conformable base.~550 m thick.

Kpu — **Upper part of Point Lookout Sandstone (Upper Cretaceous)** — Ledge-forming, well-cemented, white sandstone weathering to yellow and brown. Sandstone is tangentially to trough-cross-laminated to horizontal-planar laminated. Sand is mostly fine- to medium-grained. Upper 10 m of unit is more massive and bioturbated. Sandstone mostly cemented by silica and calcium carbonate. Trace to 1% thin-medium, tabular, light gray to gray, mudstone interbeds; mudstone is blocky. The lower 5-10 m of this unit consists of very thickly bedded (tabular) sandstone that is internally horizontal-planar laminated to tangentially cross-laminated. Interpreted as fluvio-deltaic, with minor nearshore facies. A finer-grained unit, interpreted as lagoonal facies, is mapped as a line feature. Unit base is gradational over about 1-2 m. ~65 m thick.

Kms — **Satan Tongue of the Mancos Shale (Upper Cretaceous)** — Interbedded sandstone, siltstone, and shale. Overall, about 2/3:1/3 sandstone vs. shale. Shale is commonly fissile to extremely fissile. Shale and siltstone are grayish brown to light-olive brown. Sandstone is generally in very thin to thick, tabular beds that are internally low-angle cross-laminated to hummocky-laminated to horizontal-planar laminated. Local mottling and bioturbation. Sand is mostly very fine- to fine-grained and white to yellow, weathering to pale brown. Interpreted to contain nearshore, offshore, and lagoonal facies; coal beds near the western quadrangle boundary indicate lagoonal to swamp facies and shallower water to the west. Upper contact is gradational over 50 cm. Lower contact is sharp and planar. 6-15 m-thick, thickening to the east.

Kph — **Hosta Tongue of the Point Lookout Sandstone (Upper Cretaceous)** — White to pale-brown to yellow (2.5Y 7/3), cemented, cross-stratified to horizontal-planar laminated sandstone that lies below the Satan Tongue of the Mancos Shale. Foresets are up to 100 cm thick (locally up to 300 cm thick at the base) and tangential (mostly) to trough-cross-laminated. Sand is fine- to medium-grained. 0.5-1.0%, relatively thin, gray (2.5Y 6/1) shale-mudstone beds or laminae that commonly contain organic detritus. Trace fossiliferous sandstone beds with clams and lesser oysters and gastropods. Trace intraformational pebbles. An extensive, 3-150 cm-thick, transgressive sandstone caps this unit east of the Rio Puerco; it contains abundant disarticulated shells as well as intact clams (or clam molds) and teeth. This capping bed is commonly tangentially cross-stratified (laminated to very thin beds). Interpreted as a deltaic deposit. Entire deposit is 22-30 m thick.

Kcg — **Gibson coal-bearing Member of the Crevasse Canyon Formation (Upper Cretaceous)** — Fine-grained deposits, interpreted as swamp and floodplain facies, interbedded with subordinate sandstone channel fills weakly to strongly cemented by calcium carbonate. The former display an overall dark-gray color, contrasting notably with the underlying Dalton Sandstone and Mullato Tongue of the Mancos Shale. 15-25% sandstone channel-fills that are up to 5 m-thick and lenticular over distances of 100s of meters, but also occur as thick, tabular beds. Internally, channel-fills are cross-stratified, with tangential foresets or trough cross-laminations being especially common, or horizontal-planar laminated. Sandstone is mostly fine- to medium-grained and light gray to white to very pale brown. Swamp and floodplain deposits contain 1-5% coal or organic-rich mudstone beds but generally consist of mudstone and siltstone displaying very dark-gray to light-gray, brown, and grayish brown to dark-grayish-brown colors. This fine-grained sediment exhibits horizontal-planar to wavy laminations. 1% of strata are light gray (7.5YR 7/1) siltstone to very fine-grained sandstone in thin beds that are internally horizontal-planar to wavy laminated. Interbedded within the swamp + floodplain deposits are crevasse splay, fine- to medium-grained sandstones that are < 20 cm thick and locally low-angle cross-stratified. Coal beds are thin to thick (up to 50 cm) and tabular. Local layers with abundant, concretionary iron-oxide chips, as well as local klinker zones. Base of unit intertongues northward with uppermost Mullato Tongue sands. Lower contact is sharp and locally climbs 6 m over 100's of meters of lateral distance. Top of unit is gradational with the Hosta Tongue of the Point Lookout Sandstone over several meters, although locally the base of the Hosta Sandstone is sharp and has scour relief of 10 cm. 120-130 m thick.

Kcda — **Dalton Sandstone of the Crevasse Canyon Formation (Upper Cretaceous)** — Sandstone that is in very thin to thick, tabular beds that are internally horizontal-planar-laminated and trough or tangential cross-stratified (laminated to very thin); also locally bioturbated and massive. In the western quadrangle there are medium to thick, tabular, fossil-rich beds in its upper part. Sand is mostly fine- to medium-grained and white (2.5Y 8/1) to pale-brown to light-gray (2.5Y 7-8/2-4). The upper 5 m of this unit, informally referred to as the "fossiliferous upper part", lies above a distinctive, 20-30 cm-thick, cemented bed with abundant clams and molluscan shells. 1-10% interbedded mudstone that are light-brownish gray to grayish brown (10YR 5-6/2) and internally laminated. Lower contact is gradational with the Mullato Tongue of the Mancos Shale. Interpreted as nearshore facies containing minor distributory mouth bars deposited in shallow water in front of a delta. 30-37 m thick.

Kmm — **Mullato Tongue of Mancos Shale, undivided (Upper Cretaceous)** — Marine sediment that erodes readily and displays a distinctive yellow color. Generally consists of laminations to very thin beds that are horizontal-planar to wavy (up to 2 cm amplitude) to hummocky. Sediment consists of pale brown to yellow, very fine- to fine-grained sand and silty fine sand with subordinate pale brown to light yellowish brown to grayish brown, fissile shale. Relatively abundant detrital matter, especially coal that is mostly < 1 mm but locally up to 4 mm. 5% of strata consist of lenticular to tabular, thin to medium beds of light gray sandstone that are internally horizontal planar-laminated. Trace to 1% laminae to very thin beds of crystalline gypsum, probably a product of diagenesis. Moderately to well consolidated. In the western quadrangle, the Mullato Tongue is subdivided into two units that are described below. ~95 m thick.

Kmmsl — **Mullato Tongue of Mancos Shale, sandy lower part (Upper Cretaceous)** — Fine- to medium-grained sandstone in the lower Mullato Tongue of the Mancos Shale. Laminated to very thin, medium beds that are horizontal-planar to tangential cross-stratified to wavy. Sand is very pale brown to light-gray. Sand locally fills tidal or pro-delta-related channels, with basal beds completely draping the channel bottoms and sides. Conformably overlies unit Kmll. 21-23 m thick.

Kmml — **Mullato Tongue of Mancos Shale, lowest part (Upper Cretaceous)** — Interbedded sandstone and sandy mudstone. Contains about 5% very thin to thin beds of crystalline gypsum. Being in very thin to thin, tabular beds, the sandstone is typically very fine- to fine-grained and very pale brown (10YR 7/3). Sandy mudstone is light-yellowish brown to very pale brown (2.5Y 6/3-4 and 10YR 7/3) and ripple-marked to horizontal-planar laminated. Scattered pieces of coal pieces are seen. A broken fragment of a marine shell identified as Lopha Sannionis was collected in the upper half of this unit (identified by Stephen Hook in early 2013). Depositional setting is interpreted as shallow, low-energy, nearshore marine environment containing local pro-delta sand bars. 9 m thick.

Kcdi — **Dilco Member of the Crevasse Canyon Formation (Upper Cretaceous)** — Interbedded mudstone, siltstone, and sandstone; tabular and thickly bedded to laminated. Distinguished from the Mullato Tongue of the Mancos Shale by its redder hues and darker tone. Lower contact placed at the base of the first dark-gray shale overlying the Gallup Sandstone. Mudstone is brown to very dark gray, locally organic-rich, locally yellow-stained, and locally exhibits flaser lamina of fine sand. Sandstone is fine- to medium-grained, light gray to brownish yellow, and commonly mottled and bioturbated or else massive to horizontal-planar laminated. 10% orange and yellow, ~1 cm splotches are common in the sandstone. Interpreted facies of lagoon to coastal swamp. Conformable and sharp lower contact. 3-4 m thick, thinning to the east. Not differentiated where less than 2 m thick.

Kg — **Gallup Sandstone (Upper Cretaceous)** — Light-colored and well-cemented sandstone that forms prominent cliffs in the study area. Sand is fine- to medium-grained and white to light gray to pale brown(2.5Y 7-8/3-4 and 8/1-2). Lower 2-3 m consists of very fine- to fine-grained sand in very thin to medium, tabular beds. Above lies 23-27 m of medium to very thick, tabular beds (up to 4-5 m thick) that contain internal horizontal-planar laminations, local low-angle cross-laminations, or weak to strong bioturbation. Upper 10-12 m of this unit consists of extensively cross-laminated (tangential foresets up to 50 cm tall) sandstone interbedded with lesser horizontal-laminated sandstone; clam shells are locally present. Conformable lower contact that is gradational over a few meters. Cementation likely a mixture of silica and calcium carbonate. 38-39 m thick.

Kmp — **Pescado Tongue of Mancos Shale (Upper Cretaceous)** — Gray to light yellowish brown to pale brown (2.5Y 6/1; 6-7/4), fissile mudstone (clay>silt) and shale in laminated to very thin, tabular to slightly wavy beds (<1 cm of relief). Local, greenish colors present. Upper 1 m consists of interbedded mudstone and very fine- to fine-grained sandstone, representing a gradational zone with the overlying Gallup Sandstone. Trace boulder-size concretions cemented by calcium carbonate and lesser silica. 170-180 m thick.

Ksm — **Sandstone Interval in Mancos (Upper Cretaceous)** — Light-gray sandstone observed in air photos in the northwest corner of the quadrangle. Reported to be a fossiliferous calcarenite by Williams and Cole (2007). A few meters thick.

Kml — **Lower Mancos Shale, undivided (Upper Cretaceous)** — Probably correlative to the Carlile Member of the Mancos Shale. According to Williams and Cole (2007), the Carlile Member is a medium-gray, thin-bedded marine shale 90-110 m thick.

Benavidez Ranch subsurface units

Tib — **Basalt intrusive (Upper Miocene)** — Basalt that has crystallized in the vent beneath the Benavidez maar.

Km — **Mancos Shale, undivided (Upper Cretaceous)** — Gray to light-yellowish-brown shale lying between the Gallup Sandstone and the uppermost tongue of the Dakota Sandstone; includes the Pescado Tongue (**Kmp**) and lower Mancos Shale (**Kml**) mapped on the surface. ~260 m thick.

Kdm — **Zone of interfingering Dakota Sandstone and Mancos Shale (Upper Cretaceous)** — White to gray and fine-grained sandstone cemented by calcium carbonate. Unit includes at least two Mancos Shale interbeds ~9 m thick, based on subsurface data in the quadrangle to the south (Cikoski et al., 2012). 80 m thick.

Jmbs — **Morrison Formation, Bluff Sandstone, and Summerville Formations, undivided (middle to upper Jurassic)** — The Morrison Formation consists of interbedded sandstone (white to light-gray and very fine-to fine-grained) and variegated mudstone; ~10% siltstone. The Bluff Sandstone, the middle unit, is comprised of a lower, sandstone-dominated member and an overlying, thinner interval of finer-grained sandstones and siltstones (Lucas and Heckert, 2003). The Summerville Formation, the lowest unit, is dominantly sandstone with sparse, thin interbeds of siltstone and mudstone. The sandstone is generally fine-grained and horizontally bedded (Lucas and Heckert, 2003). 190 m thick.

Jt — **Todilto Formation (middle Jurassic)** — Unit includes an upper gypsum member (Tonque Arroyo Member of Lucas et al., 1995) and a lower limestone member (Luciano Mesa Member of Lucas et al.,1995). 35 m thick.

Je — **Entrada Sandstone (middle Jurassic)** — Includes two members, of which the upper (Slick Rock Member of Lucas and Anderson, 1998) is composed of yellowish-gray, light-orange, and light-brown, fine- to medium-grained, crossbedded and tabular-bedded sandstone. The lower member (Dewey Bridge Member of Lucas and Anderson, 1998) is a reddish brown siltstone and sandstone. Description is from Williams and Cole (2007). 40 m thick.

₨ — **Triassic strata, Chinle Group and Moenkopi Formation(upper and middle Triassic, respectively)** — The Chinle Group consists of reddish-brown, medium-grained sandstone and reddish-brown, maroon, and green-gray mudstone (Williams and Cole, 2007). The Moenkopi Formation consists of thinly bedded sandstone, siltstone, and conglomerate (Heckert and Lucas (2003). 480 m thick.

Pz — **Upper Paleozoic strata (Permian)** — Unit includes the San Andres Limestone (95-100 m thick), Glorieta Sandstone (~65 m thick), Yeso Formation (230-240 m thick), and Abo Formation (~260 m thick), listed from youngest to oldest. See Williams and Cole (2007) for more detail. Greater than 600 m thick.

XY — **Paleo- and Mesoproterozoic, undivided** — Crystalline basement rock.

Geologic Cross Section