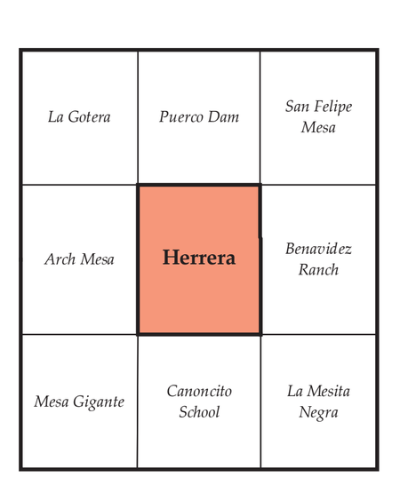
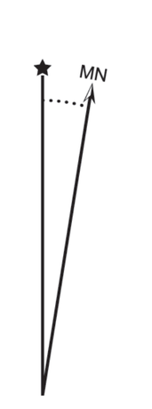
Base map from U.S. Geological Survey 2017.
North American Datum of 1983 (NAD83) World Geodetic System of 1984 (WGS84).
Projection and 1,000-meter grid: Universal Transverse Mercator, Zone 13S, shown in blue.
10,000-foot ticks: New Mexico Coordinate System of 1983(central zone), shown in red.

Roads....U.S. Census Bureau, 2015–2016
Names....GNIS, 2016
Hydrography....National Hydrography Dataset, 2014
Contours....IFSAR 4.5 m Digital Elevation Model, 2008

1:24,000

Contour Interval 20 Feet
North American Vertical Datum of 1988





Magnetic Declination
July, 2018
8º 42' East
At Map Center

Quadrangle Location

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

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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 273

Mapping of this quadrangle was funded by a matching-funds grant from the STATEMAP program of theNational Cooperative Geologic Mapping Act (Fund Number: G18AC00201), administered by the U. S.Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources, (Dr, Nelia W.Dunbar, *Director and State Geologist*; Dr. J. Michael Timmons, *Assoc. Director for Mapping Programs*).

Geologic Map of the Herrera 7.5-Minute Quadrangle, Bernalillo and Sandoval Counties, New Mexico

June 2019

by
Geoffrey C. Rawling and Daniel J. Koning

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

Explanation of Map Symbols

Contact—Identity and existence are certain and questionable where queried. The location is accurate where solid and approximate where dashed.

Gradational contact—Identity and existence are certain, and location is accurate where solid and approximate where dashed.

Key bed—Identity and existence certain, location is accurate. Used to denote when unit Kph is present but not thick enough to map the actual area.

Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence are certain and questionable where queried. The location is accurate where solid, approximate where dashed, and concealed where dotted.

Lineation on fault showing bearing and plunge

Fault showing local offset—U, on upthrown block; D, on downthrown block.

Inclined fault showing dip value and direction.

Vertical fault

Minor inclined fault showing dip value and direction.

Fault (in cross section). Arrows show relative movement along the fault.

Strike-slip fault (in cross section)—Notation of symbols show the relative movement along the fault plane. Circled dot is toward the observer, and the circled plus is away from the observer.

Horizontal bedding

Inclined bedding showing dip vaue and direction

Minor inclined joint showing dip value and direction

Direction of paleo ground-water flow—Approximate flow orientation or location.

Fluvial transport direction

Sediment transport direction determined from imbrication.

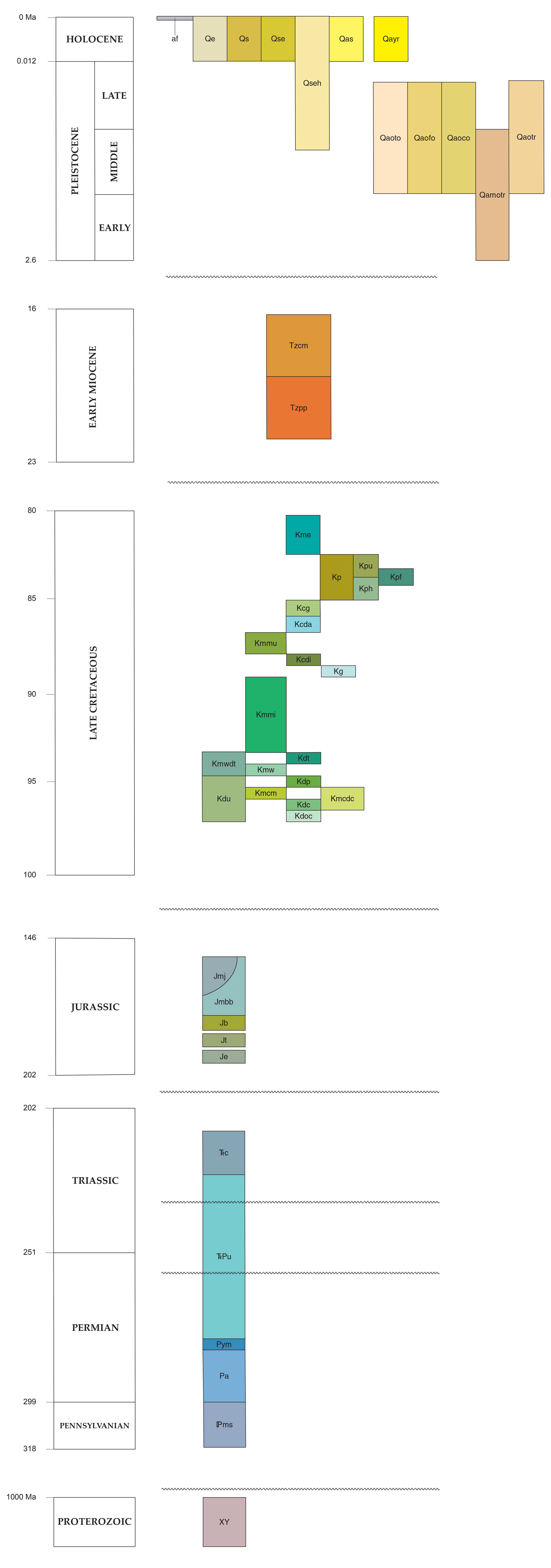
Sediment transport direction determined from crossbeds.

Direction of sediment transport, determined from eolian crossbedding in vertical or near-vertical section.

Cross section

Digital layout and cartography by the NMBGMR Map Production Group:
Phil L. Miller, Amy L. Dunn, Katie Sauer, and Kelly K. Boyd

Correlation of Map Units



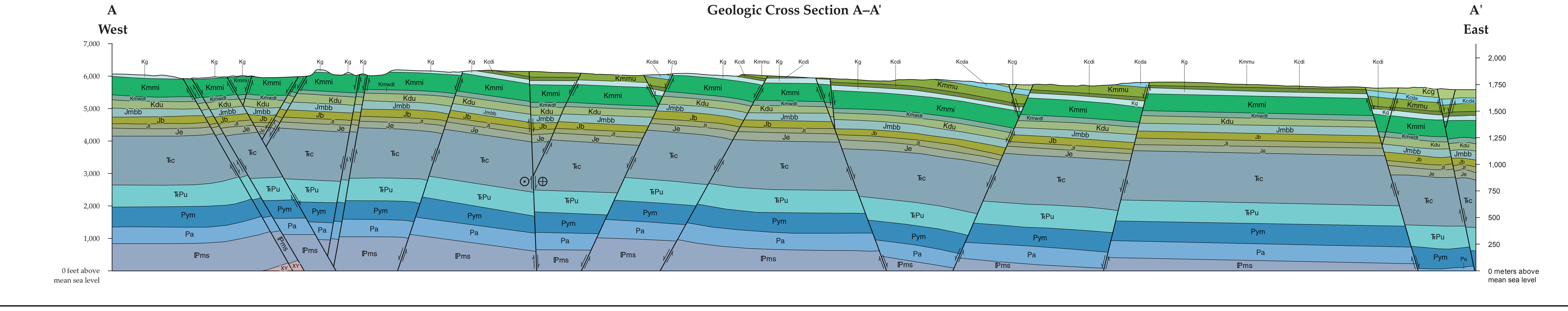
Comments to Map Users

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 may not be shown due to recent development.

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 New Mexico Bureau of Geology and Mineral Resources created the Open-file Geologic Map Series to expedite dissemination of these geologic maps and map data to the public as rapidly as possible while allowing for map revision as geologists continued to work in map areas. Each map sheet carries the original date of publication below the map as well as the latest revision date in the upper right corner. In most cases, the original date of publication coincides with the date of the map product delivered to the National Cooperative Geologic Mapping Program (NCGMP) as part of New Mexico's STATEMAP agreement. While maps are produced, maintained, and updated in an ArcGIS geodatabase, at the time of the STATEMAP deliverable, each map goes through cartographic production and internal review prior to uploading to the Internet. Even if additional updates are carried out on the ArcGIS map data files, citations to these maps should reflect this original publication date and the original authors listed. The views and conclusions contained in these map documents 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.

Geologic Cross Section A–A'



Description of Map

QUATERNARY
Anthropogenic Deposits

af — **Artificial Fill**—Excavated sand, silt, and clay that was locally moved. Generally associated with berms, dams, and exploratory drilling projects. Thickness is 1–5 m.

Eolian and Sheetflood Deposits

Qe — **Eolian Sand**—Eolian sand dunes on mesa tops or sand ramps on the lee (commonly northeast) sides of mesa tops. Deposit is massive to vaguely cross-laminated. Sand is light-brown to light-yellowish-brown (7.5-10YR 6/4) to very pale brown (10YR 7/4) to brownish yellow (10YR 6/6) to light gray (10YR 7/2), fine- to medium-grained (mostly fine-upper to medium-lower), subangular to rounded, well-sorted, and composed of quartz, about 10–25% feldspar, and 1–10% lithic and mafic grains. Thick deposits have buried soils characterized by many, coarse, subanglar blocky peds with clay illuviation and local stage I calcic horizons. Locally overlies topsoils associated with unit Qseh (described below) and locally grades laterally into the younger, upper sediment of Qse. Dunes are up to 1 m tall. Deposits are loose and 1–5 m thick.

Qs — **Sheetflood Deposits**—Massive sand and silty-clayey sand with local laminations (typically horizontal-planar) or very thin to thin beds (horizontal-planar to lenticular). Sand is brownish, very fine- to medium-grained (up to 5% scattered, coarser sand grains), subangular to rounded and well- to moderately sorted. Occupies wide topographic lows at the heads of low-order drainages. Inferred to be deposited by unconfined flow (i.e., slopewash and sheetflooding). Thickness is 1–6 m.

Qse — **Sheetflood Deposits Reworking Eolian Material**—An extensive unit that underlies low-relief, relatively low slope-angle hillslopes. Commonly grades laterally upwards into Qseh deposits or downwards into Qs or Qas deposits. Sediment consists of vaguely bedded (mostly medium to thick), or else massive, fine- to medium-grained sand overprinted by paleosols; paleosols marked by ped development, clay illuviation, and variable precipitation of calcium carbonate. Sediment inferred to be derived from erosion of uphill lithologic units and also a reworking of eolian deposits by sheetflood (slopewash) processes. Thickness is 1–5 m.

Qseh — **High-Level Sheetflood Deposits Reworking Eolian Material (Pleistocene and Holocene)**—Fine- to medium-grained sand in vague, medium to very thick, tabular beds or else massive. Underlies high-level, flat, relatively stable, gently sloping geomorphic surfaces. These surfaces typically have a darker tone on aerial photography. Sand is yellowish-brown to light-yellowish-brown (10YR 5-6/4) or light-brown (7.5YR 6/4). The sand is mostly very fine- to medium-grained, subrounded, well-sorted, and composed of quartz, minor feldspar, and minor (about 10%) lithic and mafic grains; 0–10% silt and lesser clay. The abundance of fine sand is greater than very fine sand. Sand locally interbedded with slightly clayey-silty (≈5–15% fines) sand and thin pebbly lenses. Common pedogenic horizons: internally massive or burrowed, and typically exhibit moderate to strong ped development (medium to coarse and prismatic or subangular to angular blocky), with no to variable clay illuviation (faint to distinct coats on ped faces); variable precipitation of calcium carbonate but typically stage I (lesser II) carbonate morphology; local signs of burrowing. Weakly to moderately consolidated and non-cemented. Thickness can be up to 13 m, but typically 1–6 m.

Valley Floor Deposits

Qas — **Alluvial and Sheetflood Deposits, undivided**—A combination of alluvial deposits (commonly alluvial fans) and sheetflood deposits. Sediment shares properties with both Qayr and Qs. It is mapped on relatively steeper slopes flanking valley floors (1–3°) or at the head of low-order drainages. Thickness is 1–5 m.

Qayr — **Younger Alluvium**—Sand to clayey-silty sand (estimate up to 25% fines) underlying valley floors. May include up to ≈25% slopewash, typically at the heads of drainages. The color of the sand is commonly pale brown to light-yellowish-brown (10 YR-2.5 Y6/3-4) to grayish brown to light gray to pale brown (2.5Y 5-7/2, 7/3), less commonly brown (10YR 5/2-4). Sand is massive or in very thin to thick, tabular to lenticular beds that are locally horizontal-planar laminated to thinly bedded or, less commonly, cross-laminated. Minor (0–25%) very thin to thin pebbly beds (lenticular); local medium to thick beds are internally laminated to thinly bedded; pebbles are clast- to sand-supported and commonly composed of sandstone (subrounded to subangular) and iron-oxide fragments (angular to subangular). Sand is mostly very fine- to medium-grained (0-15%, scattered coarse and very coarse sand or pebbles) but fine- to very coarse-grained within pebbly beds, subangular to rounded (with lithic grains being more subrounded than quartz and feldspar grains), moderately to well-sorted, and composed of quartz, 5–15% (est) feldspar, and 5–15% lithic grains (especially volcanic and chert grains). Locally, trace to 0.5% charcoal, 0 to 3% coal fragments, and sparse root traces are present. Few to abundant buried soils characterized by ped development and weak calcium carbonate precipitation (stage I morphology); local faint clay illuviation on very few to minor ped faces or as bridges. Top soil characterized by ped development (up to strong, coarse, prismatic to angular blocky) but typically no clay illuviation and very weak to no calcic horizons. Weakly to moderately consolidated and non-cemented (very weak to moderate HCl effervescence). Up to 5 m of exposed thickness.

Older Alluvium and Terrace Deposits

Qaofo — **Older, Fine-Grained Alluvium Deposited by Tributaries to the Cañada de Ojo**—Light yellowish brown (10YR-2.5Y 6/4), typically massive sand and silt-clay likely deposited by the Cañada de Ojo and local tributaries. Sand is mostly fine-grained, subangular, well sorted, and loose. Weakly consolidated to loose. 1–10 m thick.

Qaoco — **Older, Coarse-Grained Alluvium Deposited by the Cañada de Ojo**—Sand interbedded with subordinate sandy pebbles and pebbly sand. Gravelly intervals are up to 1 m(?) thick and laminated to thinly bedded (lenticular or cross stratified). Gravel are moderately to poorly sorted and consists of very fine to very coarse pebbles composed mainly of sandstone (subrounded to subangular) and iron oxide fragments (subangular) with trace to 1% vesicular basalt (subrounded to subangular) and trace to 2% chert + quartzite (subrounded to rounded). Trace to 5% cobbles that include vesicular basalt. Sand is yellowish brown to pale brown to very pale brown to light olive brown (2.5Y-10YR 5-7/4), fine- to very coarse-grained, subangular to subrounded, moderately to poorly sorted, and composed of quartz, minor feldspar, and 10–20% lithic grains. Deposit capped (and perhaps interbedded with) eolian sand that is light yellowish brown (10YR 6/4), fine-grained, well sorted, and relatively massive. Inferred to interfinger locally with side-stream derived, older alluvium (Qao). Loose to weakly consolidated. At least 4 m thick, thinning away from Cañada de Ojo.

Qaoto — **Older Alluvium Deposited by Tributaries to the Cañada de Ojo**—Sand and minor gravel deposited by tributaries to the Cañada de Ojo. It is identified by geomorphic position (map polygon is elongate and at a high angle to Cañada de Ojo), texture (e.g., coarser texture than adjoining Qaofo), and gravel composition reflecting local source. Gravel is typically pebble-size and angular to subangular. Sand is brown to light olive brown (10YR-2.5Y5/3), very fine- to medium-grained, and has up to 1–15% clay-silt in the matrix. The unit is loosely consolidated, and 1–5 m thick.

Qaotr — **Older Alluvium of Tributaries to Rio Puerco**—Massive sand with 10–20% sandy gravel. Sand is in thin to thick, tabular beds that are internally horizontal-planar laminated or cross-laminated (<3 cm thick foresets). Gravel is in very thin to medium, lenticular beds. Gravel consist of pebbles with 1% cobbles that are subrounded to rounded, poorly to moderately sorted, and composed of chert with 30–40% sandstone, 2% granite, trace Pedernal Chert, 1–5% quartz + quartzite, 5% petrified wood, and 2–3% intermediate-mafic volcanic rocks. Sand is pale brown to very pale brown to light yellowish brown (10YR 6/3-4, 7/3), very fine- to very coarse-grained, subangular to rounded (mostly subrounded), moderately to poorly sorted, and composed of quartz, 5–25% feldspar, 15–20% chert, and 1–10% volcanic grains (all very coarse grains are lithics). Paleoflow was to SSE. Loose to moderately consolidated and non-cemented. 3–5 m thick.

Qamotr — **Middle–Older Alluvium of Tributaries to Rio Puerco**—Predominately fine- to medium-grained sand with very minor gravel and coarse- to very coarse-grained sand. Less than 10% clay-silt. Sand is pale brown to brown (10YR 5/2-3; 6/3),very fine- to medium-grained, subangular (mostly) to subrounded, and composed of quartz, minor feldspar, and 1–3% lithic grains. Pebbles are commonly subangular and composed of iron-oxide fragments and sandstone. Tread stands 2–4 m above modern grade, and base of deposit is typically buried by Qayr. Occupies different drainage than deposits mapped as Qaotr, but they may in fact be correlative. The unit is loosely consolidated, and 2–5(?) m thick.

CENOZOIC BASIN-FILL OF THE SANTA FE GROUP
Zia Formation

Tzcm — **Chamisa Mesa Member**—Sandstone, silty-clayey sandstone, and 1–10% siltstone in thick (up to 1.5 m, very minor 10–30 cm thick beds), tabular beds that are internally massive, bioturbated (with paleoburrows), or horizontal-planar laminated. Minor intervals (a few meters thick and ≈ 5% of unit) of sandstone that are cross-stratified (forests up to 30 cm tall). Another minor (≈1% of sediment volume) and distinctive lithofacies consists of ≈1-m-thick intervals comprised of 0.5–1.0 cm thick, laterally extensive, tabular beds that are commonly strongly cemented. Sand is pink to reddish yellow (7.5YR 7/3-4 to 6/6) to very pale brown (10YR 7/3-4), very fine- to medium-grained (mostly fine-lower to medium-lower), subrounded, well to moderately sorted, and composed of quartz, 10–20% feldspar, and 10–20% chert + orangish quartz, 3–15% volcanic lithics. Locally, up to 10% medium-upper to coarse-lower sand. Clay-silt content ranges from 0–10%. Sparse (1–10%) beds that are extensively paleo-burrowed and strongly cemented. Locally, beds contain rhizoliths 2–11 mm wide and several cm long. One 10 cm thick, white limestone bed containing ≈1-mm-long ostracods. Strongly cemented beds comprise an estimated 3–10% of sediment volume; remainder are mostly weakly cemented and moderately to well consolidated. Top contact not observed. Basal contact with Tzpp not well-exposed. Compared to Tzpp, this unit is pinker, contains very fine sand and clayey-silty sand, and sand grain size is mostly fU-mU rather than fL-mL. The unit is ≈20 m thick.

Tzpp — **Piedra Parada Member**—Sandstone that is cross-laminated or in medium to thick, tabular to lenticular beds that are internally massive, borrowed, or cross-stratified (laminated to very thin foreset beds up to 30 cm tall). Sand is very pale brown (10YR 7/2-3), fine to coarse-grained (mostly fine-upper to medium-lower), subangular to rounded (mostly subrounded), moderately to well and composed of quartz, ≈15–20% feldspar, 5–25% orange-stained quartz + orangish chert, and 5–30% dark lithics (volcanic + chert). Trace to 5% very thin beds containing abundant medium-upper to coarse-upper lithic grains. Medium-upper to coarse-upper sand is wholly composed of dark chert + dark volcanic lithic grains. 1–10% medium to thick, tabular beds that are commonly burrowed and strongly cemented. Locally 1–5% prominent rhizoliths that are 0.5–2.0 cm wide and up to 60 cm long. A gravelly interval is commonly seen at base of unit. Where exposed, this basal zone consists of a 1-m-thick interval of very thin, lenticular pebble beds (very fine to coarse, subrounded to rounded) interbedded with very thin to thin, tabular beds of sand; the pebbles are subrounded, moderately sorted, and composed of chert and fine-grained rhyolites (possible fine-grained intermediate volcanic rocks). Non-gravel sediment in the basal zone is composed of pink to very pale brown (7.5-10YR 7/3-4) sand to orangish clayey-silty sand; sand is fine-lower to medium-lower (with 10–15% medium-upper to very coarse-upper), mostly subrounded, and poorly sorted. Basal contact is wavy and unconformably overlies unit Kme. 10–20% strong cementation; otherwise, weakly consolidated and non- to weakly cemented. Local cigar-shaped, consistently elongated cemented features that likely reflect paleo-groundwater flow (Mozley and Davis, 1996). Compared to unit Tzcm, this unit lacks very fine sand & silty-clayey fine sand (except in basal zone), lacks pink colors, and grain size is mostly fU-mU rather than fL-mL. The unit is 15–25? m thick.

LATE CRETACEOUS ROCKS

Kme — **Menefee Formation**—Fine-grained floodplain deposits interbedded with 10–30% sandstone channel-fills that locally fine upwards into floodplain deposits. Locally hosts abundant petrified wood or logs. Floodplain sediment consists of mudstone, siltstone, and very fine- to fine-grained sandstone. Mudstone is mostly light gray to gray to grayish-brown to dark grayish-brown to light brownish-gray to light yellowish-brown to brown; there are more greenish gray (≈5% of unit; 5Y 7/2-3) and light gray mudstones in Kme compared to Kcg. 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 to 0.5% higher in the section). In the mudstone are 0–0.5% organic fragments (up to 6 mm long) and twig or wood imprints. The siltstone and sandstone in the floodplain deposits is commonly horizontal-planar laminated. There are local layers with high concentrations of iron oxide concretions, ranging from nodule to boulder-size or occurring in lenses. Also local orange to yellow discolorations (associated with sulfur?) that occur as splotches or in thin layers. Sandstone channel fills range in size from ribbon forms (0.2–2.0 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) to tangential cross-lamination (foresets may also be very thin) to horizontal-planar laminations; also locally massive or in very thin to medium, tabular beds. Measurement of the geometry of the troughs indicate a north to southeast paleoflow direction. The sandstone is white to light gray to very pale-brown to pale brown (10YR 8/1; 2.5Y 7-8/1; 10YR 7/3-8/2; 2.5Y-10YR 6/4), weathering to very pale-brown and yellow (10YR 7-8/3; 6-7/6) to light yellowish-brown to pale brown to brown (10YR 6/3-4; 5/3). Sand grains are very fine- to medium-grained (mostly fine sand), mostly subangular, well-sorted, and composed of quartz, 5–25% feldspar, and 5–15% black to dark gray lithic and mafic grains. Trace very fine to medium pebbles composed of iron oxide-cemented, intraformational sandstone. Trace to 1% organic or coal fragments. Ripple marks are locally seen. Variably cemented by calcium carbonate and possibly clay. Preserved thickness is ≈550 m (Koning and Jochems, 2013).

Point Lookout Sandstone

Kp — **Point Lookout Sandstone, undivided**—Units Kpu and Kph, undifferentiated. See descriptions for these units below.

Kpu — **Upper Tongue (Main Body)**—White (locally yellowish or brownish), cliff-forming sandstone. Sandstone is laminated (minor 3–10-cm-thick beds), and cross-stratified (foresets up to 1 m tall) or horizontal-planar laminated. Very minor (1–5%) 10–100-cm-thick beds that are internally massive. Sand is fine-upper to medium-upper, subangular, well-sorted, and composed of quartz, 15–20% feldspar (commonly weathering to white), and 10–15% lithic grains (black, gray, or reddish-brown). Local (<1%) fine-grained intervals consisting of mudstone, intimately interbedded shale and fine sandstone, or laminated, fine-grained sandstone containing abundant clay rip-ups; mudstone is brown to pinkish-gray (7.5YR 5-6/2) and poorly to moderately fissile; these fine-grained intervals pinch out laterally, grading laterally into a laterally extensive and prominent bedding plane. The lower contact of the unit is sharp and planar or exhibits scour relief (up to 1 m). Moderately to well-cemented. The unit thickness is ≈60 m.

Kpf — **Fine-Grained Tongue Laterally Equivalent to the Satan Tongue of the Mancos Shale**—Tongue of fine-grained sediment in the lower Point Lookout Sandstone, whose base is located 8–13 m above the base of Kph; tongue separates units Kph (below) and Kpu (above). Laterally variable, but in general the lowest 0–20 cm is composed of interbedded or mixed, white to light gray to light yellowish brown-yellowish brown (10YR 5-6/4) siltstone + fine sandstone and brown (7.5YR 4-6/3) claystone (with plant imprints) that is overlain by 0–100 cm of very fissile, dark gray to brown to grayish brown (7.5YR 4/1-2, 5/2, 4-5/3; 10YR 5/2) claystone (lacking plant imprints) that grades upwards into horizontal-planar to wavy laminated, variably fissile, brown (7.5YR 5-6/1-3; 10YR 5/1-2) claystone-mudstone (10–300 cm). The laminated claystone, in turn, grades upwards into one of the following lithofacies: 1) poorly to moderately fissile, brown (7.5YR 5-6/3) claystone or interbedded claystone-siltstone; 2) splotchy (bioturbated) mudstone + siltstone (with plant remnants or imprints); 3) pinkish gray (7.5YR 6/2), very fine- to fine-grained sandstone that is massive and/or bioturbated, or 4) very-fine- to fine-grained sandstone and siltstone (light gray to white, very thin to thin and tabular beds) interbedded with subordinate light brown-brown mudstone (#3 and #4 may overlie #1 or #2). Coal beds (5–30 cm thick) locally found near base or near the top of the unit. Siltstone and very fine- to fine-grained sandstone are light gray to white, finely laminated (wavy to horizontal-planar), and intricately interbedded with minor clay lamina. Local splotches or streaks of yellow and orange. Along the eastern boundary of the quadrangle, there is commonly two lower fissile-shale beds (medium to thick and tabular) overlain by 6–8 m of sandstone or sandstone interbedded with minor clay lamina. Sharply overlies a medium to thick, tabular, laterally extensive bed of strong-brown to reddish-yellow sandstone (7.5YR 5-6/6) capping unit Kph. Upper contact is sharp and scoured, with up to 1 m relief. Typically 0.3–6 thick, but as much as 13 m thick (to east) and pinching out locally (to west).

Kph — **Hosta Tongue**—Tongue of white to light gray (2.5Y 7/1) to yellow (2.5Y 8/2-3) sandstone that is fine- to medium-grained (mostly fine-lower to medium-lower), subangular, well sorted, and composed of quartz, minor feldspar, and 2–15% dark lithic or mafic grains. Locally near Mesita Blanca, midway up in sandstone tongue is a 10–300 m thick interval of pinkish gray to gray, clayey-silty fine- to medium-grained sandstone (bioturbated) or interbedded sandstone-mudstone. Tabular beds and bioturbation are more common in lower half of tongue, and cross-stratification is somewhat more abundant in upper half (foresets are tangential and up to 30 cm tall). Local burrows in lower half are up to 7 mm wide and 20 cm long. Basal contact is commonly a scoured surface, but also locally gradational (beneath scour) over 1–20 cm. Uppermost 70–80 cm of Kph is bioturbated, with the degree of bioturbation increasing up-section; within 10–20 cm below the upper contact the sandstone is oxidized (orange-reddish) and burrowed. Top surface makes a prominent bench. Moderately to well cemented and forms ledges. Generally 6–8 m thick, but locally pinches out (i.e., NW of Mesita Blanca) or is as much as 12 m thick.

Crevasse Canyon Formation

Kcg — **Gibson Coal-Bearing Member of the Crevasse Canyon Formation**—Fine-grained deposits [interpreted as swamp, lagoon, and floodplain facies], interbedded with subordinate sandstone channel fills. The former display an overall dark-gray color, contrasting notably with the underlying Dalton Sandstone and Mullato Tongue of the Mancos Shale. 10–25% 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. Channel-fills are cross-stratified, with tangential foresets or trough cross-laminations (up to 80 cm tall) being especially common, or horizontal-planar laminated. Sandstone is white to light gray to pale brown (10YR–2.5Y 8/1-2; 2.5Y–10YR 7/3-4) and very fine- to medium-grained (mostly fine-grained), subangular, well-sorted, and composed of quartz, ≈3–25% feldspar, and 3–20% mafic + very dark lithic grains. The sandstone locally has a fine-grained matrix, giving it a "dirty" appearance. Also, organic films may coat lamination planes, there is trace organic detritus, and locally there are orange, splotchy discolorations. The sandstone is weakly to strongly cemented by calcium carbonate. Fine-grained sediment generally consist of mudstone and siltstone to very fine-grained sandstone. Siltstone and very fine-grained sandstone are commonly light gray (7.5YR 7/1) to white (2.5Y 8/1) and in laminated to thin beds. Mudstone displays the following colors: very dark-gray (7.5-10YR 3/1), gray to light gray (N5/ to N7/ and 7.5YR 6/1; 2.5Y 7/2; 7.5-10YR 5/1), brown (7.5YR 5/3-4, 4/3 and 4-6/2; 10YR 5/3), dark brown (7.5-10YR 3/3), light brown (7.5YR 6/3), grayish-brown to dark grayish-brown (10YR 3-5/2), and lesser light reddish-brown to pink (5YR 6-7/4; 7.5YR 7/3). This fine-grained sediment exhibits horizontal-planar to wavy laminations and locally exhibits reduction-related, splotchy yellow-green discolorations. Locally interbedded within the swamp + floodplain deposits are crevasse splay sandstones that are <20 cm thick and locally low-angle cross-stratified; these are composed of fine- to medium-grained, subangular to subrounded sand containing quartz, 5–10(?)% feldspar, and ≈10% very dark lithic grains and mafic grains. Fine-grained deposits contain 1–5% coal or organic-rich mudstone beds that are thin to thick (up to 50 cm) and tabular. Local layers are present with abundant concretionary iron-oxide chips, as well as local klinker zones. Unit underlies the Point Lookout Formation and overlies the Mullato Tongue of the Mancos Shale. The base of unit intertongues with uppermost Mullato Tongue sands over 5–12 m. Basal contact drawn at the top of the intertonguing (transition) zone, above which there is either a ≥3 m-thick fine-grained tongue or more than 30% fine-grained and dark-colored sediment. Top of unit is gradational with the Hosta Tongue of the Point Lookout Sandstone over 3–20 cm or else scoured (1–10 cm of scour relief). The unit thickness is 60–80 m.

Kcda — **Dalton Sandstone Member of the Crevasse Canyon Formation**—Bipartite, coarsening-upward sandstone body. The lower unit is yellowish and in medium to very thick bedded (up to 6 m), tabular beds that are internally massive with subordinate, vague, horizontal-planar laminations and lesser low-angle cross-laminations; 1–5% thin to medium (minor thick), tabular beds that are internally massive, burrowed, commonly strongly cemented, and locally have bivalve molds; 0–5% 10–20 cm thick, tabular beds that are internally cross-laminated (up to 20 cm tall and exhibiting tangential and planar foresets); near base of the unit, local hummocky ripples up to a few cm tall. Sand is pale brown to very pale-brown to yellow (2.5Y-10YR 7/3-6), locally weathering to golden colors, very fine- to medium-lower (mostly very fine-upper to fine-upper), subangular, well-sorted, and composed of quartz-rich sand with 3–5% dark lithic grains. The upper unit is more white and cross-stratified than the lower unit, with subordinate horizontal-planar laminations; foresets are laminated and up to 0.8 m tall. Sand is light gray (2.5Y 7/2), fine-upper to medium-lower, subangular, well-sorted, and composed of quartz, 10–15% weathered feldspar, and 5–7% lithic grains. Well-cemented but lacks effervescence in HCl, so cementing agent is likely silica or clays. In both units are trace to 1%, very thin to thick, tabular beds of pinkish-gray (5-7.5YR 6/2) or brown (7.5YR 5/3) fissile shale (horizontal-planar laminated). The lower contact of Dalton Sandstone is characterized by a 4–10 m thick interval of interbedded sandstone and mudstone, where the proportion and thickness of sandstone beds increases up-section. We mapped the lower contact at the top of this transitional interval, above which the proportion of shales is ≈3%. Within this transitional interval, sandstone beds are light yellowish-brown (10YR 6/4), lenticular to tabular, 30–100 cm thick, and internally massive to horizontal-planar laminated or locally hummocky ripple-laminated (up to 3 cm tall); shales are light brownish-gray (2.5Y 6/2) and horizontal-planar laminated to slightly wavy; bed contacts are sharp and planar to wavy (up to 3 cm of relief). The upper contact of Dalton Sandstone is characterized by a 10–12 m thick intertonguing zone, where the upper contact may be wavy (1–10 m of vertical relief) due to the preservation of dunal paleotopography. Interdune, paleotopographic lows are filled by either: 1) fissile, gray to light gray (7.5-10YR 6/1; 2.5Y 6-7/1) shales; or 2) light gray (2.5Y 7/2) massive to horizontal-planar laminated sand interbedded with minor very thin to medium beds of gray (7.5YR 5/1), poorly fissile shale; both types of strata are inferred to represent lagoonal facies. Where practical at 1:24,000 scale mapping, these interdunal lagoonal deposits are included in basal Kcg. Otherwise, the upper contact is placed at the top of the transition zone: above which the proportion of dark-colored and fine-grained sediment is >30%, or at the base of the lowest fine-grained bed that is ≥3 m. Uppermost dunal sands are internally massive (bioturbated) to cross-laminated. Dalton sandstone is moderately to strongly cemented, and 27–40 m thick.

Kcdi — **Dilco Member of the Crevasse Canyon Formation**—Grey to brown sandstone, shale, mudstone and impure coal. Lowermost sandstones are light grey to greyish brown (10 YR 6/1–10 YR 5/2) non-calcareous, medium- to fine-grained to silty, moderately to poorly sorted, and have a clay-rich matrix. Dominantly composed of subangular to subrounded quartz grains. Bedding is thin and way with flaser beds locally and abundant clay fragments and lenses. These beds form a continuum with very clay-rich, friable, sandy mudstone and very shaley sandstone with generally similar appearance, bedding, and weathering characteristics, though colors of the latter tend to dark greyish-brown to very dark brown (10 YR 3/2–10YR 2/2). Fissile shale is gray (10 YR 5/1) to darker brown colors. Thin to very thin coal beds are black and shaley. Uppermost sandstone beds are ledgy and resistant, light grey to white to pale yellow (2.5 Y 7/2 to 2.5 Y 8/2 to 5Y 8/3) and locally red to brick red to brown due to iron oxidation. Sandstone is non-calcareous, clean and quartz-rich, medium- to fine-grained, with a few to 10% of black and white chart. Bedding is medium to thick and parallel. Bioturbation in the form of borings and filled burrows is common, as are symmetrical anastomosing ripple marks on bedding surfaces. These upper beds are usually 1–2 m thick but are up to 8 m thick in the northcentral part of the quadrangle and often absent to the south. The unit is 0–20 m thick.

Mancos Shale

Kmmu — **Mulatto Tongue of the Mancos Shale**—Relatively sandy marine shale displaying a distinctive yellowish color and eroding readily to produce subdued topography. Local 1–4 m thick sandstone tongues (fine-lower to fine-upper) in upper 15 m of unit. Bulk of unit consists of laminations to very thin beds that are horizontal-planar to slightly wavy (up to 2 cm amplitude); sand may be in thin, tabular beds or exhibit hummocky cross-stratification (locally ripple-marked). Sharp contacts between beds. Sediment consists of very fine- to fine-grained sandstone and siltstone interbedded with subequal to subordinate proportions of fissile shale or claystone. Shale + claystone is pale brown to light yellowish-brown or brown to dark grayish brown (10YR 5-6/3-4; 10YR 4/2; 2.5Y 6/1-4; 2.5Y 5/2; 2.5Y 4-5/3). Sand is pale brown to white (2.5Y 7/3-4; 2.5Y–10YR 6/3; 2.5Y 8/2-3; 2.5Y–5Y 8/1) or light gray to very pale-brown (10YR 7/3-4; 2.5Y–10YR 7/2), mostly very fine-lower to fine-lower, subangular, well-sorted, and composed of quartz, ≈3% feldspar, and 5% mafic + lesser lithic grains. Local 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 or cross-laminated (including hummocky cross-lamination). Trace to 1% laminae to very thin beds of crystalline gypsum, probably a product of diagenesis or groundwater precipitation. Locally, paleo-burrows are present (1–2 mm wide). Moderately to well-consolidated. Thickness is 90–100 m (Koning and Jochems, 2013).

Kmmi — **Middle Part of Mancos Shale Between the Gallup Sandstone and Two Wells Sandstone Tongue of the Dakota Sandstone**—Poorly exposed shale. Dark-gray to light-yellowish-brown to pale brown fissile shale and silty shale. Laminated to thin-bedded. Upper 1 m consists of interbedded shale and very fine- to fine-grained sandstone, representing a gradational zone with the overlying Gallup Sandstone; below this transitional zone lies very fine-sandy shale. Sparse boulder-size concretions cemented by calcium carbonate and lesser silica. The unit is 160–180 m thick.

Kmw — **Whitewater Arroyo Tongue of the Mancos Shale**—Poorly exposed dark-grayish brown to light-grey, fissile shale and yellowish-brown to very pale brown, massive silty shale. The unit is 18–25 m thick.

Kmcm — **Clay Mesa Tongue of Mancos Shale**—Light- to dark-gray to very pale brown, parallel and very thin- to thin-bedded, fissile shale and silty shale with thin limestone layers and concretions. The unit becomes more silty and sandy upwards as it grades into the overlying Paguate Sandstone Tongue. It is usually poorly exposed and covered by colluvium and rubble of the Paguate Sandstone Tongue, except in vertical cliffs. The unit is 10–15 m thick.

Kg — **Gallup Sandstone**—Cliff-forming quartz sandstone. Lower portion forms a ledge or cliff and is calcareous, fine- to medium-grained, but locally coarse to very coarse, pale tan to medium reddish-brown quartz sandstone with a few percent of dark mafic mineral sand/or chert. Grains are subangular to subrounded. Parallel, medium- to very thick-bedded, to crossbedded with multi-directional troughs. In coarse, trough crossbedded areas, white chert and dark mafic minerals and lithic fragments(?) may be 15–20% of the rock. Upper portion weathers back from cliff edge and is white to pale grey. It is composed of friable fine- to medium-grained poorly-sorted, non-calcareous quartz sandstone with a few percent of pink, white, and black chert grains. Medium- to thick-bedded with broad, multi-directional trough crossbeds. Unit weathers into distinctive "beehive" domes. The unit is 35–40 m thick.

DAKOTA SANDSTONE

Kmwdt — **Whitewater Arroyo Tongue of the Mancos Shale and Twowells Member of the Dakota Sandstone, undivided**—The unit is present in the cross section only.

Kdu — **Paguate Member of the Dakota Sandstone, Clay Mesa Tongue of Mancos Shale, Cubero Member of the Dakota Sandstone, and Oak Canyon Member of the Dakota Sandstone, undivided**—The unit is present in the cross section only.

Kdt — **Twowells Sandstone Member of the Dakota Sandstone**—Shaley sandstone coarsening-upward to clean sandstone. Lowermost beds are medium gray fine-to medium-grained, non-calcareous, quartz sandstone with clay matrix and are gradational into the underlying Whitewater Arroyo Shale Tongue. The thin- to medium-thickness beds are parallel. A silty and shaley interval separates these from the uppermost beds, which are light gray to pale brown, fine- to coarse-grained, moderately well-sorted noncalcareous quartz sandstone with several percent of lithic fragments, mafic mineral grains, chert, and dark green to black glauconite, which is distinctive of the unit. Upper beds are thin to very thick with planar cross-beds prominent locally. The unit is 5–15 m thick.

Kdp — **Paguate Sandstone Member of the Dakota Sandstone**—Massive, cliff-forming clean quartz sandstone. White to pale tan, fine- to locally very fine-grained clean quartz sandstone. Grains are rounded to well-rounded. The unit often has little discernible bedding and is thus massive in appearance. Medium-brown filled burrows and round to oval concretions are abundant. Generally makes a bold cliff and abundant blocky rubble with boulders up to 10 m in diameter. In most areas a distinctive clean quartz sandstone upper layer is present, 0.5–1 m thick, that is lighter in color to white, not calcareous, well-bedded, and has well-developed, regular joints. The main body of the unit has irregular, less abundant joints. The base of the unit is usually somewhat gradational with the underlying shale; upper contact is sharp, and the unit is 6–15 m thick.

Kmcdc — **Clay Mesa Tongue of the Mancos Shale and Cubero Member of the Dakota Sandstone, undivided**—Mapped in areas of low dip where the two units cannot be illustrated separately at the scale of the map.

Kdc — **Cubero Sandstone Member of the Dakota Sandstone**—White to medium gray ledge-forming noncalcareous sandstone composed of well-sorted and subangular to subrounded quartz grains with less than 5% black and white grains of probable chert. Parallel- and thin- to medium-bedded. Bedding surfaces commonly display abundant filled burrows as well as a consistent joint pattern that forms lozenges or diamonds. The lower contact is gradational with underlying shales of the Oak Canyon Member; upper contact is sharp. Variable in thickness, generally about 10 m thick.

Kdoc — **Oak Canyon Member of the Dakota Sandstone**—Ledge-forming brown sandstone overlain by shale and probable siltstone beds. Basal sandstone is usually 1–2 meters thick, pale brown, brownish-yellow, and dark-yellowish-brown., quartzose, and not calcareous. One thick to three distinct but thinner beds may be present due to lateral facies variations. Bedding is generally flat with local zones of cross-bedding between parallel beds. Quartz grains are medium- to coarse-grained and subrounded to well-rounded. A few percent of varicolored chert grains are present. Symmetric ripples are present on some bedding surfaces and pits, and tubules are abundant, indicative of bioturbation. The sandstone forms a distinct brown ledge above underlying cliffs and rubbly slopes of Jurassic rocks. The upper Oak Canyon Member comprises about half of the unit and is a poorly exposed shale with probable siltstone and bentonite beds. The shale is usually significantly weathered back from the basal sandstone ledge and forms rubble-covered, vegetated slopes below the overlying Cubero Sandstone Member. The unit is 18–23 m thick.

JURASSIC ROCKS
Morrison Formation

Jmj — **Jackpile Sandstone Member of the Morrison Formation**—Massive, cliff-forming, white sandstone and minor mudstone. Sandstones are massive and structureless to parallel and trough cross-bedded. Color ranges from dominantly white to pale pinkish-white to pale tan. Bedding ranges from thick to very thick, with some cross-bed sets up to several meters in thickness. Sandstone is dominantly composed of rounded to angular, medium to coarse quartz grains. Chert grains and lithic fragments and/or mafic mineral grains are sparse. A few percents of fine- to coarse-grained angular, chalky white kaolinite grains are present. The upper few meters of sandstone are usually pure white due to abundant kaolinite grains and pore fill. Green and less common red mudstone are locally present as stringers and lenticular pods. Locally the unit makes a rubbly slope or irregular outcrop, but it is often a near-vertical cliff. The unit is 0–35 m thick.

Jmbb — **Brushy Basin Member of the Morrison Formation**—Slope-forming mudstone and lensoidal fluvial sandstone. Mudstone is bentonitic and light greenish-gray, reddish-gray and weak red with abundant calcareous nodules 5–10 cm in diameter. Surface is characterized by crumbly "popcorn" weathering texture due to high content of swelling clay minerals. Mudstone intervals often obscured by blocky sandstone colluvium derived from overlying units and/or sandstone interbeds. Sandstones are medium- to coarse- and very coarse-grained, locally pebbly, white, yellow, pale brown and darker colored, noncalcareous, and highly variable in degree of cementation. They represent intermittent deposition of sand in channels in a dominantly floodplain or lacustrine environment. The unit is ≈60–70 m thick.

Jb — **Bluff Sandstone**—Red to red and white banded quartz sandstone. Fine- to medium-grained, slightly calcareous quartz sandstone with fine-grained to silty matrix. Color ranges from red (2.5 YR 5/6 to dark red (10 R 5/6) with prominent white bands. Broad planar tabular cross beds are several meters high with bases tangential into subparallel very thick beds. Unit forms very distinct cliffs with a rounded top. Base not exposed; 60 m thick on Arch Mesa quadrangle to the west (Moench and Puffet, 1963).

Jt — **Todilto Formation**—The unit is present in the cross section only. Gypsum overlying limestone. The unit is 30 m thick.

Je — **Entrada Formation**—The unit is present in the cross section only. Sandstone and siltstone. The unit is 61 m thick.

TRIASSIC AND PERMIAN ROCKS

TRc — **Chinle Formation**—The unit is present in the cross section only. Mudstone, siltstone, and channel sandstone. The unit is 460 m thick.

TRPu — **Agua Zarca Sandstone Member of the Chinle Formation and Moenkopi Formation (Triassic), San Andres Limestone, Glorieta Sandstone, and Upper Part of the Yeso Formation, undivided**—The unit is present in the cross section only. Sandstone, siltstone, mudstone, limestone, shale, and gypsum. Contains multiple unconformities. The unit is 210 m thick.

PERMIAN ROCKS

Pym — **Mesita Blanca Sandstone Member of the Yeso Formation**—The unit is present in the cross section only. Siltstone and sandstone. The unit is 174 m thick.

Pa — **Abo Formation**—The unit is present in the cross section only. Mudstone and arkosic sandstone that is 162 m thick.

PENNSYLVANIAN ROCKS

IPms — **Madera Group and Sandia Formation, undivided**—The unit is present in the cross section only. Limestone, shale, arkosic limestone, and sandstone. The unit is 380 m thick.

PROTEROZOIC ROCKS

XY — **Igneous and Metamorphic Rocks, undivided**—The unit is present in the cross section only.