Preliminary Geologic Map of the La Mesita Negra Quadrangle, Bernalillo County, New Mexico (Year 2 of 2-Year)

By

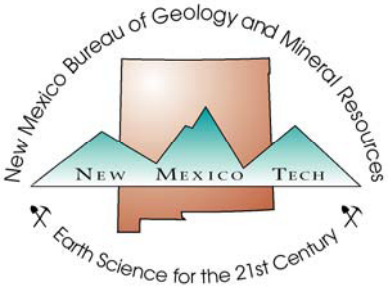
Colin T. Cikoski, Daniel J. Koning, and Sean D. Connell

June 2012

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 223

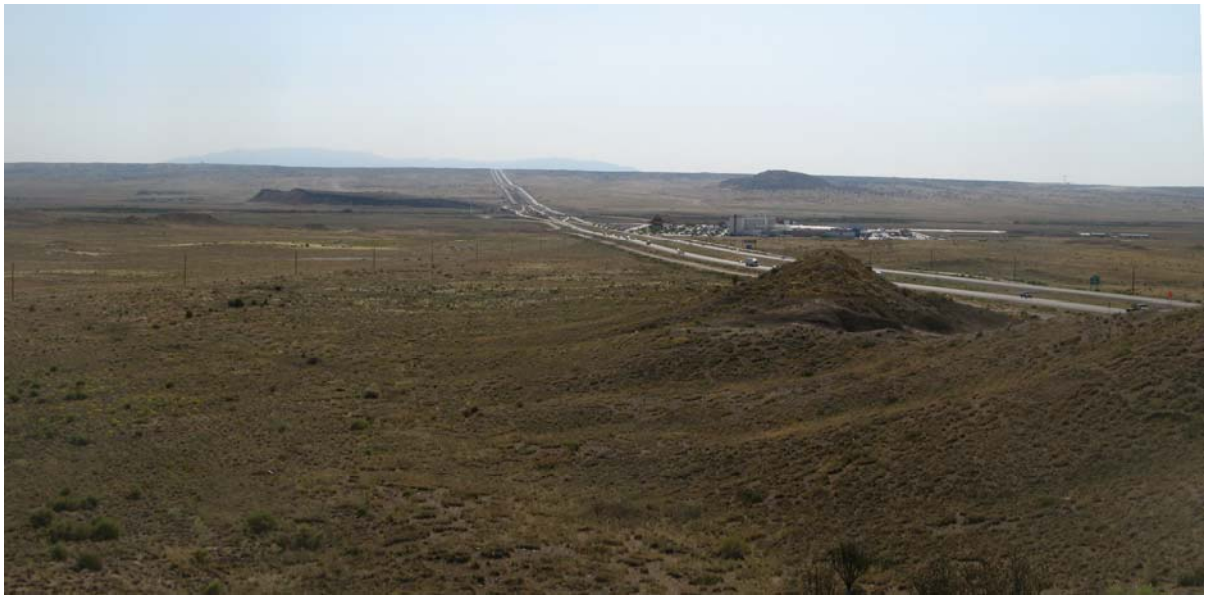
Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 10HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.



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

PRELIMINARY GEOLOGY OF THE LA MESITA NEGRA QUADRANGLE, BERNALLIO COUNTY, NEW MEXICO



Cover photo: Typical view of the La Mesita Negra quadrangle, looking east-southeast. La Mesita Negra itself is the low mesa on the left-center of the photo. Cerro Colorado is the rounded hill in the right-background. Hills in the right-foreground are underlain by the Cretaceous Menefee Formation. Large concrete building in front of Cerro Colorado is the Route 66 Casino. Scarp spanning the background of the photo is the Ceja del Puerco, underlain by the Ceja Formation. The majority of the quadrangle consists of poorly exposed gentle slopes, which are underlain by a combination of Quaternary alluvium and Miocene-Pliocene Santa Fe Group sediments.

COLIN T. CIKOSKI[1,*], DANIEL J. KONING[1], and SEAN D. CONNELL[2]
[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM 87801
[2]Chevron Energy Technology Company, San Ramon, CA 94583
[*]Compiler and corresponding mapper: colintc@nmbg.nmt.edu

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.

ACKNOWLEDGMENTS

Mapping of the La Mesita Negra 7.5' quadrangle was funded by the STATEMAP program, which is jointly supported by the U.S. Geological Survey and the New Mexico Bureau of Geology and Mineral Resources. We thank J. Michael Timmons of the NMBGMR for logistical support. We also thank Richard Luarkie, Governor of the Pueblo of Laguna, as well as the Laguna Tribal Council for permission to access and work on their land.

INTRODUCTION

The La Mesita Negra 7.5' quadrangle lies along the western margin of the Rio Grande rift geologic province at the latitude of the city of Albuquerque. The Rio Grande rift is a late Oligocene to recent intracontinental extensional zone, where the crust is extending in a generally east-west direction. Extension has broken the region into north-south elongate rift basins that have progressively filled with clastic sedimentary rocks assigned to the Santa Fe Group. In the vicinity of the study area, the rift abuts the Colorado Plateau, a relatively stable geologic province characterized by relatively weakly deformed Mesozoic strata. Upper Cretaceous rocks that predate extensional tectonics are locally exposed on the quadrangle in the footwalls of large normal faults.

GENERAL STRATIGRAPHY

The majority of the quadrangle is underlain by poorly cemented sediments of the lower Miocene through Pliocene Santa Fe Group (SFG), the unit to which all rift-related sedimentary basin fill up to and including the maximum level of aggradation are assigned (Baldwin, 1963; Hawley et al., 1969). Excluded from the Santa Fe Group are flights of inset Pleistocene to recent alluvial and eolian units which lay along the Rio Puerco valley. The Santa Fe Group units mapped here include the Piedra Parada and Chamita Mesa Members of the Zia Formation (as described by Tedford and Barghoorn, 1999; originally defined by Galusha, 1966; Figure 1), the Cerro Conejo Formation (as redefined by Connell, 2008; previously described as a member of either the Zia or Arroyo Ojito Formation by Tedford and Barghoorn, 1999, and Connell et al., 1999, respectively; Figure 2), the Navajo Draw Member of the Arroyo Ojito Formation (as defined by Connell et al., 1999; Figure 3), and the Atrisco and Rio Puerco Members of the Ceja Formation (as defined by Connell, 2008; Figure 4). In addition, we suggest the presence of an unnamed gravelly western piedmont unit that is lithologically similar to the gravels of the Cerro Conejo Formation but age correlative to the Navajo Draw Member (our unit "Towp"). The existence of such a unit is suggested by comparing the stratigraphy of the La Mesita Negra area to the stratigraphy established to the north and east of the quadrangle (e.g., Tedford and Barghoorn, 1999; Connell et al., 1999; Connell, 2008). In these other areas, reddish sandstones and mudstones of the Cerro Conejo Formation are overlain by yellowish gravelly sands and sands of the Navajo Draw Member of the Arroyo Ojito Formation. In the La Mesita Negra area, reddish sandstones resembling those of the type locality of the Cerro Conejo Formation are overlain by gravels with southeastward paleocurrent indicators, which appear to locally interbed with yellowish sandstones that resemble the Navajo Draw. We suggest that these southeast-

directed gravel beds and associated sands and sandstones may belong to a west-derived stream that interacted with the fluvial system that deposited the Navajo Draw. This hypothesis could be further addressed with sandstone petrography on the yellowish sandstones to confirm their relationship to the Navajo Draw sandstones.

It is possible that the Loma Barbon Member of the Arroyo Ojito Formation is also present on the quadrangle, lying between the Navajo Draw Member of the same Formation below and the Atrisco Member of the Ceja Formation above. The sediments in question are light colored sandstones currently assigned to the Atrisco Member (Figure 5), which lithologically could belong to either this unit or the Loma Barbon. According to Connell (2008), the contact between the Arroyo Ojito Formation and the Ceja Formation is marked by a well-developed Stage III or IV calcic/petrocalcic horizon, which he named the Rincones paleosurface. We did not observe this buried soil in the La Mesita Negra quadrangle, inhibiting accurate location of the contact and assignment of the light colored sandstones. On-going work by D.J. Koning on the Benavidez Ranch quadrangle immediately north of the La Mesita Negra quadrangle will hopefully clarify this uncertainty.

In this area, the Rio Puerco Member of the Ceja Formation is the youngest Santa Fe Group unit, and is capped by the Llano de Albuquerque geomorphic surface. This surface is not present within the quadrangle itself, but is found immediately to the east on the La Mesita Negra SE quadrangle (Shroba et al., 2003). As the highest aggradational surface of the Albquerque basin, the Llano de Albuquerque divides the underlying Santa Fe Group sediments from the younger, inset, post-SFG Quaternary alluvium.

Inset Quaternary alluvium on the La Mesita Negra quadrangle is divided into active, younger, medium, and older alluvium based primarily on geomorphic observations, as well as into Rio Puerco and tributary alluvium based on lithologic criteria. Each of these deposits are variably buried by eolian sand and sand sheets. An ash found toward the base of the older Rio Puerco alluvium (Qaro; Figure 6) was geochemically correlated to the Lava Creek B ash of the Yellowstone area by Izett and Wilcox (1982). Lanphere et al. (2002) determined an $^{40}Ar/^{39}Ar$ age of 0.639 ± 0.002 Ma for the Lava Creek B (age recalculated to fit the Fish Canyon Tuff sanidine monitor age of Renne et al., 1998), indicating a middle Pleistocene age for the older alluvium.

Isolated outcrop of the upper Cretaceous Crevasse Canyon (Figure 7) and Menefee Formations (Figure 8) are also present on the quadrangle. These occur in the footwalls of large faults along the west side of the Rio Puerco in the southern half of the quadrangle and in the northwest corner of the quadrangle. Their stratigraphic assignment is based on more extensive outcrop to the north of the quadrangle (in the case of the Crevasse Canyon Formation) and on the examination of drill core (in the case of the Menefee).

IGNEOUS HISTORY

The area apparently experienced a period of volcanic activity in the late Miocene, as indicated by the presence of the 7.14 ± 0.47 Ma dacite at Cerro Colorado and the 8.16 ± 0.05 Ma basalt at La Mesita Negra (ages from Connell et al., *in press*, and Maldonado et al., 2006, respectively; both are $^{40}Ar/^{39}Ar$ ages, recalculated to fit the Fish Canyon Tuff sanidine monitor age of Renne et al., 1998). Both volcanic deposits are laterally-restricted, suggesting igneous activity was not widespread or long-lived in this locality. The dacite is a plagioclase-horneblende-biotite porphyry dome of intercalated flow and flow breccia, with steeply-dipping

flow foliations that are concentric about the center of Cerro Colorado. The basalt is a sparsely pyroxene-phyric, tholeiitic basalt flow intercalated with sandstones of the Navajo Draw Member of the Arroyo Ojito Formation.

STRUCTURE

All structures exposed on the quadrangle are related to east-west extension of the Rio Grande rift. These structures are dominantly north- to northeast-trending normal faults of both down-to-the-east and down-to-the-west senses of offset. Notable features of the quadrangle include a horst block of upper Cretaceous Menefee Formation sandstones and mudstones that trends north-northeast along the west margin of the Rio Puerco in the south half of the quadrangle, and the Moquino fault juxtaposing upper Cretaceous Crevasse Canyon Formation mudstones and sandstones against Miocene sandstones of the Cerro Conejo Formation in the northwest corner of the quadrangle (Figure 9). The horst block can be followed at the surface for almost 7 km from the south end of the quadrangle to the middle of the quadrangle, while gravity data suggest the faults bounding the horst block can be followed further along strike (cf., Williams and Cole, 2005). To our knowledge, however, Cretaceous rocks do not crop out anywhere along this north-northeast trend on the east side of the Rio Puerco, suggesting that, although the horst-bounding faults may continue, either the horst block plunges to the north or a secondary down-to-the-east fault cuts through the horst block to down-drop the Cretaceous strata to the east. The narrow graben to the west of this horst block in the southwest corner of the quadrangle has been previously referred to as the Apache graben in the literature (cf., Tedford and Barghoorn, 1999).

Broad synclinal and anticlinal folds are also apparent in the attitudes of bedding on the quadrangle (e.g., Figure 9). We suggest that these folds are primarily related to fault geometries at depth, as depicted on cross-section A-A', for example.

FIGURES

Figure 1 - Gray sandy limestone beds overlying pale brown sandstones of the Chamita Mesa Member of the Zia Formation. Hammer is 33 cm long.

Figure 2 - Reddish brown mudstones and grayish brown conglomerates of the lower Cerro Conejo Formation. Left (west) side of outcrop is truncated by the Moquino fault.

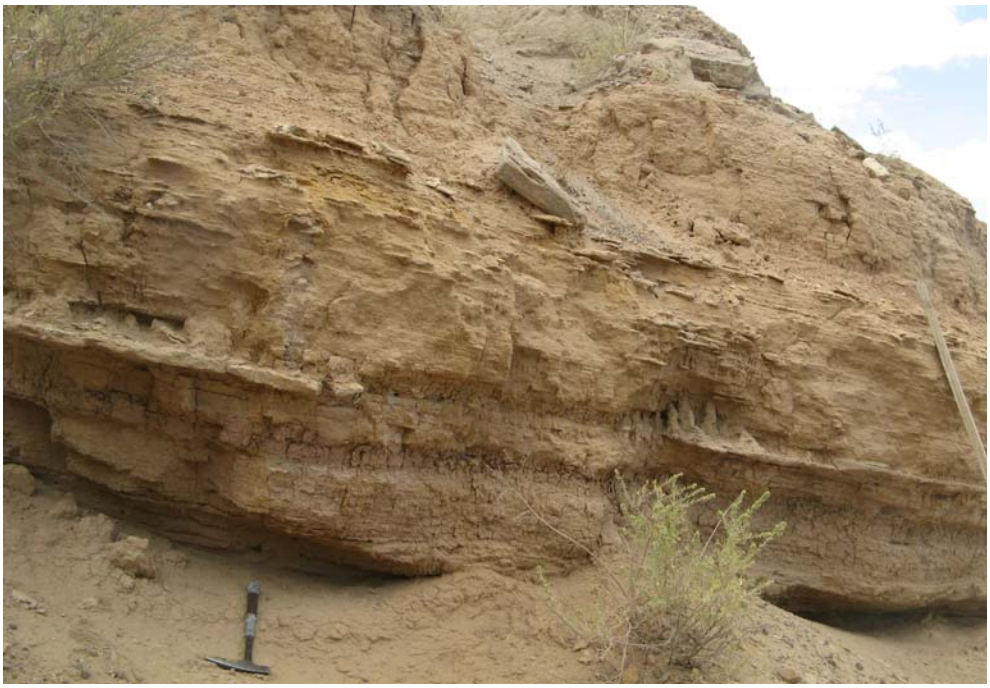
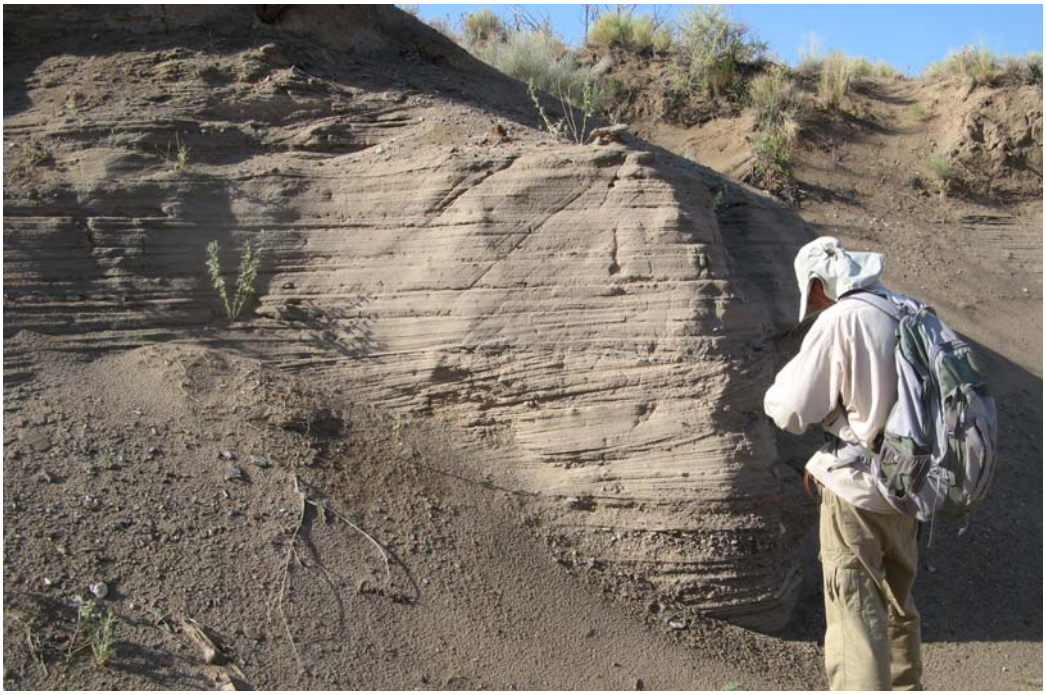
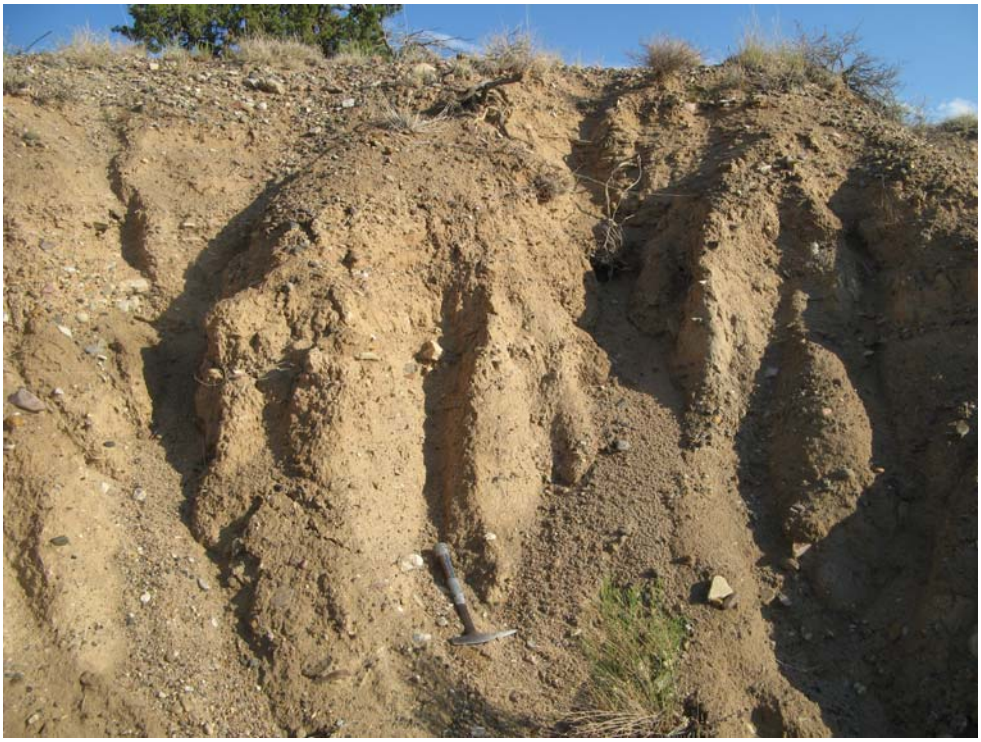


Figure 3 - Light yellowish sandstones and mudstones of the Navajo Draw Member of the Arroyo Ojito Formation. Hammer is 33 cm long.



4(a)



4(b)

Figure 4 - Ceja Member (a) and Rio Puerco Member (b) of the Ceja Formation. (a) Brownish gray sands and gravelly sands of the upper portion of the Atrisco Member of the Ceja Formation. Dan Koning is approximately 2 m tall. (b) Typical outcrop of gravelly sands of the Rio Puerco Member of the Ceja Formation. Hammer is 33 cm long.

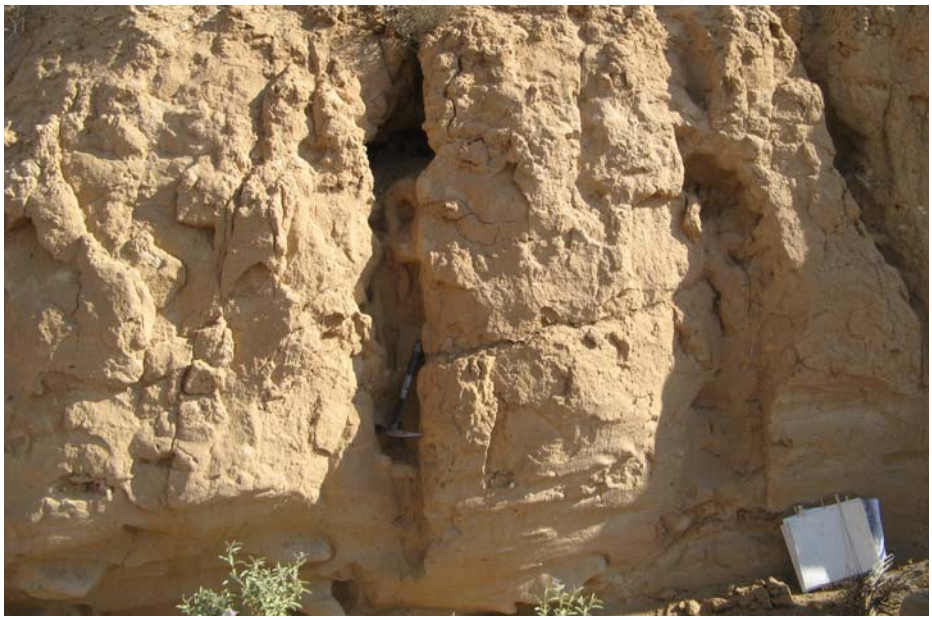


Figure 5 – Light colored, massive silty sands of the lower portion of the Atrisco Member of the Ceja Formation. Hammer is 33 cm long. This portion of the Atrisco may correlate to the Loma Barbon Member of the Arroyo Ojito Formation of Connell et al. (1999) and Connell (2008).

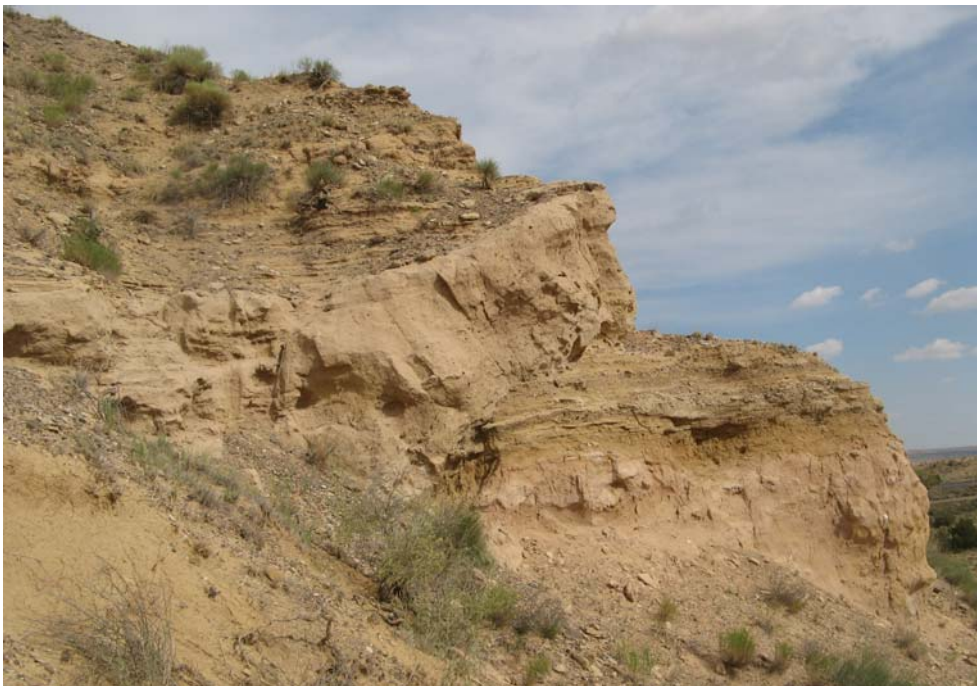


Figure 6 - Ancestral Rio Puerco sands and gravels of Qaro overlie an ash bed that is erosively emplaced into sands and gravels of the Cerro Conejo Formation. The thick, massive pale brown bed is the ash bed, with light brown pebbly sands and pale pinkish sands beneath belonging to the Cerro Conejo, and light brown gravelly sands above belonging to Qaro. Izett and Wilcox (1982) geochemically correlated this ash to the Lava Creek B ash from the Yellowstone area.

Figure 7 - Varicolored mudstones of the Cretaceous Crevasse Canyon Formation.

Figure 8 - Outcrop of the Cretaceous Menefee Formation.

Figure 9 - Panoramic view of the Moquino fault zone, looking north. The Moquino fault is down to the east (right), truncating the reddish mudstones and sandstones of the Cerro Conejo Formation in the center of the panorama. Gray outcrops in the footwall of the fault (to the left of the reddish outcrop in the center) are Zia Formation sandstones and sandy limestones. A broad anticline is apparent in the immediate hanging wall of the fault in the distance at the east (right) end of the panorama.

LA MESITA NEGRA QUADRANGLE
DESCRIPTION OF MAP UNITS

Lithologic units on the map were described from accessible outcrops; sand was described using a hand lens. Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter. Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992), Birkeland et al. (1991), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999).

Surficial deposits

af **Disturbed land and artificial fill (modern) –** Excavations and debris associated with roads, buildings, and earthen dams. Sediment generally consists of compacted clay, silt, and sand.

Qe **Eolian deposits (upper? Holocene) –** Loose sand capping ridges or blanketing the lee side of slopes (generally the north or east sides of hills). Sand is pale brown to very pale brown (10YR 6-7/3) or light yellowish brown to light brown to reddish yellow (7.5-10YR 6/4 and 7.5YR 6/6), fine- to medium-grained, subangular to rounded (mostly subrounded), well sorted, and composed of quartz, 1-15% feldspar, and 3-15% lithic + mafic grains (lithic grains include chert and volcanic grains). Commonly contains dunes on surface that are up to 1 m tall. Loose and 1-3 m thick.

Qca **Colluvium and alluvium, undivided (upper Pleistocene to Holocene) --** Colluvium, talus, and alluvial slopewash along the eastern and northern flanks of Cerro Colorado. Colluvium consists of angular-subangular gravel and clayey-silty sand. Slopewash deposits are generally gravelly sand. Unit generally overlies the Navajo Draw Member of the Arroyo Ojito Formation. Up to ~30 m thick.

Stream-valley alluvium

Qaa **Active channel and fan (modern) –** Sediment in active channels and active alluvial fans of ephemeral drainages that grade to the Rio Puerco. Sediment commonly consists of gravelly, fine- to very coarse-grained sand that is in laminated to very thin, horizontal-planar to cross-stratified beds. Unit includes silty sheetflood deposits in Cañada del los Apaches. Probably less than 2 m thick.

Qay **Younger alluvium associated with tributaries of the Rio Puerco (Holocene-uppermost Pleistocene) –** Brown to very pale brown (10YR 5-7/3) sand and pebbly sand inset into **Qam** and graded to the level of younger Rio Puerco alluvium (**Qary**). Sediment in Cañada de los Apaches and Cañada del Ojo contains more fine-grained sediment (e.g., clay, silt, and very fine-grained sand) than what is described below for smaller drainages. Deposits are massive to well stratified (mostly tangentially cross-laminated and horizontal planar-laminated). Pebbles are commonly in very thin to thin lenses, less commonly in medium to thick, fining-upward channel-fills. Pebbles are rounded to subrounded and moderately to poorly sorted. Sand is mostly fine- to coarse-grained (minor very

fine and very coarse), subrounded, moderately sorted, and composed of quartz, minor (5-20%) feldspar, and minor (5-20%) mafic + lithic grains (including chert, volcanic grains, and quartzite). Clasts and sand are derived largely from erosion of the Ceja and Cerro Conejo Formations. Buried anthrogenic hearths are locally observed. Top of sediment is commonly massive and bioturbated. Weakly consolidated and non-cemented. 1-3 m exposed thickness.

Qam **Medium-aged alluvium (middle Pleistocene) –** Sand and pebbly-cobbly sand whose eroded, upper surface lies above the **Qay** surface. Gravel is subrounded to rounded, moderately to poorly sorted, and composed largely of chert and granite with subordinate andesite to basaltic andesite (~10%), rhyolite, sandstone, basalt, and quartz + quartzite (trace gneiss and petrified wood). Sand is pale brown to very pale brown to light brown (10YR 6-7/3 and 7.5YR 6/4), fine- to very coarse-grained, subrounded to subangular, moderately to poorly sorted, and composed of quartz, minor (~10% or less) feldspar, and 7-15% mafic + lithic grains. Remnants of strongly developed calcic paleosols are irregularly preserved on hilltops. Loose and up to 18 m thick.

Unit also applied to terrace deposits associated with Cañada del Ojo and Cañada de los Apaches. The former consists of 3-5 m-thick sandy pebbles in very thin to laminated, horizontal-planar beds. Gravel are subrounded, moderately sorted, and composed of chert, 10% Mesozoic sandstone, 5-10% granite, and 1-2% light gray rhyolite + felsic tuffs; clast imbrication is to the southeast. Sand is light yellowish brown to light gray (2.5Y 6/3-7/2), mostly medium- to very coarse-grained, subrounded, moderately to poorly sorted, and composed of quartz, <7% feldspar, and ~10% lithic + mafic grains (lithic grains consist of volcanic fragments and chert). Floodplain deposits are clayey and light gray to white (2.5Y 7-8/1).

Qam(s) **Surficial sheet of sand and clayey-silty sand overlying medium-aged alluvium of the Rio Puerco and its tributaries (Holocene to middle Pleistocene) --** This surficial deposit overlies both units **Qam** and **Qarm**. It can locally be subdivided into two subunits, with the upper (Holocene) unit more extensive than the lower (middle to upper Pleistocene) unit. The upper subunit consists of interbedded very fine- to medium-grained sand and slightly clayey-silty (est 5-15% fines) sand that has experienced cumulic soil development; color ranges from brown to pale brown to light yellowish brown (10YR 5-6/3-4), with minor streaks of strong brown (7.5YR 5/6); sand is subrounded, well sorted, and composed of quratz, 10-15% feldspar, and 7-10% mafic + lithic grains; soil is manifested by ped development, stage I calcium carbonate accumulation, and none to weak clay illuviation. The top of the upper subunit is eroded and locally draped by loose eolian deposits of fine- to medium-grained sand (similar to **Qe**). The lower subunit is a massive, very fine- to very coarse-grained sand displaying a distinctive light brown to reddish brown color (7.5YR 6/4-6); cumulic soil developed on this unit corresponds with a cambic horizon with stage I calcium carbonate accumulation. 0.3-2.0 m thick.

Alluvium of the Rio Puerco

Qara **Active channel of the Rio Puerco (modern) –** Light yellowish brown to light gray (2.5Y 6/3-7/2), very fine- to medium-grained sand that is subangular, well

sorted, and composed of quartz, 5-7% feldspar, and 5-7% mafic and lithic grains. Parts of the mapped unit may actually be unit **Qary** that has been beveled by the modern, entrenched river. When the river dries up, the floor of the modern channel may be caked by a veneer of light olive brown to light yellowish brown (2.5Y 5-6/3), mud-cracked clay. Weakly to moderately consolidated and non-cemented. Thickness is probably thin (<2 m).

Qary **Younger alluvium of Rio Puerco (Holocene to uppermost Pleistocene) --** Interbedded sand and fine-grained floodplain deposits that underlie the flat floor of the Rio Puerco valley. Sand is typically well-laminated and in horizontal-planar, tangential cross-laminated, or ripple-marked bed forms; foresets are up to 1 m thick. Channel-fill sand is fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, 5-7% feldspar, and 5-12% lithic + mafic grains (lithic grains include volcanic fragments and minor chert). Sand is non-cemented and moderately consolidated; colors are light gray (2.5Y 7/2) or pale brown to light yellowish brown (2.5Y 6-7/3). Some sand beds appear dirty because of an abundance of intra-formational, mud rip-up grains. Floodplain deposits are in very thin to medium, tabular beds and exhibit a color of light brownish gray (2.5Y 6/2). These fine-grained deposits consist of hard clay, minor silt, and 20-25%, thin to thick, tabular beds of very fine- to fine-grained sand (commonly cross-laminated and ripple-marked). No notable top soil was observed. At least 10 m thick.

Qarm **Medium-aged alluvium of the Rio Puerco (middle Pleistocene) --** Relatively thick terrace fills preserved along the west side of the Rio Puerco, consisting of pebbly sand and sand interbedded with minor fine-grained, floodplain deposits. Contains more volcanic clasts than **Tcc** and its channel-fills display more cross stratification. Coarse sediment is in medium to thick, tabular beds that are internally tangentially-, planar-, or trough-cross stratified (up to 30 cm thick foresets) or horizontal planar bedded (laminated to very thin). Color of sand ranges from brown (10YR 5/3), light gray (10YR 7/2), or light yellowish brown to very pale brown (2.5Y-10YR 6-7/3). Gravel consists of very fine to very coarse pebbles with up to 20% cobbles. Clasts are subrounded to rounded, moderately to poorly sorted, and composed of 25-50% chert, 20-30% light gray to gray andesite-basaltic andesite (containing pyroxene phenocrysts), 1-12% basalt (commonly vesicular), 5-25% yellow Mesozoic sandstone, 1-10% quartzite, 5-15% red granite, trace-5% eroded-out FeO concretions, variable calcium carbonate-indurated sandstone clasts (probably from the Santa Fe Group), and trace Pedernal Chert. Sand is fine- to very coarse-grained (mostly medium- to very coarse), subrounded to subangular, moderately to poorly sorted, and composed of quartz, 1-10% feldspar, and 7-15% mafic + lithic grains (including volcanic lithic fragments and lesser chert). Floodplain deposits consist of light yellowish brown (2.5Y 6/3) silt and very fine-grained sand. Loose to moderately consolidated, with weak to moderate HCl effervescence. Locally cemented by calcite, especially where **Qarm** gravels overlie less permeable silty fine sands. Unit may be overlain by a surficial sheet of sand or clayey-silty sand up to 2 m thick (see unit **Qam(s)** description above). **Qarm** is up to 18 m thick.

Qaru **Undifferentiated alluvium of the Rio Puerco (Middle Pleistocene) --** Various terrace deposits of sand and gravel occupying a geomorphic position between **Qarm** and **Qaro** in the northwest part of the quadrangle (but it is possible that some correlate to **Qarm** and **Qaro**). Gravel consists of pebbles with ~5% cobbles and 0.5% boulders that are subrounded, poorly sorted, and composed of chert, 15% gray andesite-basalt, ~15% Mesozoic sandstone-siltstone, ~15% granite, ~5% felsic volcanic rocks, and 15-20% eroded-out FeO concretions. Sand is light yellowish brown to pale brown (2.5Y 6-7/3), subrounded to subangular, poorly sorted, and composed of quartz, <15% feldspar, and 5-10% lithic + mafic grains. Generally 1-2 m thick.

These deposits include a 10-14 m-thick, paleo-valley fill (UTM coord of: 320400 m E and 3885750 m N, NAD 27 datum) that contains abundant cobbles and boulders of a distinctive white, cherty travertine (in addition to yellow Mesozoic sandstone). The pebble fraction in this paleovalley-fill are rounded, moderately sorted, and composed of ~40% chert, 20-75% of the aforementioned cherty travertine, 15% red granite, 10% Pedernal chert, 10% quartzite, and 1-3% yellow Mesozoic sandstone. The sand fraction is a lighter color than that of **Tcc** (white to light gray (10YR 8/1-7/2) or light yellowish brown to very pale brown (10YR 6-7/4)). The sand is horizontal planar-laminated to thinly bedded to massive, mostly fine- to medium-grained, subangular, moderately to well sorted, and composed of quartz, 1-10% feldspar, and 1-5% lithic and mafic grains (including biotite).

Qaro **Older alluvium of the Rio Puerco (middle Pleistocene) --** Sandy pebbles, pebbly sand, sand, and silt-clay associated with an ancestral Rio Puerco. Gravelly beds typically occur as cross-stratified or very thin-thin, tabular-bedded channel fills; sands and silt-clay occur as laminated to very thin to medium, tabular beds. Gravel consists of pebbles with 1-10% cobbles and 0-1% boulders. Gravel are subrounded to rounded, poorly to moderately sorted, and composed of 10-25% gray andesite-basaltic andesite (pyroxene phenocrysts noted), 10-25% Mesozoic sandstone, 1-10% basalt, 15-50% chert, 1-10% red-orange granite, 5-15% FeO concretions, 1-5% rhyolite, 5-10% quartzite, 0-5% intraformational sandstone rip-ups, and 1-5% vein quartz. Channel-fill sand is yellowish brown to light yellowish brown (10YR 5-6/4) to pale brown to very pale brown (10YR 6-7/3), fine- to very coarse-grained (mostly medium- to very coarse-grained), subangular to rounded, poorly to well sorted, and composed of quartz, 5-10% feldspar, and 5-15% lithic and mafic grains (lithic grains are mostly volcanic fragments, with minor chert). Sand colors range from yellowish brown to light yellowish brown (10YR 5-6/4) or pale brown to very pale brown (10YR 6-7/3). Minor floodplain deposits in thin to thick beds that range in color from light gray to white to pale brown (2.5-5Y 7-8/1-2). Floodplain deposits consist of very fine- to fine-grained sand and clayey-silty fine sand as well as light yellowish brown to light brown (7.5-10YR 6/4) clay-silt. In the northwestern part of the quadrangle, this unit is assigned to 1-2 m-thick gravels whose straths are around 5560 ft elevation. Surface exhibits strongly developed calcic soils with stage III pedogenic carbonate morphology; also contains lens of white volcanic ash that was geochemically correlated to the 0.64 Ma Lava Creek B (LCB) tephra from Yellowstone National Park (Izett and

Wilcox, 1982). Note: 0.639 ± 0.002 Ma $^{40}Ar/^{39}Ar$ age determination on LCB ash is from Lamphere et al. (2002). Sand and gravel are loose, but floodplain sediment is moderately consolidated. Up to 25 m thick.

Qaro(s) **Surficial sheet of sand and silty-clayey sand overlying older alluvium of the Rio Puerco (Holocene to middle Pleistocene) --** This surficial unit is light yellowish brown to pale brown (10YR 6/3-4), internally massive, and composed of fine- to medium-grained, eolian sand or clayey-silty very fine- to fine-grained sand. Fine- to medium-grained sand is subrounded to subangular, well sorted, and composed of quartz, 1-10%(?) feldspar, and ~3% lithic + mafic grains. Top soil exhibits a stage II calcic soil horizon (locally with 25% $CaCO_3$ nodules ~1 cm^2 in size). Moderately consolidated, non cemented, and 0.2-3 m thick. Unit may locally overlie two older (middle to upper Pleistocene) units that both exhibit cumulic soil development, listed from top to bottom: 1) 1-2 m of relatively hard, fine- to very coarse-grained sand displaying a brown to strong brown color (7.5YR 5/4-6), with 1-5% scattered pebbles; and 2) a 1-2 m-thick unit composed of similar sediment as #1 but containing a calcic soil with III to IV carbonate morphology.

Ceja Formation of Santa Fe Group

Tcrp **Rio Puerco Member of the Ceja Formation (Plio-Pleistocene) –** Very pale brown (10YR 7-3/4), 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 rounded to subrounded, poorly sorted, and 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. Largest gravels are composed of yellowish-brown sandstone (probably derived from Cretaceous strata), basalt, and Pedernal chert. Sand is mostly medium- to very coarse-grained, subrounded to subangular, poorly to moderately sorted and composed of quartz, 15-25% lithic + mafic grains, and ~5-10% feldspar. This unit has a gradational to interfingering contact with the underlying Atrisco Member (**Tca**). Weakly consolidated and non-cemented. 35-45 m thick.

Tca **Atrisco Member of the Ceja Formation (Pliocene)–** Yellowish brown to very pale brown (10YR 5-7/4), very fine- to fine-grained sandstone and reddish brown mudstone. Unit occupies the lower part of the bluffs east of the Rio Puerco. Bedding is mostly thin to medium and tabular. Local, 1-3 m-thick channel-fills are composed of pebbly sand that is light gray and well-laminated (horizontal-planar to cross-stratified). Conformably underlies the Rio Puerco Member and unconformably overlies strata of the Arroyo Ojito or Cerro Conejo Formations. Clast and sand composition and texture similar to that of the Rio Puerco Member (described above). Weakly consolidated and non-cemented.

In the northeast part of the quadrangle, this unit is mapped below the bluffs, but this correlation is uncertain. Sediment here is bioturbated (relatively massive) or

horizontal-planar to cross-laminated, moderately to well consolidated, and contains local calcium carbonate-cemented concretions up to 30 cm long. The sediment consists of pink to light brown to reddish yellow (7.5YR 6-7/4 and 6/6), locally very pale brown (10YR 7/3), very fine- to coarse-grained sand containing minor, scattered grains of very coarse sand and very fine to fine pebbles composed of chert, quartzite, granite, and light gray volcanics. Minor pink to very pale brown to reddish brown (7.5YR 7/4 and 10YR 7/4 and 5YR 5/4) mudstone and very fine- to fine-grained sandstone in relatively thin, tabular beds; local pink to very pale brown (7.5-10YR 7/3) siltstone. Sparse channel-fills composed of well-laminated medium- to very coarse-grained sand and pebbly sand; pebbles consist of chert (including Pedernal Chert), intermediate-felsic volcanic grains, and granite. Near base of unit, channel-fills locally contain abundant pebbles of Pedernal Chert (10-40%) and granite (25-35%). Sand is subrounded to subangular, poorly to well sorted, and composed of quartz, 1-15% feldspar, and 5-15% volcanic-rich lithic + mafic grains. This lower interval is interpreted as a piedmont deposit and may possibly correlate to the Loma Barbon Member of the Arroyo Ojito Formation (late Miocene; Connell et al., 1999; Connell, 2008a). 130 m thick.

Arroyo Ojito Formation of Santa Fe Group

Ton **Navajo Draw Member (upper Miocene) –** Pale brown to pale yellow (10YR 6/3 to 2.5Y 7/3) and light yellowish brown to very pale brown (10YR 6/4 and 10YR 7/3-4), channel-fill sandstone interbedded with minor to subequal mudstone (the latter is in very thin to medium, tabular beds). Unit recognized by its pale brown to yellowish colors, moderately to well sorted sand texture, and lack of gravel. Sandy channel-fills are commonly horizontal-planar laminated, with minor very thin to thin, tabular beds. Sand is mostly very fine- to coarse-grained, subrounded (mostly) to subangular, moderately to well sorted, and composed of quartz, 1-10% feldspar, and 3-15% lithic + mafic grains (lithic grains are dominated by volcanic detritus). 10-20% silt-clay floodplain deposits whose beds are tabular and <60 cm thick; these are similar in color as the channel-fills. Pebbles are very sparse and consist of chert (including Pedernal chert), light gray volcanic rocks, and intraformational clasts of caclium carbonate, siltstone, and sandstone. Unit is weakly to well consolidated and variably cemented by calcium carbonate. One cigar-shaped, strongly cemented channel-fill(?) trends 172 degrees. To the south, this unit resembles the Cerro Conejo Formation at its type area (Connell et al., 1999). Locally subdivided into two units based on composition and color. Thickness not well constrained, but estimated to be 150-200 m.

Ton_r **Red sandstone –** Reddish-brown, eolianite sandstone (2.5YR 4/4-5/4) exposed along flanks of Cerro Colorado and as pods of reddish-colored (stained?) sandstone in **Ton** south of Cerro Colorado. 35-40 m thick.

Ton_c **White tufa –** White calcium carbonate-cemented sandstone and conglomerate (lithoid tufa) within unit **Ton**; may be an ancient spring deposits in the Arroyo Ojito Formation. Corresponds to unit Qc (caliche) in Kelley (1977). >18 m thick.

Towp **Western piedmont facies of Arroyo Ojito Formation (upper Miocene) --** Fine- to coarse-grained sandstone interbedded with subordinate (5-10%) pebbly channel-fills and minor (1-5%) mudstone and muddy sand beds. Sand colors are generally light yellowish brown to very pale brown (10YR 6/4 to 7/3-4), or light

brown to reddish yellow (7.5YR 6/4-6) to pink (7.5YR 7/3-4); with some 10YR 5-6/6 and 7.5YR 5/4. Mudstone colors are variable, ranging from reddish brown (2.5YR 4/4) to light brown (7.5YR 6/4) to light yellowish brown (10YR 5-6/4) to brown (10YR 4-5/3).

Mudstone is in very thin to thick, tabular beds that are internally horizontal-planar laminated. Sandstone is in medium to thick, tabular beds that are internally laminated to very thinly bedded (horizontal-planar to cross-stratified, with foresets up to 2 cm-thick); also internally massive. Pebbly channel-fills are in very thin to medium, tabular to lenticular beds, with lesser cross-stratification (up to 20 cm thick foresets).

In the pebbly channel fills, sand is medium- to very coarse-grained and gravel is comprised of very fine to very coarse pebbles (trace cobbles) that are subrounded to rounded, poorly to moderately sorted, and composed dominantly of chert (mostly black to brown to orange) with 1-10% quartzite, 3-10% quartz, 0.5-10% gray (minor brown) rhyolite-dacite, 1-10% felsic tuff (some of which is welded; also a brownish pink, quartz-bearing tuff), 1-25% calcium carbonate and intra-formational calcium carbonate-cemented sandstone, trace extra-formational sandstone, trace to 1% petrified wood, 0-1% granitoids, and 0-trace basalt; a few channel-fills contain up to 35% red granitoids and 0.5% Pedernal chert(?) clasts. Granitoid clasts are more abundant to the south.

Sand ranges from very fine- to very coarse-grained but is mostly fine- to medium-grained; some fine- to medium-grained sand beds contain up to 10% scattered pebbles and coarse- to very coarse sand grains. Sand is subrounded to subangular, moderately to well sorted (moderately to poorly sorted in the pebbly channel fills), and composed of quartz, 1-15% feldspar, and 5-15% lithic grains (light gray-gray volcanic grains + chert) + mafic grains. Trace to 0.5% paleosols that are commonly 10-20 cm thick and light brown to reddish yellow to yellowish red (7.5YR 6/4-6 to 5YR 5/6); these are manifested by illuviated clay and precipitated calcium carbonate, including 1-20% pebble-size calcium carbonate nodules (which are commonly vertically elongated); ped development is moderate, fine to coarse, and subangular blocky; there are few to many, faint to prominent clay films on ped faces and occurring as bridges. Sandstone is weakly to moderately consolidated and variably cemented (but mostly non to weakly cemented); gravel is weakly consolidated and non to weakly cemented. 240-250 m thick.

Cerro Conejo Formation of Santa Fe Group

Tcc **Cerro Conejo Formation (middle Miocene) --** Tan to orange sandstone interbedded with minor conglomerate and mudstone intervals; only mapped west of the Rio Puerco. Generally a fluvial depositional environment, with minor eolian intervals. No fossils or tephra beds observed so age control is lacking. Correlation to the Cerro Conejo Formation is based on the unit's stratigraphic position (i.e., overlying the Zia Formation and underlying the Navajo Draw Member of the Arroyo Ojito Member). The sparse conglomerate beds here are consistent with observations of minor conglomerate beds in the Cerro Conejo Formation east of

the Rio Puerco 15 km to the northeast (Tedford and Barghoorn, 1999). The Cerro Conejo Formation is truncated on its west end by the Moquino fault, and we interpret that only its upper third is exposed (see cross section). This interpretation is consistent with the apparent lack of the following features seen in the lower to middle part of the unit to the north (Tedford and Barghoorn, 1999): 1) a strongly cemented interval in its basal 30 m; and 2) two laterally extensive, 1-2 m-thick, green mudstone and associated limestones about 50 m above the base of the unit; and 3) a 70 m interval near the middle of the unit with frequent ash beds. May be strongly cemented near faults, otherwise non- to weakly cemented and moderately consolidated. Unit is divided into two intervals in the northwestern part of the quadrangle (described below).

In the southwestern quadrangle, the unit is a sandstone that is thinly to thickly bedded or massive (locally minor, vague cross-laminations). Additionally, there is 1-5% pebbly sand and 10-20% mudstone, sandy mudstone, and siltstone. Colors range from light brown to pink to reddish yellow to pinkish white (7.5YR 6-7/4, 5-7.5YR 6/6, or 7.5YR 8/2), with slightly lesser very pale brown to light yellowish brown (10YR 6-7/4). Pebbles are very fine to fine, subrounded, well sorted, and composed of chert, 10-20% quartz and quartzite, 5% light gray rhyolite or felsic tuff, and 1-5% eroded-out FeO concretions. Sand is very fine- to very coarse-grained (mostly fine- to medium-grained), subangular to rounded (mostly subrounded), moderately to well sorted, and composed of quartz, 1-13% feldspar, and 5-15% lithic + mafic grains (lithic grains include volcanic fragments and lesser chert). Some fine- to medium-grained sand beds contain 0.5% scattered coarse- to very coarse-grained sand grains and very fine pebbles of volcanic rocks and chert. Unit is variably cemented but mostly non to weakly cemented, with only 1-5% strong cementation; weakly to well consolidated

Tccu **Upper Cerro Conejo Formation --** Sandstone interpreted to reflect a mix of fluvial and eolian depositional processes, interbedded with minor light reddish brown mudstone. Eolian strata are recognized by thick cross-stratification (tangentially cross-laminated foresets up to 3 m-thick), lenticular grain-flow beds (20-100 cm wide), lack of soft sediment deformation features, paucity of conglomerate, lack of mudstone, and presence of rhizoliths. Sand is very pale brown (10YR 7/4), fine- to very coarse-grained (mostly fine- to medium-grained), subrounded to subangular, poorly to well sorted, and composed of quartz, minor feldspar (<5%), and 5-15% lithic grains (silicified volcanic grains and chert) + minor mafics. Locally, paleosols are present, up to 40 cm thick, that exhibit evidence of clay illuviation and calcium carbonate accumulation (2.5YR 6/6, with many, prominent clay films on ped faces and minor, scattered calcium carbonate nodules 1-10 mm wide; strong, coarse to very coarse, angular to subangular blocky peds). Weakly to well consolidated; non to weakly cemented by calcium carbonate (except locally near faults). 70-80 m thick

Tccl **Lower Cerro Conejo Formation --** Very pale brown to pink (7.5-10YR 7/3-4), with lesser light yellowish brown (10YR 6/4) to light brown (7.5YR 6/4), sandstone and pebbly sandstone interbedded with minor conglomerate beds and minor light reddish brown (5YR 5-6/4) claystone-mudstone. Locally distinct

channel-fills of conglomerate and sandstone; channel stratification consists of laminated to very thin, horizontal-planar to cross stratified beds (minor medium, lenticular to U-shaped beds). Sandstone may also be in very thin to thin, tabular beds. Gravel consist of rounded to subrounded, poorly sorted, very fine to very coarse pebbles and 1-3% cobbles composed largely of volcanic rocks and chert, with lesser quartzite and trace petrified wood. Volcanic pebbles are mostly a light gray to gray dacite (hornblende ± pyroxene ± biotite phenocryst assemblage) with ~10% silicified(?) rhyolite and 1-3% basalt. Cobbles are generally basalt or a pink, welded tuff. Channel trends and clast imbrication indicate a generally southeast flow direction. Sand is fine- to very coarse-grained (mostly fine- to medium-grained), subangular to rounded (mostly subrounded), moderately to well sorted, and composed of quartz, 3-5%(?) feldspar, and 10-20% lithic grains (chert and felsic volcanic grains) + minor mafics. Local soft sediment deformation features. ~1% paleosols marked by clay illuviation and vertically elongated calcium carbonate nodules 2-3 cm wide (filling paleo-burrows?). Mudstone is generally in very thin to thick, tabular beds; one mudstone interval is about 10 m-thick. Variably cemented by calcium carbonate. Base of unit not observed. At least 250 m thick.

Zia Formation of Santa Fe Group

Tzc **Zia Formation, Chamisa Mesa Member (lower Miocene)** -- Very pale brown (10YR 7/3-4) to pink (7.5YR 7/4) sandstone interbedded with 0-1% mudstone and 1% sandy limestone. Lesser light gray (10YR 6-7/2) or pale yellow (2.5Y 7/2) sandstone colors. Mudstone is in very thin to thin, tabular beds. Sandy limestone is chalky-white and in thin to thick, tabular beds (internally laminated to very thinly, tabular to wavy bedded). Sandstone is in very thin to thick, tabular beds that are internally horizontal-planar laminated to internally massive. Sand is very fine- to very coarse grained (mostly fine- to medium-grained), subangular to rounded (mostly subrounded), moderately to well sorted, and composed of quartz, 5-25% lithic + mafic grains, and 1-5%? feldspar. Lithic grains mostly consist of chert and silcified(?) volcanic grains, and tend to be medium- to very coarse-grained. Local rhizoliths. Trace pebbly beds whose clasts are subrounded, moderately sorted, and composed of silcified, felsic volcanic rocks, chert, and minor quartzite. Weakly to moderately consolidated and variably cemented by calcium carbonate (about 10-15% of strata are strongly cemented). Interpreted as a fluvial facies because of local very coarse grains, rip-ups, and lack of definitive eolian cross stratification. Paleosols are much less common in this unit than the overlying Cerro Conejo Formation and consist of very thin Bw horizons. Base of unit corresponds to a 1-5 m-thick clay-rich interval. At least 100 m thick.

Tzp **Zia Formation, Piedra Parada Member (lower Miocene) --** Light gray (10YR 7/1-2), medium- to coarse-grained sandstone that is extensively cross-laminated. Unit lacks gravel and mudstone beds. Sand is rounded to subangular (mostly subrounded), well sorted, and composed of quartz, 15-25% lithic grains (volcanic and chert grains) + very minor mafics. About 20-35% of unit is strongly cemented by calcium carbonate. Local rhizoliths are observed. Base of unit commonly consists of a 1-2 m-thick, tabular, strongly cemented bed of sandstone. Unit unconformably overlies Cretaceous rocks, and the lower contact exhibits 2-3 m of

paleo-topographic relief. Lag pebbles are locally observed on this unconformity and are composed of well-varnished, rounded chert, minor quartzite, minor FeO concretions, and 1% petrified wood. 20-25 m thick.

Neogene volcanic rocks

Td **Dacite vent at Cerro Colorado (upper Miocene) –** Reddish-brown to reddish-yellow to medium gray dacitic lava associated with vent at Cerro Colorado (Red Hill). Consists of variably porphytic flows and flow breccias with steeply-dipping flow foliations that are concentric about the center of Cerro Colorado. Phenocrysts consist of 5-15% plagioclase (up to 4 mm across, subhedral, clear and vitreous to white and chalky, typically more degraded in redder [more oxidized?] flows), 3-7% amphibole (thin black needles up to 1 mm long), and <1-1% biotite (platy and up to 2 mm across, black to dark reddish brown). Single-crystal laser fusion $^{40}Ar/^{39}Ar$ age determination on plagioclase yielded an age of 7.16 ± 0.47 Ma (Maldonado et al., 2006). Early investigations of this vent complex were published by Wright (943).

Tb **Basaltic lava at La Mesita Negra (upper Miocene) –** Light gray to gray, tholeitic basalt flows exposed along floor of Rio Puerco Valley. These contain 10-15% vesicules up to 2 cm long. Hand lens observations show an aphanitic groundmass, with 7-10% pyroxene phenocrysts (0.5-4.0 mm long) altered to goethite or limonite. $^{40}Ar/^{39}Ar$ age determination on groundmass concentrate yielded age of 8.16 ± 0.05 Ma (Maldonado et al., 2006).

Cretaceous strata

Kmf **Menefee Formation (upper Cretaceous) --** Light to dark gray to brownish gray to pale brown mudstones interbedded with minor, light gray to yellow to white sandstone and silty fine sandstone (mostly fine-grained). Mudstones were deposited on a floodplain and are typically well laminated and very fine grained, with local gypsum crystals up to 5 mm across; colors of 2.5Y 5-8/1-5/2, 10YR 7/2-8/2, and 2.5Y 7/3 were measured. There is also minor siltstone and very fine-grained sandstone floodplain deposits. About 1% coal beds, which are thickest and most common at the base of the formation (based on well logs). Pieces of petrified wood are observed in outcrops. Sandstones were deposited as channel-fills and occur as medium to thick, tabular beds that are internally planar to tangential cross-stratified or trough cross-stratified. Trough cross-stratification indicates a general northeast-east paleoflow direction. Sandstone exhibits fresh colors of 2.5Y 7-8/1-2 to 7/3 and weathered colors of 7.5YR 6-7/6 to 7/8 or 10YR 6/4; exposed outcrops are commonly varnished. Sandstone is very fine- to medium-grained (mostly fine- to medium-grained), subangular to subrounded, well sorted, and composed of quartz, 5-15% feldspar, and 5-15% mafic and lithic grains (that include light gray volcanic fragments and chert). Sandstone is cemented by calcium carbonate and locally by iron oxides. Both lithologies commonly bear stains of reddish, orangish, yellowish, dark brownish, and black colors from iron and manganese oxides. 610-620 m thick

Kcc **Crevasse Canyon Formation (upper Cretaceous) --** Light gray, light reddish brown, light yellowish brown, and brown fine sandstones and mudstones. Measured colors of 2.5YR 4/5, 10YR 7/1, 2.5Y 6/4, and 2.5Y 7/3. Sandstone occur in thin to thick, tabular beds and as channel-fills; these beds are internally

massive, thinly bedded, or cross-stratified. Sand is very fine- to fine-grained, locally silty, subangular to subrounded, well sorted, and composed dominantly of quartz with minor cherty lithic grains + mafic grains (up to 15%) and sparse feldspars (up to 5%). Mudstones occur in tabular, medium to thick beds that are internally massive. Typically poorly indurated, but cementation increases down-section. 150-160 m thick

Subsurface units depicted in the cross section *-- Unless noted otherwise, these were described using cuttings logs and geophysical logs from the XTO Westland #15-1 well.*

Tz **Zia Formation, undivided (lower Miocene) --** Differentiation of the Chamisa Mesa and Piedra Parada Members is difficult using subsurface data, so the Zia Formation is undivided where buried east of the Moquino fault. Sand grains are clear to pink, frosted, subrounded to rounded, moderately to well sorted, and weakly consolidated. 210-220 m total thickness. The following subunits were differentiated in the XTO Westland #15-1 well, listed in descending order (youngest to oldest):

1) 34 m (112 ft) of very fine- to fine-grained sand interbedded with clayey sand.
2) 138 m(454 ft) of very fine- to fine-grained sand; fine- to medium-grained sand, trace rock fragments, and trace plagioclase were noted in the middle of this subunit; a 5 m (15 ft)-thick green mudstone was noted 152 m (498 ft) below the top of the subunit, which appears to contain an ash bed (indicated by a high gamma spike)
3) 40 m (131 ft) of sandstone interbedded with ~5% mudstone beds; sand contains trace plagioclase and trace rock fragments.

Tis **Unit of Isleta #2 (upper Eocene to Oligocene) --** Compared to the overlying Zia Formation, this unit contains less borehole washouts, shows a slightly higher gamma ray signature, is slightly more dense, and seems to contain more fining-upward channel-fills. Redder colors were also suggested by the cuttings log. The contrast between this unit and the overlying Zia Formation is more obvious in the XTO Westland #15-1 well logs than the XTO Armijo Trust #27-1 well logs. Sand is clear and frosted, very fine- to medium-grained, subangular to subrounded, moderately sorted, and has trace rock fragments (including granite). Correlation to Unit of Isleta #2 is based on descriptions of that unit in Lozinsky (1994) for wells a few km east and northeast of the quadrangle (i.e., Shell West Mesa Federal #1 and the Carpenter Atrisco Grant 1). ~250 m total thickness in the XTO Westland #15-1 well, but >618 m thick in wells east of the quadrangle (Shroba et al., 2003). The following subunits were differentiated in the XTO Westland #15-1 well, listed in descending order (youngest to oldest):

1) 43 m (142 ft) of clayey sandstone; 10% clay beds at 32 m (106 ft) below top of unit.
2) 62 m (202 ft) of sandstone interbedded with 10-20%, reddish mudstone (muddy intervals are up to 5 m (16 ft) thick); trace consolidated sandstone with calcite cement.
3) 67 m (220 ft) of sandstone channel-fills intercalated with subequal floodplain deposits of siltstone and reddish mudstone.
4) 46 m (152 ft) of subrounded, moderately to well-sorted sandstone; sandstone is

white to gray in lower 2/3 of unit; minor red, soft, calcareous shale.
5) 30 m (100 ft) of sandstone channel-fills and minor mudstone; sand is subrounded to rounded and cemented by calcium carbonate.

Tg **Galisteo Formation (Eocene) --** Although not seen in the XTO Westland #15-1 well, the Galisteo Fm is interpreted in the Westland Development 1-Y well (2.5 km east of the eastern quadrangle boundary) and shown in a nearby cross section of Connell (2008b). In outcrop, it consists of variegated red, green, purple, and gray mudstone interbedded with yellowish brown, crossbedded, arkosic sandstone and conglomerate (Connell, 2008b). Thickness is uncertain, but here it is likely less than the 390 m reported in the Westland Development 1-Y well.

Kpl **Point Lookout Sandstone (upper Cretaceous) --** Clean, light gray (10YR-2.5Y 7/1-2) sandstone. Sand is mostly fine- to medium-grained, subangular to subrounded, well sorted, and composed of quartz, 3-12% feldspar, and 8-12% mafic + lithic grains. Local horizontal-planar laminations within medium(?) to thick(?) beds. Described using cores from the XTO Armijo Trust #27-1 well.

Kg **Gallup Sandstone (upper Cretaceous) --** Predominately sandstone with minor shale. Sand is white-gray, very fine- grained, subrounded, well sorted, and cemented by calcium carbonate. Shales are silty and exhibit colors of gray, green, tan, brown, and orange.

Kmu **Upper Mancos Shale (upper Cretaceous) --** Gray to dark gray, blocky to sub-blocky, firm, calcareous to very calcareous mudstone and 10% siltstone. Local limestone beds. Upper half contains very fine- to fine-grained, white to gray, subrounded, well sorted sandstone cemented by calcium carbonate.

Kth? **Tres Hermanos Formation(?) (upper Cretaceous) --** This formation is tentatively applied to a 24 m (80 ft)-thick sandstone body within the Mancos Shale. Sand is white, very fine- to fine-grained, subrounded, moderately sorted, and cemented by calcium carbonate.

Kml **Lower Mancos Shale (upper Cretaceous) --** Gray to dark grayish brown, blocky to platy, fissile, silty shale with local limestone beds.

Kd **Dakota Sandstone (upper Cretaceous) --** White to gray, fine-grained, rounded, well sorted sandstone cemented by calcium carbonate. Unit includes two interbedded, mudstone-rich intervals, each of which are ~9 m thick. The mudstone is gray to dark gray to dark grayish brown, silty, and calcareous.

Jmbs **Morrison Formation, Bluff Sandstone, and Summerville Formations, undivided (middle to upper Jurassic) --** The Morrison Formation consists of interbedded sandstone and mudstone. Sandstone is white to gray, very fine- to fine-grained, rounded to subrounded, well to moderately sorted, and cemented by calcium carbonate. Mudstone is gray to dark grayish brown to light green to red to orange. ~10% siltstone that ranges in color from gray to dark gray to brown to light green. 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, 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) --** The Todilto Formation consists of 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) --** The Entrada Sandstone is comprised of two members. The upper member (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.

Tr **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.

Pzu **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. The San Andres Limestone is a light gray to light brown, thin to medium-bedded limestone. Light gray, quartz sandstone lenses are present near its base. The Glorieta Sandstone is a white to light gray, medium-grained quartz arenite; it is thickly bedded and well-indurated. Sandstones of the Yeso Formation are light brown, light red, or gray and locally gypsiferous. The Abo Formation consists of reddish brown mudstone interbedded with grayish white and light orange, lenticular beds of arkosic and conglomeratic sandstone. Description slightly modified from Williams and Cole (2007). Greater than 600 m thick.

SUMMARY OF GEOCHRONOLOGIC DATA.

Map No.	Map unit	Lat. (ºN)	Lon. (ºW)	Lab. No.	Method	Material	Age ± 2σ (Ma)	Comment
S1	Tb	35.0417	-106.9308	CH-13	RFIH	groundmass	8.16 ± 0.05	La Mesita Negra[1]
S2	Td	35.0294	-106.9051	NMGRL-8945	SCLF	plagioclase	7.16 ± 0.47	Cerro Colorado[2]
S3	Qao	35.0287	-106.9752	na	GCC	glass	0.639 ± 0.002	Lava Creek B[3]

Notes: Methods include resistance furnace incremental heating (RFIH), single crystal laser fusion (SCLF), and geochemical correlation (GCC). $^{40}Ar/^{39}Ar$ age determinations recalculated to revised Fish Canyon sanidine standard (Renne et al., 1998). Date for Lava Creek B ash from Lanphere et al. (2002). Sources include: [1]Maldonado et al. (2006), [2]Connell et al. (*in press*), and [3]Izett & Wilcox (1982).

WELL DATA AND STRATIGRAPHIC PICKS

	Shell Laguna Wilson Trust #1	**XTO Armijo Trust #27-1**	**XTO Westland #15-1**
Code	*shlagwt1*	*xtoarmt1*	*xtowlan1*
Loc (S-T-R)	08.09N.01W	27.10N.01W	15.10N.01W
API (RG)	30-001-20001	30-001-20010	30-001-20012
Lat (°)	35.0241	35.0610	35.0900
Lon (°)	-106.9676	-106.9243	-106.9245
Ground-surface elev. (ft)	5,415	5,342	5,367
Total depth (ft)	11,115	5,482	6,632
Fm	XY	Jm	Jm
Year completed	1972	2005	2005
Unit top (ft)			
Santa Fe Group (Zia Fm + basal Cerro Conejo Fm)	0 (Quaternary alluvium)	0	0
Unit of Isleta #2	–	1754	1734
Menefee Fm	10	2,569	2550
Point Lookout Sandstone	2039	3,572	4,566
Crevasse Canyon Formation	2205	3,634	4,654
Gallup Sandstone	2,652	4,170	5,184
Mancos Shale (subsuming possible Tres Hermanos Fm)	2,779	4,307	5318
Dakota Sandstone	3,678	5,020	6,128
Morrison Fm	3,855	5,244	6,398
Todilto Fm	4,478	–	–
Entrada Sandstone	4,590	–	–
Chinle Group	4,719	–	–
San Andres Limestone	6,300	–	–
Glorieta Sandstone	6,618	–	–
Yeso Formation	6,830	–	–
Abo Formation	7,605	–	–
Madera Group	8,461	–	–
Sandia Formation	10,500	–	–
Crystalline basement	11,102	–	–

REFERENCES

Baldwin, B. 1963. Part 2, Geology. *In* Spiegel, Zane, and Baldwin, *eds*. Geology and Water resources of the Santa Fe area, New Mexico. USGS Water-supply Paper 1525: 21-89.

Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.

Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey, a division of the Utah Department of Natural Resources, Miscellaneous Publication 91-3, 63 p.

Compton, R.R., 1985, Geology in the field: New York, John Wiley & Sons, Inc., 398 p.

Connell, S.D., 2008a, Refinements to the stratigraphic nomenclature of the Santa Fe Group, northwestern Albuquerque basin, New Mexico: New Mexico Geology, v. 30, n. 1, p. 14-35.

Connell, S.D., 2008b, Geologic map of the Albuquerque-Rio Rancho metropolitan area and vicinity: New Mexico Bureau of Geology and Mineral Resources, Geologic Map 78, 1:50,000 scale.

Connell, S.D., Koning, D.J., and Cather, S.M., 1999, Revisions to the stratigraphic nomenclature of the Santa Fe Group, northwestern Albuquerque Basin, New Mexico,: New Mexico Geological Society, 50th Field Conference Guidebook, p. 337-353.

Connell, S.D., Smith, G.A., Geissman, J.W., and McIntosh, W.C., *in press*, Climatic controls on nonmarine depositional sequences, Albuquerque Basin, Rio Grande rift, north-central New Mexico, *in* Hudson, M.R., and Grauch, V.J.S., eds., New Perspectives on the Rio Grande rift: from tectonics to groundwater: Geological Society of America, Special Publication.

Galusa, T., 1966, The Zia Sand Formation, new early to medial Miocene beds in New Mexico: American Museum Novitates, no. 2271, 12 pp.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Hawley, J.W., Kottlowski, F.E., Seager, W.R., King, W.E., Strain, W.S., and LeMone, D.V. 1969. The Santa Fe Group in the south-central New Mexico border region: *in* Kottlowski, F.E. and LeMone, D.V., eds., Border stratigraphy symposium: New Mexico Bureau of Geology and Mineral Resources, Circular 104, p. 52-76.

Heckert, A.B., and Lucas, S.G., 2003, Triassic stratigraphy in the Zuni Mountinas, west-central New Mexico: New Mexico Geological Society Guidebook, 54th Field Conference, Geology of the Zuni Plateau, p. 245-262.

Ingram, R.L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geological Society of America Bulletin, v. 65, p. 937-938, table 2.

Izett, G. A. and Wilcox, R. E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada: U.S. Geological Survey, Miscellaneous Investigations Map I-1325, scale 1:4,000,000.

Kelley, V.C., 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 60 p.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., Obradovich, J.D., 2002, Revised ages for tuffs of the Yellowstone Plateau volcanic field: assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event: Geological Society of America Bulletin, v. 114, n. 5, p. 559-568.

Lozinsky, R.P., 1994, Cenozoic stratigraphy, sandstone petrology, and depositional history of the Albuquerque basin, central New Mexico, *in* Keller, G.R., and Cather, S.M., eds., Basins of

the Rio Grande rift -- structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291. p. 73- 82.
Lucas, S.G., and Anderson, O.J., 1998, Jurassic stratigraphy and correlation in New Mexico: New Mexico Geology, v. 20, p. 97-104.
Lucas, S.G., and Heckert, A.B., 2003, Jurassic stratigraphy in west-central New Mexico: New Mexico Geological Society Guidebook, 54th Field Conference, Geology of the Zuni Plateau, p. 289-301.
Lucas, S.G., Anderson, O.J., and Pigman, C., 1995, Jurassic stratigraphy in the Hagan basin, north-central New Mexico: New Mexico Geological Society, 46th Field Conference, p. 247-255.
Maldonado, F., Budahn, J.R., Peters, L., and Unruh, D.M., 2006, Geology, geochronology, and geochemistry of basaltic flows of the Cat Hills, Cat Mesa, Wind Mesa, Cerro Verde, and Mesita Negra, central New Mexico: Canadian Journal of Earth Sciences, v. 43, n. 9, p. 1251-1268.
Munsell Color, 1994 edition, Munsell soil color charts: New Windsor, N.Y., Kollmorgen Corp., Macbeth Division.
Renne, P.R., Swisher, C.C., W.D., Deino, Karner, D.B., Owens, T.L., and dePaolo, D.J., 1998, Intercalibration of standards, absolute ages and uncertainties in $^{40}Ar/^{39}Ar$ dating: Chemical Geology, v. 145, n. 1-2, p. 117-152.
Shroba, R.R., Thompson, R.A., Schmidt, D.L., Personius, S.F., Maldonado, F., and Brandt, T.R., 2003, Geologic map of the La Mesita Negra SE quadrangle, Bernalillo County, New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2416, 1:24,000 scale.
Soil Survey Staff, 1992, Keys to Soil Taxonomy: U.S. Department of Agriculture, SMSS Technical Monograph no. 19, 5th edition, 541 p.
Tedford, R.H., and Barghoorn, S., 1999, Santa Fe Group (Neogene), Ceja del Rio Puerco, northwestern Albuquerque Basin, Sandoval County, New Mexico: New Mexico Geological Society Guidebook, 50th Field Conference, Albuquerque, Geology, p. 327-335
Udden, J.A., 1914, The mechanical composition of clastic sediments: Bulletin of the Geological Society of America, v. 25, p. 655-744.
Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.
Wright, H.E., Jr., 1943, Cerro Colorado, an isolated non-basaltic volcano in central New Mexico: American Journal of Science, v. 241, n. 1, p. 43-56.
Williams, P.L., and Cole, J.C., 2005, Preliminary geologic map of the Albuquerque 30' x 60' quadrangle, north-central New Mexico: US Geological Survey, Open-file Report 2005-1418, version 1.0; http://pubs.usgs.gov/of/2005/1418.