NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES
A DIVISION OF **NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY**

Dr. Peter A. Scholle
Director* and *State Geologist

Dr. Paul W. Bauer
Geologic Mapping Program Director

Geology of the Bernalillo and Placitas quadrangles, Sandoval County, New Mexico

PLATE III of III.

Map Unit Descriptions and Correlation of Units

1:24,000

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Bernalillo quadrangle
NMBMMR OF-DM-16
May 1998

Sean D. Connell[1]

Placitas quadrangle
NMBMMR OF-DM-2
June 1995

Sean D. Connell[1], Steve M. Cather[2], Bradley Ilg[3], Karl E. Karlstrom[3], Barbara Menne[3], Mark Picha[3], Chris Andronicus[3], Adam S. Read[2], Paul W. Bauer[2], and Peggy S. Johnson[2]

[1]*New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801, Albuquerque Office, Albuquerque, NM 87106*
[2]*New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801*
[3]*Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131*

Map Unit Descriptions

Cenozoic Deposits

Neogene (Quaternary and Tertiary) System

Colluvial, landslide, eolian, and anthropogenic deposits

Thin surficial deposits derived from wind and mass-movement processes, or extensive areas disturbed by open-pit aggregate mining or construction.

af — **Artificial fill (Historic)** — Dumped fill and areas affected by human disturbances. Locally mapped where areally extensive or geologic contacts are obscured.

daf — **Disturbed land and artificial fill, undivided (Historic)** — Dumped fill and areas affected by open-pit aggregate mining or construction. Locally mapped where disturbance is areally extensive or geologic contacts are obscured.

Qe — **Eolian sand (Holocene)** — Unconsolidated, light-brown to light yellowish-brown (10YR), moderately to well sorted, fine-to medium-grained sand primarily recognized as low-relief narrow dunes west of the *Rio Grande*. Soil development is very weak to nonexistent. Variable thickness, ranging from 0-16 ft (0-5 m).

Qae — **Eolian sand and stream alluvium, undivided (Holocene to uppermost Pleistocene)** — Unconsolidated to poorly consolidated, moderately to well sorted, light reddish-brown to light-brown (7.5-10YR), fine- to medium-grained sand and silty sand with scattered pebbles that commonly forms a relatively thin, discontinuous mantle over upland areas west of the *Rio Grande*. Soil development is weak (Bw and Bwk horizons) with maximum Stage I carbonate morphologic development. Surface is commonly stabilized by vegetation where not disturbed by human activity. May locally contain hydrocollapsible soils. Mapped only where areally extensive or thick. Variable thickness, ranging from 0-16 ft (0-5 m).

Qls — **Landslide debris (upper to middle Pleistocene)** — Poorly consolidated and very poorly sorted, sand, brecciated Santa Fe Group deposits, and minor mud deposited by mass-movement processes, commonly along steep hillslopes. Locally forms rotated (Toreva blocks in Sections 8 and 9, T13N, R4E) blocks of gravity-transported basalt and Santa Fe Group sediments that exhibit hummocky topography and bowl-shaped closed depressions along headwall scarps. Locally subdivided into older (Qls_1) and younger (Qls_2) units. Arrows indicate direction of movement. Estimated thickness ranges from 20-100 ft (6-30 m).

Qca — **Colluvium and alluvium, undivided (Holocene to upper-middle Pleistocene)** — Poorly consolidated, poorly sorted and stratified, fine- to coarse-grained, clast- and matrix-supported deposits derived from a variety of mass-movement hillslope processes, including debris flow, shallow slump and creep. Deposits are delineated by sedimentary character and surface morphology. Gravel clasts are typically angular and composition generally reflects local upslope provenance. Locally present on the eastern slope of Sandia Mountains where deposits commonly surround small unmapped bedrock inliers. May locally contain hydrocollapsible soils. Differentiated where areally extensive, thick, or obscures geologic contacts. Variable thickness, ranging from 0-16 ft (0-5 m).

Qcb — **Basaltic colluvium (Holocene to middle Pleistocene)** — Poorly consolidated and sorted sedimentary breccia composed of angular to subangular basalt boulders that mantle slopes below the mesa-capping basalt of Santa Ana Mesa (*Tbsa*) along the southeastern margin of Santa Ana Mesa. Variable thickness, ranging from 0-16 ft (0-5 m).

Alluvium of the Rio Grande

Fluvial deposits derived from the ancestral and modern *Rio Grande*. Unconformably overlies upper Santa Fe Group deposits (commonly Loma Barbon Member and axial-fluvial deposits of the ancestral *Rio Grande*). Interfingers with eastern-margin piedmont alluvium and western-margin alluvium. Subdivided into six formations on the basis of inset relationships and, to a lesser extent, soil morphology.

Qrp, Qrp_2, Qrp_1 — **Las Padillas Formation (Historic to uppermost Pleistocene)** — Unconsolidated to poorly consolidated, pale-brown (10YR), fine- to coarse-grained sand and rounded gravel with subordinate lensoidal interbeds of fine-grained sand, silt, and clay derived from the *Rio Grande*. Recognized in drillholes and named for deposits underlying the broad inner valley floodplain near the community of Las Padillas in southwest Albuquerque (Connell *et al*., 1998). Unconformably overlies upper Santa Fe Group deposits (*QTob* and *QTsa*) and is commonly gravelly at the base. Underlying Santa Fe Group deposits may be locally cemented with calcium carbonate. Probably interfingers with stream alluvium of units *QHa* and *Qay*. Deposit surface (top) comprises the modern surface of aggradation for *Rio Grande* fluvial deposits. Locally divided into older (Qrp_1) and younger (Qrp_2) subunits on the basis of inset relationships as estimated from available aerial photography. Also subdivided into modern channel deposits of the *Rio Grande* (*Qrpr*) and Rio Jemez (*Qrpj*). Approximately 50-80 ft (15-24 m) thick.

Qrpr — **Modern channel facies (Historic)** — Unconsolidated sand and gravel within the active channel of the *Rio Grande*.

Qrpj — **Sandy floodplain alluvium of the Rio Jemez (Historic)** — Unconsolidated sand and gravel at the mouth of the *Rio Jemez*.

Qra — **Arenal Formation (upper Pleistocene)** — Poorly consolidated deposits of very pale-brown to yellow (10YR) sandy pebble to cobble gravel recognized along the northwestern margin of the *Rio Grande* inner valley. Named for exposures just west of the Arenal Main Canal in southwest Albuquerque (Connell *et al*., 1998), where it underlies Lambert's (1968) Primero Alto terrace surface. Gravel clasts are primarily rounded quartzite and subrounded volcanic rocks (commonly welded tuff and rare pumice) with minor granite. Soil development is very weak with Stage I carbonate morphology. The basal contact is approximately 50 ft (15 m) above the top of the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Approximately 10-20 ft (3-6 m) thick.

Qrd — **Los Duranes Formation (upper(?) to upper-middle Pleistocene)** — Poorly to moderately consolidated deposits of light reddish-brown, pale-brown to yellowish-brown (5-10YR) gravel, sand, and minor sandy clay derived from the ancestral *Rio Grande*. Locally covered by discontinuous veneer of undivided alluvium and eolian deposits (*Qae*). Interfingers with, and is overlain by, western-margin alluvium (*Qam*). Unconformably overlies deposits of the Loma Barbon Member (*QTob*). Map relationships and scattered drill-hole data suggests that the basal contact forms low-relief strath approximately 20 ft (6 m) above the top of the Las Padillas Formation (*Qrp, Rio Grande* floodplain). This basal contact is inset approximately 100 ft (30 m) below the base of the Edith Formation (*Qre*). Provisionally correlated with the Los Duranes Formation of Lambert (1968). Deposit contains the Rancholabrean mammal *Bison latifrons* (Locality B-7; Smartt et al., 1991, SW1/4, NE1/4, Section 19, T13N, R4E), which supports a middle Pleistocene deposit age. Correlative deposits to the south locally bury the late-middle Pleistocene (156±20 ka, Peate *et al*., 1996) basalt of the Albuquerque volcanoes (Connell, 1996, *unpubl. data*). Approximately 20-23 ft (6-7 m) thick in map area.

Qrm — **Menaul Formation (upper to upper-middle Pleistocene)** — Poorly consolidated deposits of yellowish-brown (10YR) pebble gravel and pebbly sand derived from the ancestral *Rio Grande*. Named by Lambert (1968) for exposures to the south in Albuquerque. Gravel clasts are dominated by rounded quartzite pebbles that are generally smaller in size than pebbles and cobbles in the Edith Formation (*Qre*). Forms discontinuous, probably lensoidal, exposures along the eastern escarpment of the inner valley escarpment of the *Rio Grande*. The basal contact is approximately 85-118 ft (26-36 m) above the top of the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Poorly exposed remnants of a partially eroded soil on eastern-margin piedmont alluvium (Qpm_1) indicates that the Menaul Formation unconformably overlies Qpm_1. Conformably overlain by eastern-margin piedmont alluvium (Qpm_2), and is inset by younger stream alluvium (*Qay*). May represent lenses of fluvial gravel associated with the Los Duranes Formation (*Qrd*) east of the *Rio Grande*. Thickness is generally less than 10 ft (3 m).

Qre — **Edith Formation (middle Pleistocene)** — Poorly to moderately consolidated, locally cemented deposits of pale-brown to yellowish-brown (10YR) gravel, sand and sandy clay derived from the ancestral *Rio Grande*. Forms laterally extensive outcrops along the inner valley escarpment of the *Rio Grande* that are physically correlated to Lambert's (1968) type locality to the south (see Connell, 1997; Connell *et al*., 1998). Forms an upward-fining succession consisting of a 7-26 ft (2-8 m) thick, basal quartzite-rich, cobble gravel that grades up-section into a 13-32 ft (4-10 m) thick succession of yellowish-brown (10YR) sand and reddish-brown mud. The upper contact is locally marked by a thin, white (5Y) diatomite. Gravel clasts contain abundant rounded quartzite (about 30%) and volcanic rocks (about 40%) with subordinate granite, metamorphic, and sandstone clasts, and very rare rounded welded Bandelier Tuff. Unit unconformably overlies upper Santa Fe Group deposits (*QTob* and *QTsa*), and is conformably overlain by eastern-margin piedmont alluvium (Qpm_1). A partially exposed buttress unconformity between eastern-margin piedmont alluvium (Qpm_2) and upper Santa Fe Group deposits (*QTob, QTsa*, and *QTsp*) locally marks the eastern extent. Basal contact is generally well exposed and forms a low-relief strath approximately 40-80 ft (12-24 m) above the top of the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Locally contains Rancholabrean fossils (Lambert, 1968; Lucas *et al*., 1988). Moderately developed soils on overlying eastern-margin piedmont deposits (Qpm_1) suggest a middle Pleistocene age for unit. Variable thickness, up to 10-40 ft (3 to 12 m).

Qrl — **Lomatas Negras Formation (middle Pleistocene)** — Moderately consolidated and weakly cemented sandy pebble to cobble gravel primarily composed of subrounded to rounded quartzite, volcanic rocks, granite and minor basalt. Discontinuously exposed and recognized as a lag of rounded quartzite-bearing gravel approximately 230-245 ft (70-75 m) above the top of the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Basal contact forms a low-relief strath cut onto the Loma Barbon Member (*QTob*). Unconformably(?) overlain by western-margin alluvium (*Qam*). Correlative deposits to the south underlie the late-middle Pleistocene (156±20 ka, Peate *et al*., 1996) Albuquerque volcanoes basalt. Unit may be correlative to fluvial terrace deposits Qta_1 of Smith and Kuhle (1998a), which contains the *ca*. 602 ka Lava Creek B ash. Generally less than 16 ft (5 m) thick.

Alluvium

Divided into stream-valley alluvium, western-margin alluvium, and eastern-margin piedmont alluvium. Stream-valley alluvium (*QHa* and *Qay* units) typically contain poorly to well sorted, poorly to well stratified, clast- and matrix-supported deposits associated with modern and late Pleistocene entrenched arroyos across the map area. Gravel composition reflects upland lithology. Stream-terrace deposits typically have an elongate planform shape and are associated with major drainages. Western-margin alluvium is delineated west of the inner valley of the *Rio Grande* (*Qam* and *Qao* units) and generally contains poorly to moderately sorted, moderately stratified, and clast and matrix supported deposits derived from uplands underlain by deposits of the Arroyo Ojito Formation (Loma Barbon and Ceja(?) Members). Eastern-margin piedmont alluvium (*Qpo* and *Qpm* units) contains generally poorly sorted, poorly stratified, clast- and matrix-supported deposits having angular to subangular clasts of granitic, metamorphic, sandstone, and minor limestone derived from the western and northern slopes of the Sandia Mountains and eastern basin margin.

Stream-valley alluvium

QHa, QHao — **Youngest stream alluvium (Historic to Holocene)** — Unconsolidated deposits of brown, light gray-brown, and yellowish-brown (10YR) sand, silty to clayey sand, and gravel. Boulders are common along the base of Rincon Ridge and northwestern front of the Sandia Mountains. Inset against eastern-margin piedmont alluvium (Qpm_2) and stream alluvium (*Qay*). Underlies modern arroyos that grade westward to the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Very weakly developed soils exhibit no pedogenic carbonate at the surface and weak Stage I carbonate morphology at depth. Locally subdivided into an older (*QHao*) deposit on the basis of inset relationships. Forms extensive valley border alluvial fans along the margins of the inner valley of the *Rio Grande*. These valley border alluvial fans may locally contain hydrocollapsible soils. Geomorphic surface Q9 of Connell (1995, 1996). Variable thickness, up to 40 ft (12 m).

Qay, Qay_2, Qay_1 — **Younger stream alluvium (Holocene to uppermost Pleistocene)** — Poorly consolidated deposits of very pale-brown to light-brown (7.5-10YR) sand to sandy clay loam and gravel. Inset against alluvium of units *Qpm* and *Qam*. Slightly dissected surface possesses well-developed constructional bar-and-swale topography. Weakly developed soils exhibit Stage II carbonate morphology and minor clay film development. Associated with broad valley fill units within modern stream valleys that grade to the Las Padillas Formation (*Qrp, Rio Grande* floodplain). Hibben (1941) reported Rancholabrean mammals (*Mastodon* and *Equus*) within this unit near the Village of Placitas (see also Kelley and Northrop, 1975, p. 72-73). Archaic (2-6 ka) projectile points were also reported in this deposit (probably near the deposit base) just north of state highway NM 165, near the Village of Placitas (Bruce Huckle, UNM Maxwell Museum, 1999 *written communication*). Locally includes undivided stream alluvium (*QHa*) in narrow arroyos. Locally divided into older (Qay_1) and younger (Qay_2) subunits on the basis of inset relationships at the southwestern corner of the Bernalillo quadrangle. Spring deposits are locally interbedded within reaches of the Arroyo de San Francisco (notably in Section 15, T13N, R5E). Forms broad valley border alluvial fans along the margins of the inner valley of the *Rio Grande*. These valley border alluvial fans may locally contain hydrocollapsible soils. Geomorphic surface Q8 of Connell (1995, 1996). Variable thickness, up to 70 ft (21 m).

Western-margin alluvium

Qam — **Middle western-margin alluvium, undivided (upper to middle Pleistocene)** — Poorly consolidated deposits of yellowish-brown to reddish-yellow (7.5-10YR) sand to silty-clayey sand and minor gravel. Gravel is primarily composed of red granite, chert, basalt, and minor gray volcanic rocks recycled from the Arroyo Ojito Formation. Locally well stratified and slightly cemented with calcium carbonate. Inset against older western-margin alluvium (*Qao*) and is inset by young stream alluvium (*Qay*). Soil development is variable and possesses Stage II to III carbonate morphology. Delineated west of the *Rio Grande*, where deposits are associated with broad valley fill units that interfinger with the Los Duranes Formation (*Qrd*). Correlative to eastern-margin piedmont alluvium (*Qpm*) and geomorphic surfaces Q6-Q7 of Connell (1995, 1996). Variable thickness, up to 200 ft (61 m).

Qao — **Older western-margin alluvium, undivided (middle to lower Pleistocene)** — Poorly consolidated deposits of light reddish-brown (7.5-10YR) sand with pebble to cobble gravel interbeds primarily composed of red granite, chert and basalt recycled from the Arroyo Ojito Formation. Unconformably overlies upper Santa Fe Group deposits (*QTob, QToc(?)*), and the Lomatas Negras Formation (*Qrl*). Inset by western-margin alluvium (*Qam*). Unit is poorly exposed and commonly capped by thin veneer of undivided eolian and alluvium (*Qae*). Soil development is variable and possesses Stage I to III carbonate morphology. Delineated west of the *Rio Grande*, where deposits are associated with broad valley fill units overlie the Lomatas Negras Formation. Generally correlative to older eastern-margin piedmont alluvium (*Qpo*) and geomorphic surfaces Q3-Q5 of Connell (1995, 1996). Variable thickness, up to 50 ft (15 m).

Eastern-margin piedmont alluvium

Qpy, Qpy_2, Qpy_1 — **Younger eastern-margin piedmont alluvium (Holocene to uppermost Pleistocene)** — Unconsolidated deposits of brown, light gray-brown, and yellowish-brown (10YR) sand, sandy clay loam and gravel. Boulders are common along mountain-front alluvial fans along the flanks of Rincon Ridge and northern Sandia Mountains. Deposit surface is weakly dissected and possesses well developed bar-and-swale topography. Soils possess Stage I to II+ carbonate morphology and few thin clay films. Locally subdivided into older (Qpy_1) and younger (Qpy_2) subunits on the basis of soil-profile and inset relations. Commonly buries the Edith Formation (*Qre*) and terminates against the escarpment of the inner valley of the *Rio Grande*. Geomorphic surface Q9 of Connell (1995, 1996) Variable thickness, up to 120 ft (36 m).

Qpm — **Middle eastern-margin piedmont alluvium, undivided (upper to middle Pleistocene)** — Poorly consolidated deposits of very pale-brown to light-brown (7.5-10YR) sand to silty and clayey sand, and gravel derived from the Sandia Mountains. Unconformably overlies the Edith Formation (*Qre*) and is inset by younger stream alluvium (*Qay*). Gravel clasts are predominantly subangular metamorphic and porphyritic granite along the western mountain front, and dominated by limestone and sandstone with subordinate granite and metamorphic rocks along the northern flank of the Sandia Mountains. Granite and limestone clasts are moderately to deeply pitted, and schist clasts are locally slightly split. The slightly dissected deposit surface possesses subdued, constructional bar-and-swale topography on interfluves. Weakly developed soils exhibit Stage II to III+ carbonate morphology and minor to moderate clay film development. Locally divided into two subunits. Variable thickness, up to 140 ft (43 m).

Qpm_2, Qpm_{2a}, Qpm_{2b} — **Middle eastern-margin piedmont alluvium, younger subunit (upper to middle Pleistocene)** — Moderately consolidated deposits of very pale-brown to strong yellowish-brown (7.5-10YR), poorly to moderately stratified and sorted, silty clay and loamy sand and gravel. Inset against eastern-margin piedmont alluvium (*Qpo* and Qpm_1), and conformably overlies the Menaul Formation (*Qrm*). Deposit surface along the mountain front is slightly to moderately dissected and exhibits subdued bar and swale topography on interfluves. The top of the deposit is deeply dissected along the eastern escarpment of the inner valley of the *Rio Grande*. Soils are moderately developed and possess Stage II carbonate morphology and few to common, thin to moderately thick clay films. Locally divided into older (Qpm_{2a}) and younger (Qpm_{2b}) deposits on the basis of inset relationships. Remnants of a broad, west-sloping constructional piedmont-slope, herein named the Del Agua geomorphic surface, are preserved on the younger subunit (locally mapped as Qpm_{2b}) between *Del Agua Cañon* and *Sandia Wash*. Geomorphic surface Q7 of Connell (1995, 1996).

Qpm_1 — **Middle eastern-margin piedmont alluvium, older subunit (middle Pleistocene)** — Moderately consolidated deposits of light- to strong-brown (7.5YR) and very pale-brown to light-gray (7.5-10YR), poorly to moderately stratified and sorted, sand clayey sand and gravel. Inset against older eastern-margin piedmont alluvium (*Qpo*) and unconformably overlies the Edith Formation (*Qre*). Dissected deposit surface exhibits subdued erosional ridge-and-ravine topography. Subdued bar-and-swale constructional topography is locally preserved on broad non-dissected interfluves. Moderately well developed soils with Stage III+ carbonate morphology and many moderately thick clay films. Geomorphic surface Q6 of Connell (1995, 1996).

Qpo — **Older eastern-margin piedmont alluvium (middle to lower Pleistocene)** — Poorly to moderately sorted and stratified gravel and sand with minor silty-clay mixtures. Granite clasts are commonly grussified or deeply pitted, schist clasts are typically split, and limestone clasts are moderately to deeply pitted. Map relationships suggest that deposits are inset against the gravel of Lomos Altos (*Tsla*) and are truncated by a buried escarpment formed during deposition of the Edith Formation. Locally divided into four subunits. Variable thickness, ranging up to 46 ft (14 m).

Qpo_4 — **Older eastern-margin piedmont alluvium, youngest subunit (middle Pleistocene)** — Poorly exposed cobble gravel overlying a strath along the southern margin of *Las Huertas Creek*. Inset against older eastern-margin piedmont deposits (Qpo_3). Deposit is inset by the Edith Formation (*Qre*). Approximate thickness is less than 10 ft (3 m).

Qpo_3 — **Older eastern-margin piedmont alluvium, younger subunit (middle Pleistocene)** — Moderately consolidated deposits of pale- to dark-brown (7.5-10YR) clay loam to silty clay loam and cobble to boulder gravel. Gravel clasts are dominated by limestone, metamorphic rocks, and sandstone along the northern flank of the Sandia Mountains. Poorly exposed, inset against older eastern-margin piedmont alluvium (Qpo_1), and overlies a formerly broad, northwest-sloping pediment surface cut on Santa Fe Group and older rocks. The western margin of unit is truncated by a buttress unconformity that probably formed during deposition of the Edith Formation (*Qre*). Deposit surface is slightly dissected, exhibits subdued bar-and-swale topography. Soils are moderately developed and exhibit weak Stage III carbonate morphology and many to continuous, thick clay films. Geomorphic surface Q5 of Connell (1995, 1996). Generally thickens to the northwest, from 7-20 ft (2-6 m).

Qpo_2 — **Older eastern-margin piedmont alluvium, middle subunit (middle to lower Pleistocene)** — Poorly to moderately sorted and moderately consolidated deposits of brownish-yellow to yellowish-brown (10YR) gravel and sandy clay loam. Gravel clasts are predominantly granite, metamorphic, and subordinate limestone. Locally contains grussified granite and split metamorphic clasts. Very poorly exposed and mostly buried by eastern-margin piedmont alluvium (*Qpy* and *Qpm*) on the hangingwall of the Rincon fault (NW1/4, Section 12, T12N, R5E). Soils are strongly developed and locally exhibit Stage III to IV carbonate morphology. Geomorphic surface Q4 of Connell (1995, 1996). Estimated thickness is 7 ft to more than 45 ft (2-14 m).

Qpo_1 — **Older eastern-margin piedmont alluvium, older subunit (lower Pleistocene)** — Moderately consolidated deposits of very pale-brown to brown (7.5-10YR) sandy clay loam to silty clay loam and poorly sorted, subangular to subrounded, limestone cobble to boulder gravel. Gravel clasts are predominantly granite, metamorphic, and limestone. Unit is poorly exposed and forms a discontinuous gravelly veneer overlying a formerly extensive pediment surface near the Village of Placitas, as well as a strath just south of *Las Huertas* Creek. Inset against the gravel of Lomos Altos (*Tsla*) and inset by eastern-margin piedmont alluvium (*Qpm*). Soils are partially stripped and exhibit Stage II or III carbonate morphology. Commonly exposed on the footwalls of the Valley View, Rincon, and Lomos faults. Deposit surface is moderately dissected and is about 30-105 ft (9-32 m) above local base level. Geomorphic surface Q3 of Connell (1995, 1996). Thickness is variable, up to 7 ft (2 m).

Upper Santa Fe Group

Western basin-margin deposits (Arroyo Ojito Formation)

QTo — **Arroyo Ojito Formation, undivided (lower Pleistocene to upper Miocene)** — Cross section only. Base of unit is not exposed in map area. Estimated thickness is approximately 4,200 ft (1,280 m). Divided into two members in the map area.

QToc — **Arroyo Ojito Formation, Ceja(?) Member (lower Pliocene to lower Pliocene)** — Light-red to reddish-yellow (2.5-7.5YR), moderately consolidated, slightly cemented, slightly tilted, stratified sandstone and pebbly sandstone with minor siltstone and claystone interbeds. Gravel clasts are dominated by subangular to subrounded red granite, light-gray tuff, and basalt with subordinate chert, sandstone and minor quartzite. Conformably overlies the Loma Barbon Member of the Arroyo Ojito Formation (*QTob*) and is recognized by fairly abrupt increase in gravel content. Tentatively correlated to Kelley's (1977) Ceja Member although stratigraphic position is ambiguous. Unit could also be a coarse-grained lens of gravely sandstone within the Loma Barbon Member (*QTob*). Approximately 40-60 ft (12-18 m) thick in map area.

QTob — **Arroyo Ojito Formation, Loma Barbon Member (lower Pliocene to upper Miocene)** — Well consolidated, weakly to moderately cemented, yellowish-brown to yellowish-red and reddish-brown (5-10YR), fine-grained silty sandstone with interbedded mudstone and scattered, lensoidal, weakly to well cemented, cobbly to bouldery sandstone interbeds. Gravel clasts are predominantly subangular red granite, subrounded basalt and light-gray tuff, and minor sandstone derived from the northwestern margin of the Albuquerque Basin and eastern slope of the Sierra Nacimiento. Named after a succession of reddish-brown sandstone, gravel, and mudstone exposed just north of Loma Barbon. A primary airfall lapilli tuff (Locality B-1, SE1/4, SW1/4, NW1/4, Section 10, T13N, R3E), present about 10 ft (3 m) below Ceja(?) Member deposits (*QToc(?)*), yields a $^{40}Ar/^{39}Ar$ date of 6.82±0.04 Ma (NMGRL 8925, W.C. McIntosh, 1998, *written communication*) and is tentatively correlated with the Peralta Tuff Member of the Bearhead Rhyolite. A recycled subrounded rhyodacite(?) clast (Locality B-4) yields an $^{40}Ar/^{39}Ar$ date of 4.59±0.21 Ma (NMGRL 9136, W.C. McIntosh, 1998, *written communication*). Interfingers with, and is overlain by axial-fluvial deposits (*QTsa*), which are exposed east of the inner valley of the *Rio Grande*. Correlative deposits (unit *QTst* of Cather and Connell, 1998) are overlain by the basalt of Santa Ana Mesa (*Tbsa*). Locally includes thin, discontinuous lenses of unit *QTsa* along the margins of the inner valley of the *Rio Grande*. Estimated hydraulic conductivity is poor to moderate. Base is not exposed but is at least 425 m thick in borings (*e.g.*, wells RRU12 and SAP2).

Tobc — **Syntectonic colluvial wedge unit (upper Miocene to Pliocene)** — Reddish-brown to orange-brown (5-10YR) sandstone and mudstone associated with the hanging wall of the Luce fault (Section 11, T13N, R03E). Pinches out east of the Luce fault and is interpreted to be an intra-formational colluvial wedge associated with fault movement within the Loma Barbon Member (*QTob*). Thickness ranges from 0 to 46 ft (14 m).

Axial-fluvial deposits (ancestral Rio Grande)

QTsa — **Axial-fluvial deposits of the ancestral *Rio Grande* (lower Pleistocene to upper Miocene(?))** — Variable proportions of poorly to moderately consolidated, generally weakly cemented, very pale-brown to yellowish-brown (10YR) subhorizontally bedded to slightly east-tilted sand, gravel and mud deposited by the ancestral *Rio Grande*. Sand is typically well sorted and crossbedded. Sand is locally well cemented along faults (see Locality P-6). Gravel clasts are predominantly rounded quartzite, with volcanics (intermediate, silicic, and basaltic), minor metamorphic rocks, granite, and chert. Mudstone ranges in color from light brown to grayish green. Clast imbrication measurements indicate generally south to southwest paleoflow. The presence of recycled clasts of lower Bandelier Tuff (Locality P-3, P-4, and P-5) and an Irvingtonian "aged" *Glyptotherium* (Locality B-5; Lucas *et al*., 1993, p. 6) indicate an early Pleistocene age for the upper part of this unit. Similar fluvial deposits interfinger with western basin-margin deposits beneath the basalt of Santa Ana Mesa (*Tbsa*). Correlative deposits to the north are late Miocene to early Pleistocene in age (Smith and Kuhle, 1998b). May be correlative with axial-stream deposits of the Sierra Ladrones Formation (Machette, 1978) described along the southern margin of the Albuquerque Basin. Estimated hydraulic conductivity is moderate to high. Base is not exposed. Estimated thickness is 2,200 ft (670 m).

QTst — **Transitional fluvial-piedmont deposits** — Interfingered axial-fluvial deposits (*QTsa*) and Santa Fe Group eastern basin-margin piedmont deposits ($QTsp_{cs}$ and *QTsp*). Transitional deposits are defined as the zone of overlap between the easternmost outcrops of axial river deposits and the westernmost outcrops of piedmont sandstone and conglomerate. Mudstone is commonly ambiguous as to its position within the facies tract (piedmont vs. axial), and is not a factor in delineating the transitional facies (Cather, 1997). A rounded pumice clast from a lens of fluvial sand and gravel (Locality B-6) has been identified by $^{40}Ar/^{39}Ar$ dating as the *ca.* 1.6 Ma lower Bandelier Tuff (W. C. McIntosh, 1995 *written communication*).

Eastern basin-margin piedmont deposits

QTt — **Travertine and spring deposits (middle Pleistocene to Pliocene)** — Light-gray nodular to massive limestone interlayered with mudstone. Prominent outcrop at the northern tip of the Cuchilla de San Francisco (Sections 14 and 15, T13N, R5E) where deposits overlie and interfinger with Santa Fe Group eastern basin-margin piedmont deposits ($QTsp_{cs}$) on the hangingwall of the San Francisco fault. Spring deposits are locally present along depositional contacts and faults. Variable thickness, up to 50 ft (15 m) thick.

Qss — **Suela Alluvium (lower Pleistocene)** — Moderately consolidated and weakly cemented deposits of brown, very pale-brown to white (7.5YR-2.5Y) sandy loam, sand and subrounded to subangular cobble to pebble gravel overlying remnants of extensive, relatively smooth, northwest-sloping pediment surface that cuts across the trace of the Placitas fault. Gravel clasts contain abundant subrounded to subangular limestone, granite, sandstone, and metamorphic rocks. Limestone clasts are typically pitted, and granite clasts are locally grussified. The basal contact is unconformable along the northern flank of the Sandia Mountains, but becomes conformable with the underlying axial-fluvial deposits (*QTsa*) northwest of the Escala and Lomos faults. The deposit surface (top) forms a broad, northwest-sloping constructional surface herein named the Las Huertas geomorphic surface. The Las Huertas geomorphic surface is commonly buried by thin veneer of light-brown eolian sand, diverges downstream of *Las Huertas Creek*, between about 110-165 ft (34-50 m), and is underlain by moderately to strongly developed soils exhibiting III+ carbonate morphology. In the map area, the Las Huertas geomorphic surface is interpreted to mark the end of upper Santa Fe Group deposition and the initiation of Quaternary incision by the *Rio Grande*. Bar-and-swale topography is absent and soils exhibit Stage III+ carbonate morphology, and very few thin silica and clay films. Overlies Bandelier Tuff-bearing piedmont and fluvial deposits ($QTsp_{cs}$ and *QTsa*) and is thus, younger than about 1.1 Ma. Geomorphic surface Q2 of Connell (1995, 1996). Generally thickens to the northwest, from about 7 to 16 ft (2-5 m).

Tsla — **Gravel of Lomos Altos (upper Pliocene)** — Well consolidated deposits of very pale-brown to brown (10YR-2.5Y), sandy clay loam, sandy loam and subrounded to subangular, limestone-dominated, cobble to pebble gravel overlying remnants of a formerly broad pediment cut on Santa Fe Group eastern basin-margin piedmont deposits ($Tspu_c$, Tsp_c) on Lomos Altos. The basal contact is about 260-328 ft (80-100 m) above local base level, is inset against Santa Fe Group piedmont deposits ($Tspu_c$), and is recognized on the footwalls of the Lomos, Escala, and southern Valley View faults. Soils are strongly developed, partially stripped and exhibit Stage IV+ carbonate morphology. Unit may be equivalent to the Tuerto gravel of Stearns (1953) or the gravel of Lookout Park of Smith and Kuhle (1998a). Correlative deposits west of the Escala fault are probably buried beneath the Suela alluvium (*Qss*) and piedmont deposits of unit $QTsp_{cs}$. Geomorphic surface *QT1* of Connell (1995, 1996). Thickens northward from 13-60 ft (4-18 m) thick.

QTsp — **Piedmont deposits, undivided (lower Pleistocene to Miocene)** — Subhorizontally stratified to slightly east-tilted, reddish-brown to yellowish-brown and very pale-brown (7.5-10YR) conglomerate, gravelly sandstone, and sandstone with subordinate siltstone and rare mudstone. Conglomerate clasts are predominantly composed of subangular limestone, metamorphic rocks, with minor granite and sandstone. Clast imbrications indicate generally west to southwest paleoflow. Includes unit *Tsp* on cross section. May be correlative with piedmont-slope and alluvial fan deposits of the Sierra Ladrones Formation (Machette, 1978) exposed at the southern margin of the Albuquerque Basin. Thickens to the east and interfingers with axial-fluvial deposits (*QTsa*) to the west. Moderate to low estimated hydraulic conductivity. Thickness is variable and estimated to range from 3,000-7,000 ft (915-2,135 m) thick. Divided into four subunits based on dominant deposit texture (see Cather, 1997).

$QTsp_c$ — **Piedmont deposits, conglomerate subunit** — Predominantly conglomerate (conglomerate:sandstone ratio is greater than 2) with subordinate sandstone and very rare mudstone interbeds. Conglomerate clasts contain pebbles, cobbles, and boulders of lithologies similar to clasts in underlying Santa Fe Group eastern basin-margin piedmont deposits ($QTsp_{cs}$). Sandstone is coarse to very coarse and typically crossbedded or horizontally laminated. Matrix-supported conglomerate is common and interpreted to represent debris flow deposits.

$QTsp_{cs}$ — **Piedmont deposits, conglomerate and sandstone subunit** — Sub-equal conglomerate and sandstone. Conglomerate is typically poorly sorted and clast supported, consisting primarily of pebbles and cobbles of Paleozoic limestone, sandstone, siltstone, and chert, and Proterozoic granite, gneiss, phyllite, and schist. Proterozoic detritus becomes more abundant in the southern part of the quadrangle. Sandstone is horizontally laminated or trough crossbedded, moderately to poorly sorted, and commonly pebbly. Mudstone is rare. Volcanic ash (Locality P-2) is present near the top and may be correlative to the Bandelier Tuff (Dunbar, 1997, *personal communication*). On the basis of stratigraphic position (e.g., stratigraphically above recycled lower Bandelier Tuff clasts in unit *QTsa*), this ash is probably correlative to the ca. 1.1 Ma upper Bandelier Tuff.

$QTsp_s$ — **Piedmont deposits, sandstone subunit** — Sandstone (conglomerate:sandstone ratio is less than 0.5), with subordinate siltstone. Sandstone is mostly horizontally laminated with subordinate trough and planar crossbedding. Conglomerate occurs in shallow, lenticular beds, is mostly clast supported, and consists dominantly of pebbles of Paleozoic sedimentary rocks and Proterozoic crystalline rocks. Siltstone is massive to faintly laminated and forms tabular to broadly lenticular beds.

$QTsp_{sm}$ — **Piedmont deposits, siltstone and mudstone subunit** — Siltstone and mudstone with rare sandstone.

Middle and lower Santa Fe Group, undivided

Eastern-basin margin piedmont deposits

Tsp — **Piedmont deposits, undivided (lower Pliocene(?) to Miocene)** — Cross section only. Slightly to moderately tilted, well consolidated, and well cemented, sandstone and limestone-dominated conglomerate, sandstone, and mudstone derived from the Sandia Mountains and eastern basin margin. Deposits are generally better cemented and more steeply dipping than overlying upper Santa Fe Group eastern basin-margin piedmont deposits (*QTsp*, $QTsp_c$, $QTsp_{cs}$, $QTsp_s$, and $QTsp_{sm}$). May be correlative to piedmont-slope and alluvial fan deposits of the Sierra Ladrones or Popotosa formations (Machette, 1978) exposed at the southern margin of the Albuquerque Basin. Estimated thickness is approximately 9,840 ft (3,000 m). Locally divided into five mappable subunits based on dominant deposit texture (see Cather, 1997) and clast composition.

$Tspu_c$ — **Piedmont deposits, limestone-bearing conglomerate subunit** — Well consolidated and cemented, limestone-dominated gravel capping the top of Lomos Altos. Recognized by an abrupt increase in limestone clasts. Approximately 40 ft (12 m) thick.

Tsp_c — **Piedmont deposits, conglomerate subunit** — Conglomerate (conglomerate:sandstone ratio of 2) with subordinate sandstone. Mudstone is absent. Conglomerate is mostly clast supported, although matrix-supported deposits are locally present. Clast content varies upsection. Phaneritic early Tertiary volcanic clasts derived from the Espinaso Formation (*Te*) are present near the base of the section exposed along the southern end of the Cuchilla de Escala (Locality P7), with Paleozoic and Proterozoic detritus dominating upsection. Volcanic pebbles and cobbles are absent at Lomos Altos (Locality P8).

Tsp_{cs} — **Piedmont deposits, conglomerate and sandstone subunit** — Subequal sandstone and conglomerate. Mudstone is rare. Sandstone is medium- to very coarse-grained and is typically horizontally laminated or trough crossbedded. Conglomerate is mostly clast supported and consists largely of Paleozoic limestone, sandstone, siltstone, and chert with subordinate Proterozoic lithologies.

Tsp_s — **Piedmont deposits, sandstone subunit** — Sandstone (conglomerate:sandstone ratio is less than 0.5), with subordinate siltstone. Sandstone is mostly horizontally laminated with subordinate trough and planar crossbedding. Conglomerate occurs in shallow, lenticular beds, is mostly clast supported, and consists dominantly of pebbles of Paleozoic sedimentary rocks and lesser amounts of Proterozoic crystalline rocks. Siltstone is massive to faintly laminated and forms tabular to broadly lenticular beds.

Tsp_{sm} — **Piedmont deposits, siltstone and mudstone subunit** — Subequal siltstone and mudstone, with rare sandstone.

Volcanic and intrusive rocks

Tvc — **Canjilon Tuff (upper Pliocene)** — Oval-shaped tuff-breccia diatreme that intrudes east-tilted sandstone of the Loma Barbon Member (*QTob*), just south of Santa Ana Mesa. Generally dips 50° or less towards the center of the diatreme; bedding is subvertical near faults. Contains numerous basalt dikes and brecciated basalt dikes, flows and plugs, where mappable, that are differentiated as basalt and basaltic breccia beds of the Canjilon Tuff (*Tvcb*). Contains a circular tuff ring near the center of diatreme. Map of diatreme interior is simplified from Kelley and Kudo (1978).

Tvcb — **Basalt and basaltic breccia beds** — Locally brecciated basalt flows and feeder dikes interlayered within the Canjilon Tuff (*Tvc*). Yields a K-Ar date of 2.61±0.09 Ma (Kudo et al., 1977) and $^{40}Ar/^{39}Ar$ dates of 2.14±0.66 Ma and 2.52±0.43 Ma (Locality B-2 and B-3; NMGRL 9132 and 9131, respectively, W.C. McIntosh, 1998, *written communication*).

Tbsa — **Basalt of Santa Ana Mesa (upper Pliocene)** — Tholeiitic flood basalt with modal affinities to alkali olivine basalt (Kelley and Kudo, 1978, p. 9). Locally, a thin (0-13 ft or 0-4 m thick), discontinuous basaltic tuff locally underlies the base (Spiegel, 1961, Cather and Connell, 1998). Bachman and Mehnert (1978) report a K-Ar date of 2.5±0.3 Ma. In the adjoining San Felipe quadrangle, Cather and Connell (1998) report $^{40}Ar/^{39}Ar$ dates of 2.24±0.22 to 1.77±0.21 Ma (NMGRL 8926, 8927, 8928) for this unit. Variable thickness between 20-40 ft (6-12 m) along southern margin of Santa Ana Mesa.

Tmi — **Mafic or intermediate dike (upper Oligocene)** — A single, approximately 4,000 ft (1,250 m) long, northeast-trending mafic to intermediate dike, about 0.6 mi (1 km) north of the village of Placitas (San Antonio de las Huertas Grant). Unconformably overlain by Santa Fe Group eastern basin-margin piedmont deposits (Tsp_c) and yields a $^{40}Ar/^{39}Ar$ date of 30.9±0.5 Ma (NMGRL 3183, W. C. McIntosh, 1995, *written communication*).

Paleogene System

Te — **Espinaso Formation (Oligocene)** — Cross section only. Unit comprises the remnants of widespread, coarse-grained, volcaniclastic aprons that accumulated adjacent to volcanic vent complexes of the Ortiz Mountains. Consists primarily of upward-coarsening or crudely stratified tuffaceous sandstone, conglomerate, and debris-flow deposits. Variable thickness, up to 4,265 ft (1,300 m).

Tg — **Diamond Tail and Galisteo Formations, undivided (Oligocene to upper Paleocene)** — Cross section only. Unit consists of red to white mudstone, sandstone, and conglomerate deposited within fluvial channels and broad floodplains in an early Tertiary basin between Albuquerque and Santa Fe, New Mexico. Previous workers (Stearns, 1953; Kelley and Northrop, 1975; and Menne, 1989) have mapped Galisteo Formation in the area (NE1/4 of Section 36, T13N, R4E); however, relatively poor exposures, faulting, and ambiguous textural and stratigraphic relationships preclude differentiation on the map. Variable thickness, up to 4,250 ft (1,295 m).

Mesozoic Erathem

Upper Cretaceous

Kmf — **Menefee Formation, undivided** — Contains three informal members: a lower member (324 ft or 99 m thick), the Harmon Sandstone (140 ft or 43 m thick), and an upper member (740 ft or 225 m thick). Upper and lower members are similar and contain, in order of abundance: gray, tan to orange-tan, cross-bedded, and laminated to thick-bedded siltstone and sandstone; dark-gray to olive-gray and black shale; dull, dark-brown to shiny black lignitic coal; and maroon to dark-brown iron concretions. The upper member has a greater abundance of shale, carbonaceous material, ironstone, thicker coal seams, and lenticular beds of calcareous sandstone. The light-gray to buff or gray-tan Harmon Sandstone is a medium grained, well-sorted, quartz sand with cross-bedding and limonite staining. Thickness of the Harmon Sandstone is variable and thins to at least 73 ft (22 m) in the Hagan embayment east of Placitas. The lower contact between the Menefee Formation and the Point Lookout Sandstone (*Kpl*) is interfingering and gradational. Total unit thickness varies regionally from 680 ft to 1,200 ft (205 m to 365 m) due in part to post-depositional erosion.

Kpl — **Point Lookout Sandstone** — Gray-tan to light-tan and drab-yellow, very fine- to fine-grained, massive, quartz sandstone with limonitic sandstone lenses and interbedded thin gray shale. The unit is weakly cemented and a prominent ridge- and ledge-former. Both upper and lower contacts are interfingering and gradational. Unit thickness ranges from about 240 ft (73 m) near Placitas, to 315 ft (96 m) in the Hagan embayment.

Km_u — **Mancos Shale, upper member** — Medium- to dark-gray to olive-gray shale, and silty shale, with less abundant very fine to fine-grained, locally gypsiferous sandstone. This unit is an upper tongue of the lower member of the Mancos Shale (Km_l) and forms valleys and covered slopes between the more resistant Point Lookout Sandstone (*Kpl*) and Hosta-Dalton Sandstone (*Khd*). The unit produces poor quality, high sulfate ground water. Upper and lower contacts are gradational. Thickness is variable and difficult to measure due to cover but ranges from about 240 ft (73 m) west of Placitas, to 360 ft (110 m) in the Hagan embayment.

Khd — **Hosta-Dalton Sandstone** — Drab, yellow-gray to yellow-tan, very fine- to medium-grained, weakly cemented sandstone with olive-brown sandstone lenses. The unit is a moderate ridge- and ledge-former. Upper and lower contacts are gradational. Unit thickness ranges from 210 ft (64 m) near Placitas to 370 ft (112 m) in the Hagan embayment (where it contains a considerable amount of siltstone and fissile shale that does not exist in the Placitas area).

Km_l — **Mancos Shale, lower member** — Lithology is similar to the upper Mancos Shale (Km_u) with subequal proportions of olive-brown to gray to black shale and laminated to interbedded, olive-brown to gray, very fine grained sandstone, siltstone, and shale. Selenite and white to yellow gypsum are interbedded throughout the unit. The dark gray shale typical of the lower section intertongues with the underlying sandstone of the Dakota Formation (*Kd*) and the upper contact is gradational. Unit thickness is highly variable regionally and across the study area, ranging from 850 ft (260 m) west of Placitas to 1,850 ft (565 m) in the Hagan embayment. Thickness near the Village of Placitas is intermediate.

Kd — **Dakota Formation** — Medium-bedded, pervasively silica-cemented, medium-grained, yellowish-gray to orange-yellow quartz arenite. Thin interbeds of dark-gray lower Mancos Shale (Km_l) are common. Sandstones are well cemented and weather to angular and blocky ridges. Unit thickness ranges from 75 ft (23 m) west of Placitas, to less than 25 ft (8 m) in the Hagan embayment.

Upper Jurassic

Jm — **Morrison Formation, undivided** — Three members are commonly recognized in northern New Mexico but are not differentiated in this map area. In descending stratigraphic order, the members are: the Jackpile Sandstone, the Brushy Basin Shale, and the Salt Wash Sandstone (the Westwater Canyon Sandstone of former usage, Lucas *et al*., 1995). The uppermost Jackpile Sandstone is a distinctive gray-white, kaolinitic, fine- to medium-grained sandstone with a thickness of about 70 ft (21 m) near Placitas. The Brushy Basin member is a gray, green, and maroon mudstone and shale, with interbedded and intercalated gray to tan sandstone. Thickness is about 240 ft (73 m) near Placitas. The Salt Wash Sandstone is a gray to yellow-buff, medium-grained and weakly cemented sandstone, with a unit thickness of 215 ft (66 m) near Placitas. The Recapture Shale member has been redefined by Lucas *et al*. (1995) as the Summerville Formation of the upper San Raphael Group (Lucas and Anderson, 1997). However, due to poor exposure in the study area, it remains undifferentiated from the Morrison Formation. The Summerville Formation is approximately 325 ft (100 m) thick and consists of purple-gray, red-brown, and green-gray mudstone interbedded with tan, gray, and greenish-gray, very fine grained sandstone. Total thickness of the Morrison and Summerville formations combined is relatively uniform regionally, ranging from about 850 ft (260 m) near Placitas to 780 ft (240 m) in the Hagan embayment.

Middle Jurassic

Jt — **Todilto Formation, undivided** — Two members are commonly recognized in north-central New Mexico (Lucas *et al*., 1995), but are not differentiated in the map area. In descending stratigraphic order, the two members are the Tonque Arroyo Member and Luciano Mesa Member. The Luciano Mesa Member is a medium-gray to olive-gray, laminated, fetid, micritic limestone. Dark-brown to black carbonaceous mud is interbedded with limestone laminations near the base and gypsum interlayers are present from the middle to the top of the limestone member. The Tonque Arroyo Member is locally present as a white gypsum bed. Upper and lower contacts are sharp. The unit is included in the middle San Raphael Group of Lucas and Anderson (1997). Thickness of the Luciano Mesa Member ranges from 5 ft (1.5 m) southwest of the Village of Placitas, to about 20 ft (6 m) just east of the Cuchilla de San Francisco. Where present, the Tonque Arroyo member is as much as 45 ft (14 m) thick. Total unit thickness is up to 65 ft (20 m).

Je — **Entrada Formation** — Variably colored, very fine- to fine-grained, weakly cemented, crossbedded, eolian, quartz sandstone with coarser-grained components. Near Placitas, the Entrada Formation is characterized by three distinct units differentiated by color: a lower unit (75 ft or 23 m) of pale reddish-brown to grayish-pink sandstone, a middle unit (15 ft or 4.5 m) of gray-green sandstone, and an upper unit (30 ft or 9 m thick) of grayish-yellow or light-tan sandstone. Due to the local dip of 20° to 30°, the Entrada Formation forms round, nonvegetated slopes rather than the cliffs and ledges typical of other localities. Included in the lower San Raphael Group of Lucas and Anderson (1997). The contact with the underlying Chinle Group (*Ꞧcp*) is disconformable. Total unit thickness ranges from about 120 ft (37 m) near Placitas, to 71 ft (22 m) in the Hagan embayment.

Upper Triassic

Ꞧcp — **Chinle Group, undivided Petrified Forest Formation and Correo Sandstone** — Predominantly reddish-brown mudstone interbedded with thin subordinate sandstone and limestone-pebble conglomerate. The formation is only partially exposed near Placitas due to faulting. Thickness and lithologic descriptions presented here are from the Hagan embayment. Although three informal subunits are recognized near Placitas that are distinct hydrostratigraphic units, they are not differentiated at the surface. The upper unit is a thick reddish-brown mudstone, overlain by relatively thin intervals of reddish-orange siltstone and a reddish-brown to tan coarse sandstone (Correo Sandstone equivalent according to Picha, 1982). The middle unit consists of medium-grained moderately cemented sandstone interbedded with minor mudstone. The lower unit is a reddish-brown to purple to greenish-gray mudstone interbedded with silty to fine-grained sandstone. Gypsum and limestone-conglomerate lenses, characteristic of the Petrified Forest Formation, are pervasive throughout the unit. The lower contact with the underlying Agua Zarca Formation (*Ꞧz*) is gradational and interfingering. The formation varies regionally in thickness from about 1,300 ft to 1,650 ft (400 m to 500 m), and in the Hagan embayment is measured at 1,590 ft (485 m), Picha (1982).

Ꞧz — **Chinle Group, Agua Zarca Formation** — Medium-grained, tan to white and light grayish-pink, thin- to medium-bedded quartz arenite and feldspathic arenite with minor interbedded reddish-brown mudstone. Interbedded mudstone is similar to the Petrified Forest Formation (*Ꞧcp*). The sandstone is dominant and is very well cemented with silica, forms major ridges, and typically is highly fractured. The lower contact with the underlying Moenkopi is disconformable. The total unit thickness near Placitas is 220 ft (67 m).

Middle and Lower Triassic

Ꞧm — **Moenkopi Formation** — Laminated to thick-bedded, maroon-brown, micaceous, fine-grained sandstone and siltstone intercalated with minor reddish-brown mudstone. Sandstones and mudstones are moderately to weakly cemented and locally friable with generally low porosity. Both upper and lower contacts are unconformable and regional thickness varies significantly. The unit is poorly exposed in the Placitas area and thickness ranges from at least 45 ft (14 m) near the Village of Placitas to 100 ft (30 m) in the Hagan embayment.

Paleozoic Erathem

Upper Permian

Ps — **San Andres Formation** — Light gray to tan, thin- to medium-bedded limestone with interbedded grayish-white sandstone, similar to the Glorieta Formation (*Pg*), at the base. The limestones are well indurated, have a high fracture porosity, and are locally cavernous. The lower contact with the Glorieta Formation is gradational. Unit thickness ranges from about 80 ft (24 m) near Placitas to 130 ft (40 m) in the Hagan embayment.

Pg — **Glorieta Formation** — White to grayish white, massively bedded, well-indurated, medium-grained, quartz arenite. In some localities, a greenish-yellow silty mudstone, 2 to 3 ft (60 to 90 cm) thick, occurs near the top of the formation. The sandstone is extremely well cemented with silica, is often strongly fractured, and forms prominent ridges and ledges. The lower contact with the Yeso Formation (*Py*) is disconformable and sharp. Unit thickness varies from about 50 ft (15 m) near Placitas to 35 ft (11 m) in the Hagan embayment.

Lower Permian

Py — **Yeso Formation, undivided** — Two members of the Yeso Formation are recognized but not divided in the map area: the San Ysidro Member, and the underlying Meseta Blanca Member. The San Ysidro Member is a friable, orange-brown, laminated to thickly bedded, silty to fine-grained sandstone and interbedded siltstone with minor gypsum and limestone layers. A moderately cemented coarse sandstone occurs at the base. The Meseta Blanca Member is lithologically distinct and consists of a light-orange to gray-white, medium- to coarse-grained, moderately cemented sandstone. Picha (1982) mapped an informal lower Yeso member as a separate unit in the Hagan embayment (*Pyl*) that is similar to the San Ysidro Member. The lower contact with Abo Formation (*Pa*) is conformable, but is commonly difficult to discern because of similar lithologies. Total thickness is 680 ft (207 m) in the Hagan embayment.

Pyl — **Yeso Formation, lower member** — Informal lower sandstone member of the Yeso Formation is lithologically similar to the San Ysidro Member (as described above). Differentiated east of the Cuchilla de San Francisco (see Picha, 1982).

Pa — **Abo Formation** — Predominantly a reddish-brown mudstone alternating with grayish-white to light-orange lenticular beds of medium- to coarse-grained sandstone. The Abo Formation is distinguished from the Yeso Formation (*Py*) based primarily on a slight color change from orange-brown to reddish-brown and a higher proportion of coarser-grained orange or white sandstone. The sandstone is locally conglomeratic and arkosic in the lower part. The lower contact with the Madera Formation (*IPm*) is gradational and interfingering, with about 20% limestone units interbedded in reddish-brown mudstone over the lower 80 ft (25 m). The top of the lowermost laterally continuous and relatively thick limestone bed is chosen as the Madera Formation contact. Unit thickness on Cuchilla de San Francisco is 1,070 ft (325 m), Picha (1982).

Upper and Middle Pennsylvanian

IPm — **Madera Formation, undivided** — An informal upper arkosic limestone member and a lower gray limestone member of the Madera Formation are recognized, but not differentiated in this study area. The upper arkosic limestone member is gray, greenish-gray, olive-gray, tan, and buff-brown fossiliferous limestone (57% of upper member) interbedded with intervals of subarkosic sandstone and mudstone. Limestone is thinly to thickly bedded and massive with sparsely disseminated chert. Sandstones and mudstones vary from reddish-brown to maroon to greenish-gray and gray and are lenticular and laterally discontinuous. Arkosic sandstones are typically coarse- to medium-grained and commonly contain granules and pebbles. The lower gray limestone member is a gray, ledge-forming, cherty limestone separated by thinner less resistant intervals of light-brown, pale greenish-brown, tan, greenish-gray, and gray argillaceous limestone. A distinct 7 ft (2 m) thick interval of medium- to coarse-grained, green, subarkosic sandstone lies 160 ft (50 m) below the top of the lower gray limestone member and provides a marker for the lower unit. The top of the lower gray limestone member is placed at the top of the uppermost cliff-forming limestone exposed on the western rim of the Crest of Montezuma (referred to locally as Montezuma Mountain) and is also approximately coincident with the top of Cuchilla Lupe. The upper arkosic limestone member is approximately 615 ft (187 m) thick and the lower gray limestone member is approximately 645 ft (197 m) thick. Total unit thickness is 1,260 ft (385 m) on the Crest of Montezuma (Picha, 1982).

IPs — **Sandia Formation** — Consists of a variety of lithologies including, in descending stratigraphic order: interbedded brown claystone and gray limestone, massive gray limestone, and a lower olive-brown to gray, subarkosic, fine- to coarse-grained sandstone. The contact with overlying Madera Formation (*IPm*) is chosen at the base of the lowest thick limestone ledge. The lower contact is unconformable with the Arroyo Peñasco Group, where present, or Proterozoic basement. Sandia Formation limestones are distinct from the Madera Formation limestones as they are typically thinner-bedded, clast-supported, greenish, and contain abundant siliciclastic material. Unit is 193 ft (59 m) thick on the Crest of Montezuma.

Mississippian

Ma — **Arroyo Peñasco Group, Espiritu Santo Formation, undivided (locally includes the Log Springs Formation)** — These are the oldest sedimentary rocks in the area and rest unconformably on a relatively planar surface of Proterozoic basement. The Espiritu Santo Formation is composed of a basal member, the Del Padre Sandstone, and an unnamed upper member. Mississippian exposures are discontinuous with the thickest section in the vicinity of the Sandia Mountains found on the west slope of the Crest of Montezuma (generally only the basal Del Padre Sandstone is recognized). The Del Padre Sandstone, about 6 ft (2 m) thick, is a distinctive quartz-cobble conglomerate overlain by a very coarse-grained, green and purplish-brown sandstone. Stromatalitic limestones, about 30 ft (10 m) thick, are above the basal Del Padre Sandstone followed by limey mudstones, dolomites and minor wackestones. Microfossils found above the Del Padre Sandstone member indicate an Osagean age (Armstrong and Mamet, 1974). Undulose extinction and sutured quartz grain boundaries in thin sections of the basal conglomerate suggest a pre-Pennsylvanian tectonic history (Read *et al*., 1999). Unconformably overlying the Espiritu Santo Formation, on the west slope of the Crest of Montezuma, are fluvial red shales and siltstones of the Log Springs Formation (6 - 10 ft or 2 - 3 m thick) that are not differentiated from the Arroyo Peñasco Group. The total measured thickness of the Arroyo Peñasco Group is 73 ft (22 m) on the west slope of the Crest of Montezuma (Armstrong and Mamet, 1974).

Proterozoic Erathem

Mesoproterozoic

Yp — **Pegmatite and aplite dikes** — Dikes, pods, and lenses ranging from <1 in. up to >50 ft (<3 cm to >15 m) in thickness and up to 1 mi. (1.6 km) in length; interpreted to be coeval with the Sandia granite (*Ys*).

Ys — **Sandia granite** — Mainly megacrystic biotite monzogranite to granodiorite. K-feldspar megacrysts, up to ~1 in. (3 cm) long, are commonly aligned in a magmatic foliation. Contains numerous ellipsoidal enclaves of microdiorite, fine-grained granite, and gabbro (interpreted to be mingled mafic magmas), and xenoliths of quartzite and mafic metavolcanic rock. Pegmatite and aplite dikes (*Yp*), and quartz veins are ubiquitous. Various radioisotopic dates are available: U-Pb-zircon+sphene yields an age of 1,455±12 Ma (Tilton and Grunenfelder, 1968, recalculated by S. Getty, unpublished); U-Pb-zircon yields an age of 1,437±47 Ma (Steiger and Wasserburg, 1966, recalculated in Kirby *et al*., 1995); U-Pb-zircon yields an age of 1,446±26 Ma (Unruh, unpublished data); $^{40}Ar/^{39}Ar$ data yield an age of 1,422±3 Ma from hornblende and 1,423±2 Ma from muscovite (Kirby *et al*., 1995); apatite fission track dates range from 14±4 Ma at low elevation to 30±5 Ma at high elevation (Kelley *et al*., 1992).

Paleoproterozoic

Y/Xu — **Meso/Paleoproterozoic rocks, undivided** — Cross section only.

Xr — **Metarhyolite** — Multiply deformed, fine-grained, quartz-muscovite schist with distinctive fine-grained quartz porphyroclasts (eyes) (interpreted to be relict quartz phenocrysts). These rocks are exposed in the core of the Crest of Montezuma monocline beneath the Arroyo Peñasco Group (*Ma*) and bounded by the East Las Huertas fault to the west.

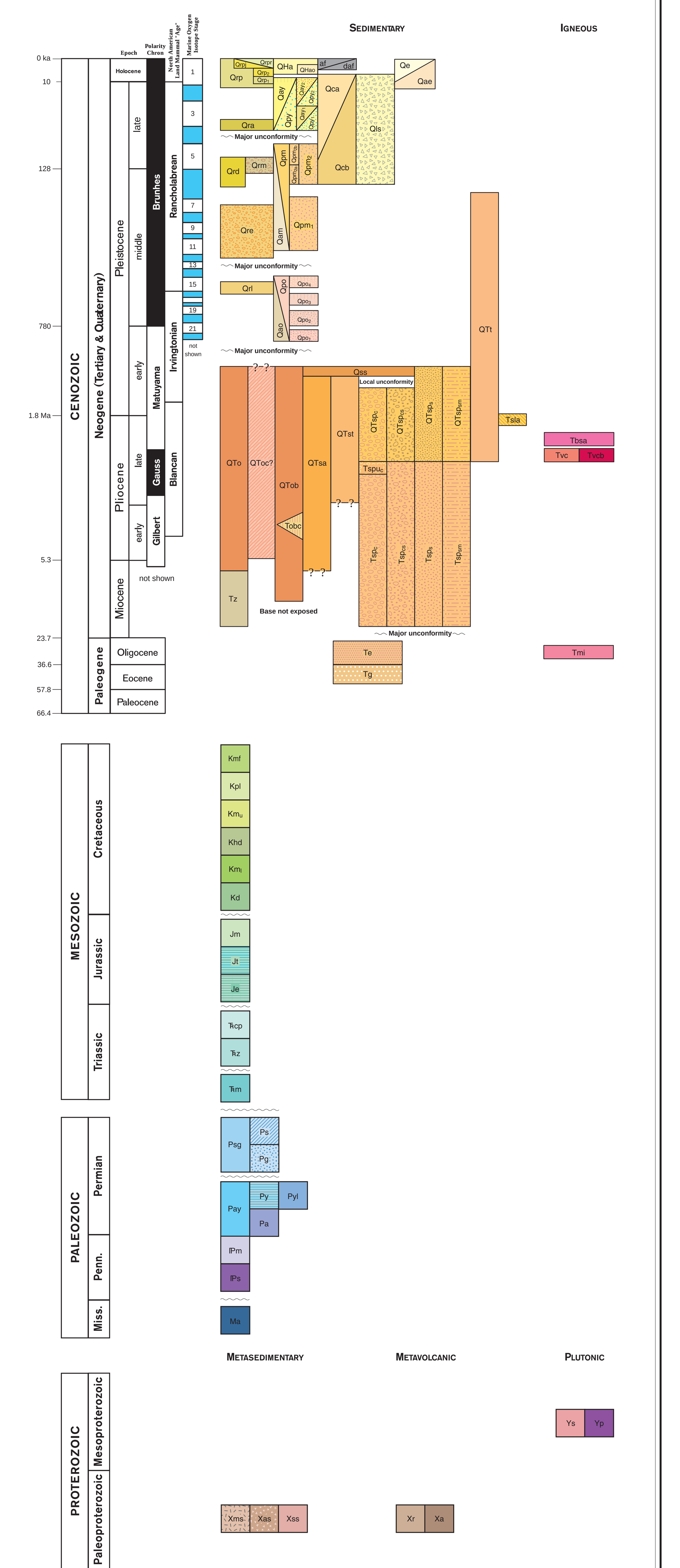
Xa — **Amphibolite and amphibole-biotite schist** — Massive green amphibole-plagioclase schist with lensoidal bodies of calc-silicate and calc-pelite interlayered with amphibolite and metapelite. Protolith is interpreted to be volcanic.

Xms — **Mica schist and phyllite** — Quartz-muscovite schist and phyllite with local andalusite porphyroblasts, commonly crenulated.

Xas — **Andalusite-biotite schist** — Pelitic andalusite and biotite schist, locally contains chlorite.

Xss — **Sillimanite-biotite schist and gneiss** — Pelitic sillimanite and biotite schist and gneiss, locally contains K-feldspar.

Correlation of Units



References

Armstrong, A. K., and Mamet, B. L., 1974, Biostratigraphy of the Arroyo Peñasco Group, Lower Carboniferous (Mississippian), North-Central New Mexico: *in: New Mexico Geological Society*, 25th Field Conference Guidebook, p. 145-158.

Bachman, G. O., and Mehnert, H. H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: *Geological Society of America Bulletin*, v.89, p. 283-292.

Cather, S. M., 1997, Toward a hydrogeologic classification of map units in the Santa Fe Group, Rio Grande rift, New Mexico: *New Mexico Geology*, v. 19, n. 1, p. 15-21.

Cather S. M., and Connell, S. D., 1998, Geology of the San Felipe Pueblo 7.5-minute quadrangle, Sandoval County, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-File Report DM-19, scale: 1:24,000.

Connell, S. D., 1995, *Quaternary geology and geomorphology of the Sandia Mountains piedmont, Bernalillo and Sandoval Counties, central New Mexico*: [M.S. Thesis] Riverside, University of California, 390 p., 3 plates.

Connell, S. D., 1996, Quaternary geology and geomorphology of the Sandia Mountains piedmont, Bernalillo and Sandoval Counties, central New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-File Report 425, 414 p., 3 plates (open-file release of Connell, 1995).

Connell, S. D., 1997, Geology of the Alameda 7.5-minute quadrangle, Bernalillo and Sandoval Counties, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-File Digital Map 10, scale 1:24,000.

Connell, S. D., Allen, B. D., Hawley, J. W., and Shroba, R. S., 1998, Geology of the Albuquerque West 7.5-minute quadrangle, Bernalillo County, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-File Report DM-17, scale: 1:24,000.

Geissman, J. W., Brown, L., Turrin, B. D., McFadden, L. D., and Harlan, S., 1990, Brunhes chron excursion/polarity episode recorded during the late Pleistocene Albuquerque volcanoes, New Mexico, USA: *Geophysical Journal Int.*: v. 102, p. 73-88.

Hibben, F. C., 1941, Evidences of early occupation in Sandia Cave, New Mexico, and other sites in the Sandia-Manzano region: *Smithsonian Institute Miscellaneous Collections*, v. 99, n. 23, publication 3636, 44 p.

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

Kelley, V. C., and Kudo, A. M., 1978, Volcanoes and related basalts of Albuquerque Basin, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Circular 156, 30 p, 2 plates.

Kelley, V. C., and Northrop, S. A., 1975, Geology of the Sandia Mountains and vicinity: *New Mexico Bureau of Mines and Mineral Resources*, Memoir 29, 136 p.

Kelley, S. A., Chapin, C. E., and Corrigan, J., 1992, Late Mesozoic to Cenozoic cooling histories of the flanks of the northern and central Rio Grande rift, Colorado and New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Bulletin 145, 39 p.

Kirby, E., Karlstrom, K. E., and Andronicus, C. L., 1995, Tectonic setting of the Sandia pluton: An orogenic 1.4 Ga granite in New Mexico: *Tectonics*, v. 14, p. 185-201.

Kudo, A. M., Kelley, V. C., Damon, P. E., and Shafiquillah, M., 1977, K-Ar ages of basalt flows at Canjilon Hill, Isleta volcano, and Cat Hills volcanic field, Albuquerque-Belen Basin, central New Mexico: *Isochron/West*, n. 18, p. 15-16.

Lambert, P. W., 1968, *Quaternary stratigraphy of the Albuquerque area, New Mexico* [Ph.D. dissertation]: Albuquerque, University of New Mexico, 329 p.

Lucas, S. G. and Anderson, O. J., 1997, The Jurassic San Rafael Group, Four Corners region: *in: New Mexico Geological Society*, 48th Field Conference Guidebook, p. 115-132.

Lucas, S. G., Anderson, O. J., and Pigman, C., 1995, Jurassic Stratigraphy in the Hagan Basin, North-Central New Mexico: *in: New Mexico Geological Society*, 46th Field Conference Guidebook, p. 247-255.

Lucas, S. G., Williamson, T. E., and Sobus, J., 1988, Late Pleistocene (Rancholabrean) mammals from the Edith formation, New Mexico: *New Mexico Journal of Science*, v. 28, n. 1, p. 51-58.

Lucas, S. G., Williamson, T. E., and Sobus, J., 1993, Plio-Pleistocene stratigraphy, paleoecology, and mammalian biochronology, Tijeras Arroyo, Albuquerque area, New Mexico: *New Mexico Geology*, v. 15, n. 1, p. 1-8.

Machette, M. N., 1978, Geologic map of the San Acacia Quadrangle, Socorro County, New Mexico: *U.S. Geological Survey* Geologic Quadrangle Map GQ-1415, scale 1:24,000.

Menne, B., 1989, *Structure of the Placitas area, northern Sandia uplift, Sandoval County, New Mexico* [M.S. thesis]: Albuquerque, University of New Mexico, 163 p.

Peate, D. W., Chen, J. H., Wasserburg, G. J., and Papanastassiou, D. A., 1996, ^{238}U-^{230}Th dating of a geomagnetic excursion in Quaternary basalts of the Albuquerque Volcanoes field, New Mexico (USA): *Geophysical Research Letters*, v. 23, n. 17, p. 2271-2274.

Picha, M. G., 1982, *Structure and stratigraphy of the Montezuma salient-Hagan basin area, Sandoval County, New Mexico* [M.S. thesis]: Albuquerque, University of New Mexico.

Read, A. S., Karlstrom, K. E., Ilg, B., 1999 (*in press*), Mississippian Del Padre Sandstone or Proterozoic Quartzite?: *minipaper in: New Mexico Geological Society*, 50th Field Conference Guidebook.

Smartt, R. A., Lucas, S. G., Hafner, D. J., 1991, The giant Bison (*Bison latifrons*) from the middle Rio Grande Valley of New Mexico: *The Southwestern Naturalist*, v. 36., n. 1, p. 136-137.

Smith, G. A., and Kuhle, A. J., 1998a, Geology of the Santo Domingo Pueblo SW 7.5-minute quadrangle, Sandoval County, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-file Digital Geologic Map OF-DM 26, scale 1:24,000.

Smith, G. A., and Kuhle, A. J., 1998b, Hydrostratigraphic implications of new geologic mapping in the Santo Domingo Basin, New Mexico: *New Mexico Geology*, v. 20, n. 1, p. 21-27.

Spiegel, Z., 1961, Geology of the lower Jemez River area, New Mexico: *New Mexico Geological Society*, Guidebook 12, p. 132-138.

Steiger, R .H., and Wasserburg, G. J., 1966, Systematics in the Pb^{208}-Th^{207}-U235, and Pb^{206}-U^{238} systems: *Journal of Geophysical Research*, v. 71, p 6065-6090.

Stearns, C. E., 1953, Tertiary geology of the Galisteo-Tonque area: New Mexico: *Geological Society of America Bulletin*, v. 64, p. 459-508.

Tilton, G. R., and Grunenfelder, M .H., 1968, Uranium-lead ages, Science, v. 159, p. 1458-1461.

U.S. Geological Survey and Sial Geosciences, Inc., 1998, Description of digital aeromagnetic data collected north and west of Albuquerque, New Mexico: *U.S. Geological Survey*, Open-File Report 97-286, http://www.ngdc.noaa.gov/seg/potfld/ad_sys.html.