From: Bill Brown <bill@brownenviro.com>
Sent: Monday, November 13, 2017 4:47 PM
To: Sidney Hill
Subject: Comments on the Proposed Sandoval County Oil and Gas Ordinance
Attachments: Sandoval county oil and gas comments WJB.pdf

Here are my comments
Thanks
Bill Brown

November 13, 2017
shill@sandovalcountynm.gov

To: Attention: Sandoval County Commission
Sandoval County, New Mexico

From: William Brown, P.G.
15 Snow Peak Road
Placitas, New Mexico 87043

RE: Comments on the Proposed Sandoval County Oil and Gas Ordinance

Introduction

The recently proposed “Stoddard Ordinance” in its current form poses a potentially serious threat to the long-term drinking water supply for the citizens of Sandoval County and potentially surrounding counties, pueblos, and municipalities, including the City of Albuquerque, the City Rio Rancho, and the Town of Bernalillo.

As part of the Comprehensive Zoning Ordinance of the Sandoval County, NM " SECTION 2. PURPOSE. “The provisions of this Ordinance are designed to promote health and the general welfare of the County; to secure safety from fire, flood, and other dangers; to protect local water resources; to facilitate adequate provisions for transportation, water and wastewater systems, schools, parks and other community requirements; to conserve the value of property; and to provide for the compatible development of land and other natural resources in Sandoval County."

The Stoddard Ordinance does not adequately meet the stated purposes of the Zoning Ordinance.

Hydrogeologic Setting

Sandoval County straddles several major geologic provinces including the San Juan Basin on the west and the Rio Grande Rift in the east. The San Juan basin is characterized by a broad depression with a relatively simple geologic environment.

The attached Figures 1 and 2 highlight the geologic setting in the eastern and more densely populated portions of the County. The Rio Grande Rift is characterized by numerous north-south trending normal faults which have resulted in the sediment infilled Rio Grande basin bounded by the uplifted Sandia mountains to the east. Tertiary and Quaternary basin fill sediments (shown in orange and brown on the attached maps), are the primary source of the Santa Fe aquifer. This aquifer provides drinking water for over half a million people in Sandoval, Bernalillo, and Valencia Counties. Proposed oil and gas exploration would penetrate these shallower aquifer zones and extend into the deeper Mesozoic and Paleozoic bedrock formations (shown in blues and greens on Figures 1 and 2). These underlying bedrock zones would likely be “fracked” as part of the oil and gas exploration/production well drilling process.

Potential Threats to Water Supplies

As can be seen on Figures 1 and 2, numerous faults are present in the vicinity of Bernalillo and Placitas areas. Implementation of Fracking in the proximity of these complicated and extensive fault zones poses a threat to overlying groundwater zones. Because of the highly complex large-scale nature of faulting in the area, the effects of fracking (and subsequent grouting) cannot be fully predicted. Horizontal fracking of bedrock adjacent to faults can result in facilitated migration of hydrocarbon contaminants (both oil and gas) along the fault zones to overlying groundwater zones. It should be noted that only the large-scale faults are shown on Figures 1 and 2; numerous smaller faults and fractures are present in the subsurface which are not shown on the maps/cross sections which further complicate the hydrogeology of the area.

Aquifer sensitivity to oil and gas production in the County generally increases from west to east. This is especially true in the vicinity of Placitas. Faulting in the Placitas area has also juxtaposed Mesozoic and Paleozoic (targets for oil-gas exploration) geologic formations against younger Tertiary and Quaternary Santa Fe aquifer formations. Fracking in these areas is even more problematic and potentially threatening to the areas water supply.

Conclusions

Oil and gas exploration and production is not an exact science and many things can go wrong during drilling, fracking, and grouting processes in complex geologic environments. This has been documented at numerous locations throughout the United States.

The current rush to approve what is a short-sighted and flawed policy towards oil and gas production in Sandoval County oversimplifies a complex problem and ignores the long-term needs of the Citizens of Sandoval County. The County Planning and Zoning Director does not currently have the expertise or the resources to make decisions which may drastically affect the long-term water supply for thousands of people.

At a minimum, Sandoval County should specify wellhead protection areas limiting or preventing oil and gas production within portions of the County based on aquifer sensitivity and land use. This is especially true in the eastern portions of the County and Placitas in particular due to its highly complex geology and potential aquifer sensitivity. *No other water supply is available to the residents and municipalities in these critically sensitive areas.* Historically, Mitigation of oil-gas exploration contaminants to drinking water aquifers is cost-prohibitive and generally impractical. Long-term litigations are usually the result.

Implementation of a more comprehensive approach to oil and gas exploration in Sandoval County can effectively mitigate these potential problems.

William Brown, P.G. Hydrogeologist
Placitas, NM

NMBMMR Open File Map Series
OF–GM–2 and OF–GM–16
Map last modified 17 February 2000
PLATE I of III.

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 I of III.
17 February 2000 Revision

Bernalillo quadrangle
NMBMMR OF-GM-16
May 1998

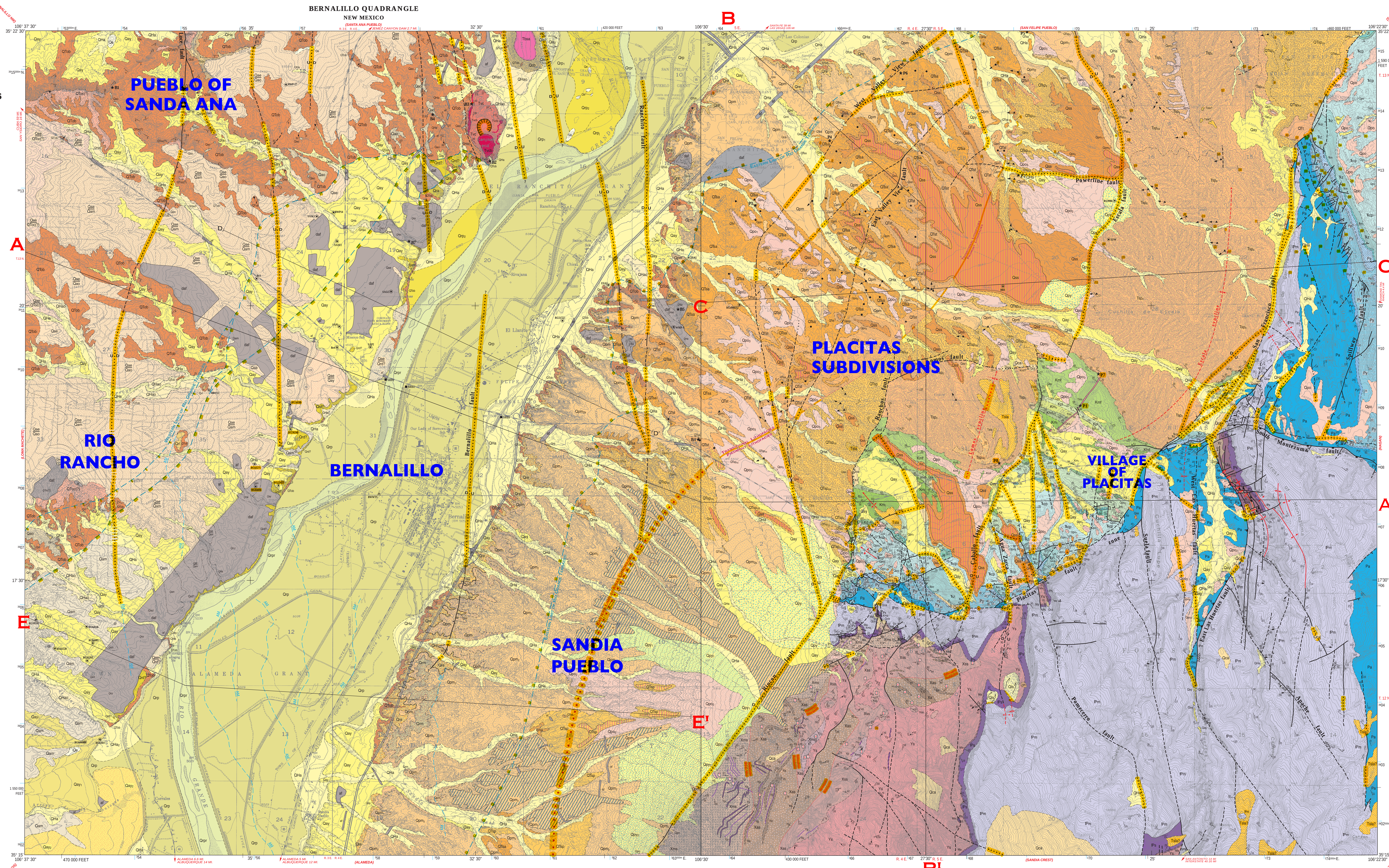
Sean D. Connell[1]

Placitas quadrangle
NMBMMR OF-GM-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]

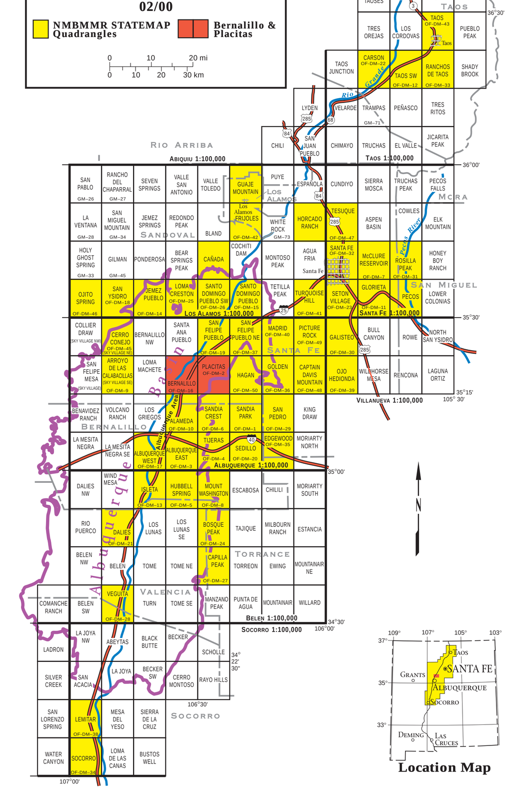
[1]*New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801, Albuquerque Office, Albuquerque, NM 87106*
[2]*New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801*
[3]*Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131*

David J. McCraw
Mark M. Mansell
Glen E. Jones
Rebecca J. Titus
Digital Cartography



Explanation of Map Symbols

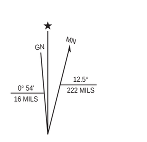
- B—B' Location of geologic cross section
- Geologic contact—solid where exposed, dashed where approximately located; dotted where concealed
- Geologic contact interpreted location within units *af* and *daf*
- Approximate location of buried contact separating the ancestral *Rio Grande* axial-fluvial deposits (Q*Tsa*) and piedmont deposits (Q*Tsp*) of the Upper Santa Fe Group on the Bernalillo quadrangle
- Approximate location of contacts separating the transitional (Q*Tst*) and piedmont ($QTsp_{cs}$ and $QTsp_s$) deposits of the Upper Santa Fe Group on the Placitas quadrangle; dotted where concealed
- Normal fault—Tic showing dip; solid where exposed, dashed where approximately located, dotted where concealed, queried where inferred; ball and bar on downthrown side, upthrown (U) and downthrown (D) sides indicated where concealed and/or interpreted
- Reverse fault—Tic showing dip; solid where exposed, dashed where approximately located, dotted where concealed; teeth on upthrown side; ball and bar added where reactivated as a Tertiary normal fault
- Anticline—Trace of axial plane showing direction of plunge; dashed where approximately located, dotted where concealed, queried where inferred
- Syncline—Trace of axial plane showing direction of plunge; dashed where approximately located, dotted where concealed, queried where inferred
- Monocline with anticlinal bend—Trace of axial plane; short arrow on steeper bend; dashed where approximately located, dotted where concealed, queried where inferred
- Monocline with synclinal bend—Trace of axial plane; short arrow on steeper bend; dashed where approximately located, dotted where concealed, queried where inferred
- Breccia or gouge zones
- Slickensides on fault
- Strike and dip of bedding, horizontal bedding
- Strike and dip of overturned bedding—ball indicates top of beds known from sedimentary structures
- Strike and dip of joint or fracture
- Strike and dip of S_1 foliation
- Strike and dip of S_2 foliation
- Strike and dip of magmatic foliation in granite defined by alignment of megacrysts
- Magmatic foliation in granite defined by mafic enclaves
- Trend and plunge of lineation—defined by elongate minerals or stretched grains
- Andalusite / Sillimanite — Metamorphic facies—Showing boundary between diagnostic mineral assemblages
- 7 — Metamorphic minerals locality— [1] sillimanite; [2] andalusite; [3] sillimanite and K-feldspar; [4] sillimanite - andalusite +/- K-feldspar and cordierite; [5] sillimanite - andalusite +/- cordierite; [6] chlorite - muscovite +/- biotite; [7] wollastonite; [8] calcite + quartz
- Diatomite marker bed at top of Edith Formation (Qre)
- Paleoflow direction—measured azimuths of imbricated clasts
- Gravels with affinities to western basin-margin deposits
- Gravels with affinities to ancestral *Rio Grande* fluvial facies
- Gravels with affinities to eastern basin-margin deposits
- Approximate extent of buried fluvial terrace risers of the ancestral *Rio Grande* (post Santa Fe Group)—Hachured towards fluvial terraces; Lomatas Negras Fm. (single hachured line), Edith Fm. (double hachured line), Los Duranes Fm. (triple hachured line), and Arenal Fm. (quadruple hachured line)
- AM — Aeromagnetic anomaly (interpreted from U. S. Geological Survey and Sial Geosciences, Inc., 1998)
- Mine or quarry, adit, shaft
- Direction of landslide failure and surface movement
- Basalt bed
- Approximate boundary of tuff ring
- ★B5 Selected locality, Placitas (P), and Bernalillo (B) quadrangles
- EFW Water-supply well, included abbreviation
- ESA1 Exploratory or groundwater monitoring well, including abbreviation
- SHD2 Exploratory geotechnical boring, including abbreviation
- Las Huertas geomorphic surface
- Del Agua geomorphic surface



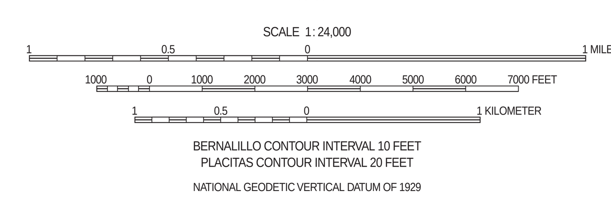
Base from U.S. Geological Survey 1954, photorevised 1972
Polyconic projection, 1927 North American datum
10,000-foot grid based on New Mexico coordinate system, cental zone1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue
Dashed land lines indicate approximate locations
West boundaries of San Felipe Grant and Sandia Pueblo Grant adjacent to Rio Grande omitted due to insufficient data

S. D. Connell: geologic mapping, compilation, Phanerozoic stratigraphy and regional structural interpretation refined from borehole data analyses, unit descriptions and correlations, and structural cross sections; geology depicted in areas of disturbance (af and daf) interpreted from aerial photography

D. J. McCraw M. M. Mansell, and G. E. Jones: digital cartographic production



UTM GRID AND 1972 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET



BERNALILLO CONTOUR INTERVAL 10 FEET
PLACITAS CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

LOCATION OF QUADRANGLES

UTM GRID AND 1954 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

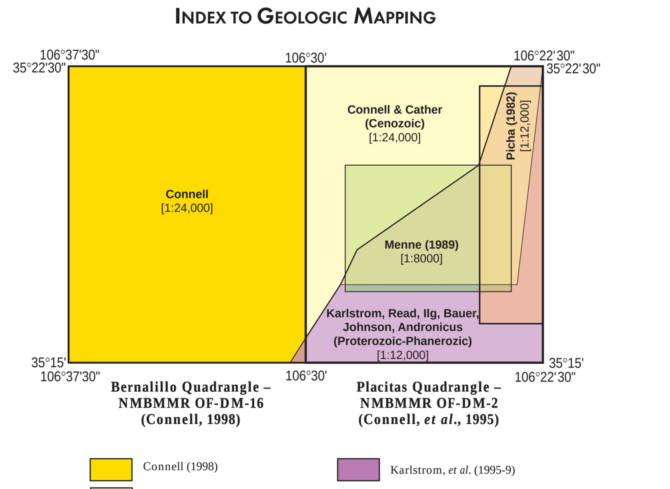
Base from U.S. Geological Survey 1954
Polyconic projection, 1927 North American datum, 10,000-foot grid based on New Mexico coordinate system, cental zone
1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue

Geologic mapping: S. D. Connell (Quaternary), S. M. Cather (Cenozoic), Bradley Ilg (S.E. section of quadrangle), C. Andronicus, A. S. Read, and K. E. Karlstrom (Proterozoic), B. Menne and M. Picha (M.S. Theses – Phanerozoic)

D. J. McCraw, M. M. Mansell, and Glen E. Jones: digital cartographic production

Mapping of these quadrangles was funded by matching-funds grants from the 1995 and 1997 **STATEMAP** component of the **National Cooperative Geologic Mapping Program** coordinated by the **U.S. Geological Survey** and the **New Mexico Bureau of Mines and Mineral Resources**.

Index to Geologic Mapping



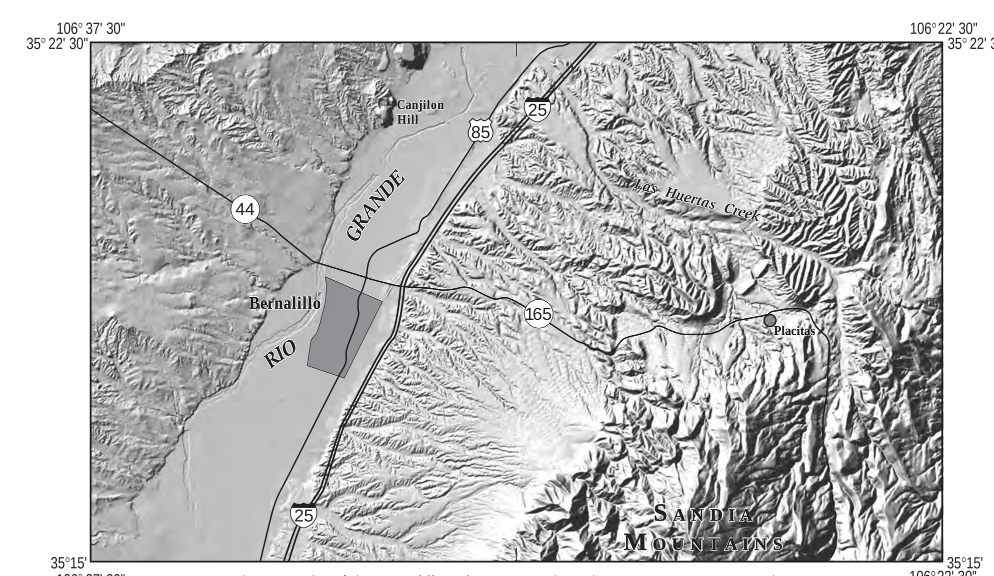
Comments to Map Users

A geologic map graphically displays information on the distribution, nature, orientation and age relationships of rock and surficial units and the occurrence of structural features. These data are derived from geologic field mapping, compilation of published and unpublished work, analyses of borehole geophysics and well-cuttings, and photogeologic interpretation. Locations of geologic unit contacts are not surveyed; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Portions of the study area were mapped at scales larger than depicted on the geologic map; therefore, the user should be aware of significant variations in map detail. 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.

This map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region (Please note the date of last modification in the upper right of Plate I). The contents of this map and associated report should not be considered final and complete until reviewed and published by the New Mexico Bureau of Mines 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 or expressed or implied, of the State of New Mexico or the U.S. Government.

Tentative correlations of alluvial units in the study area, based upon stratigraphic relations, landscape-topographic position, degree of soil development and physical correlation of units.

This Study	*Connell (1996)*	*Lambert (1968)*
QHa, QHao	Q9	Qya
Qrp, Qrp_{1-2}, Qrpr	Qfp9	Qfa
Qay	Q8	Qya
Qay_2	Q7	Qya
Qrm	Qoa2	Qm
Qre	Qoa1	Qe
Qpm	Q6	Qop
Qpo	Q5, Q4, Q3	Qop
QTob, QTsp	Q2, QT1	Qu(?)s, Tm



Physiography of the Bernalillo - Placitas area based upon 10-m USGS DEM data.

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Geologic Mapping Program Director

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

PLATE II of III.

Geologic Cross Sections

1:24,000

17 February 2000 Revision

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]

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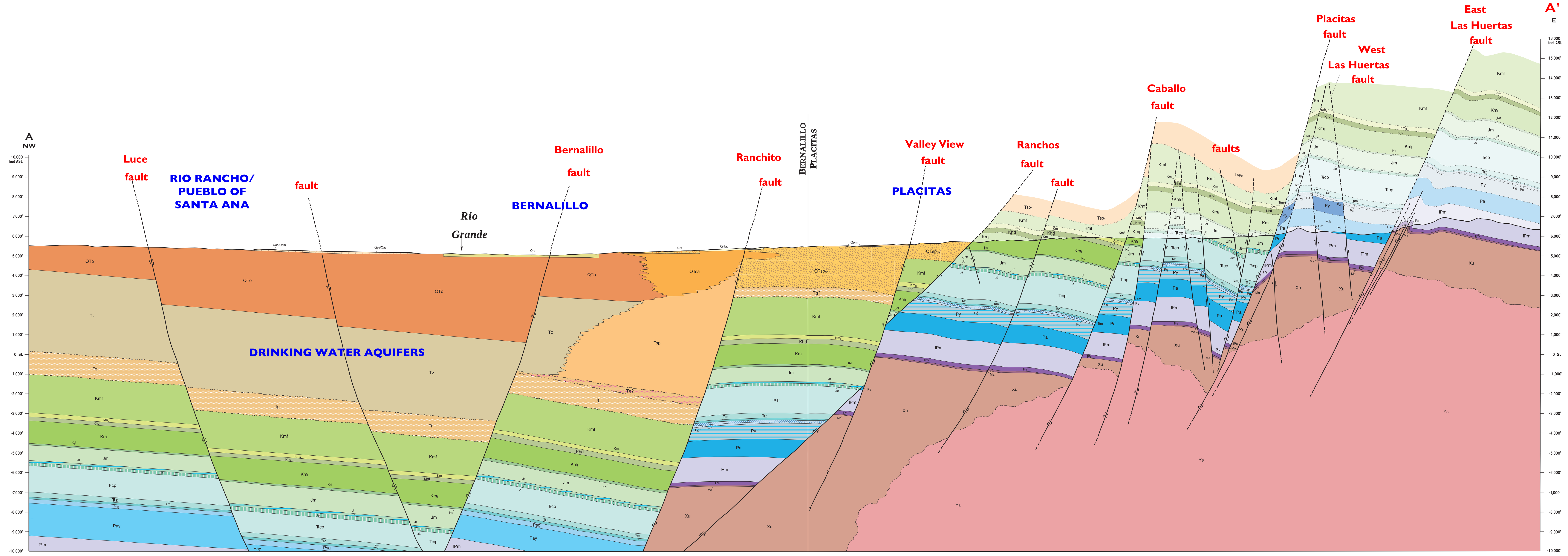
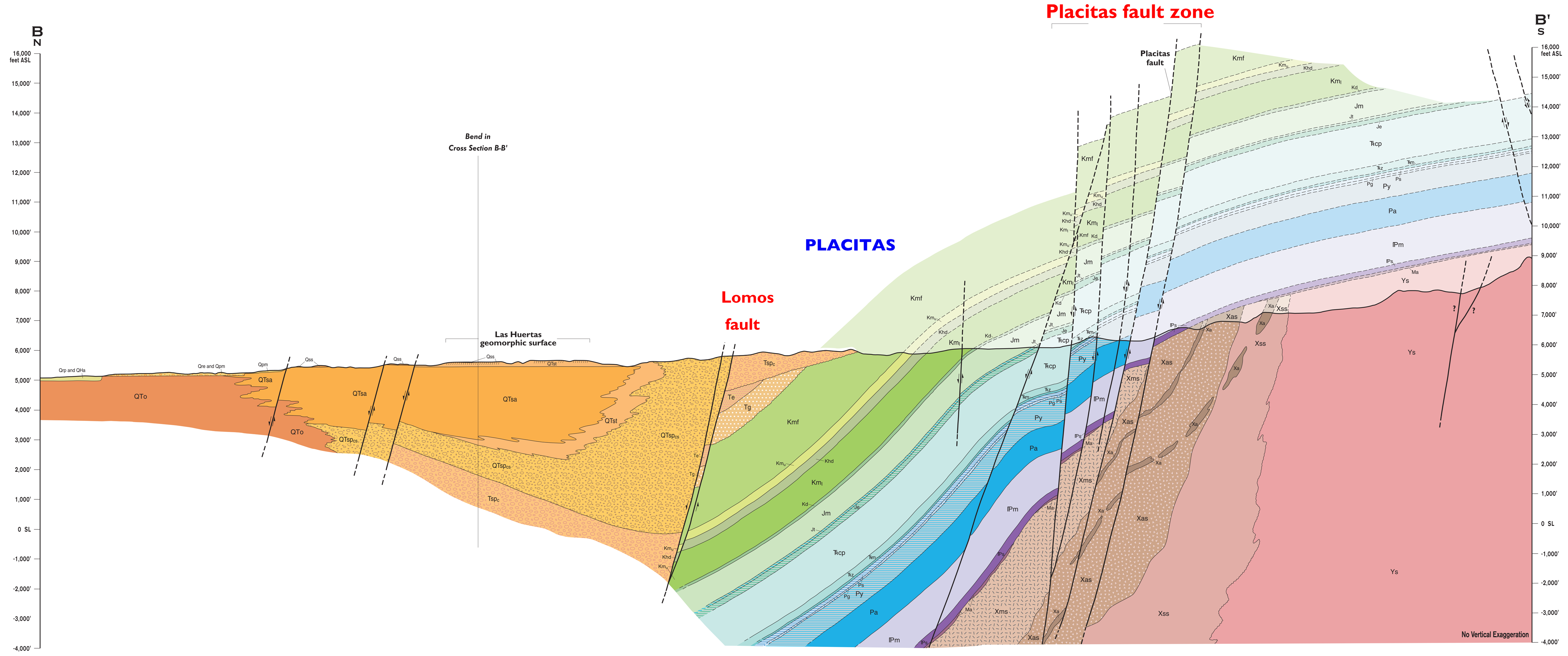
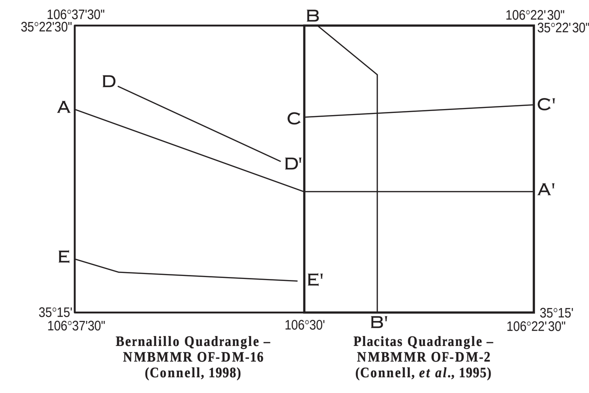




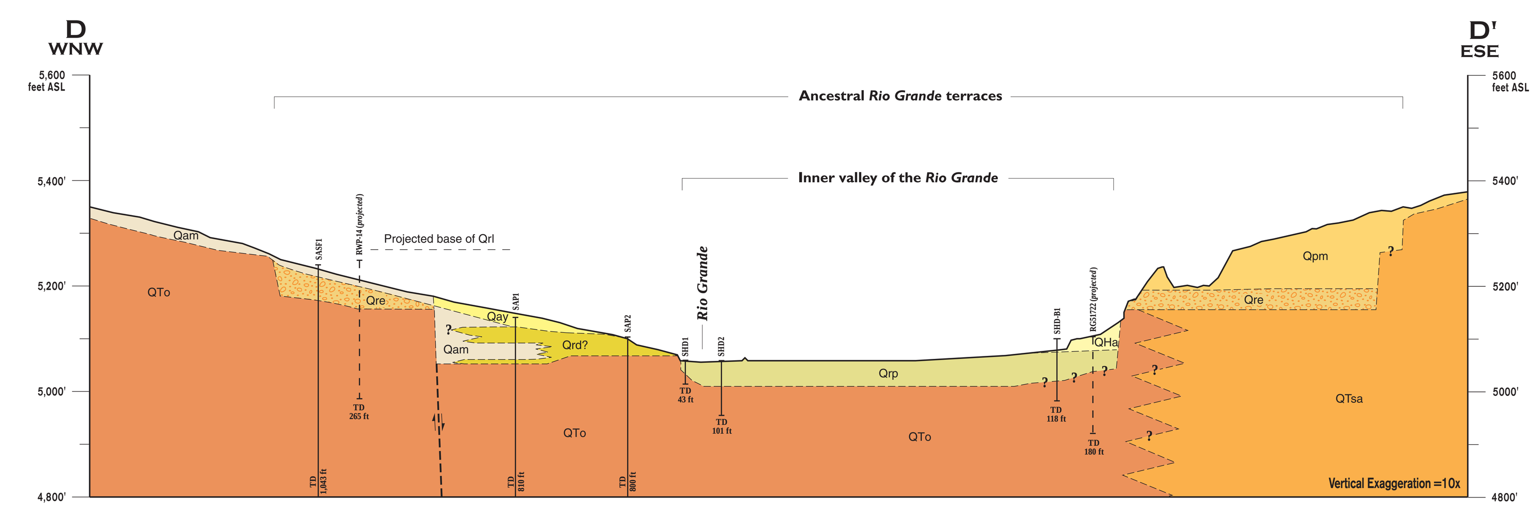
Cross Section Locations

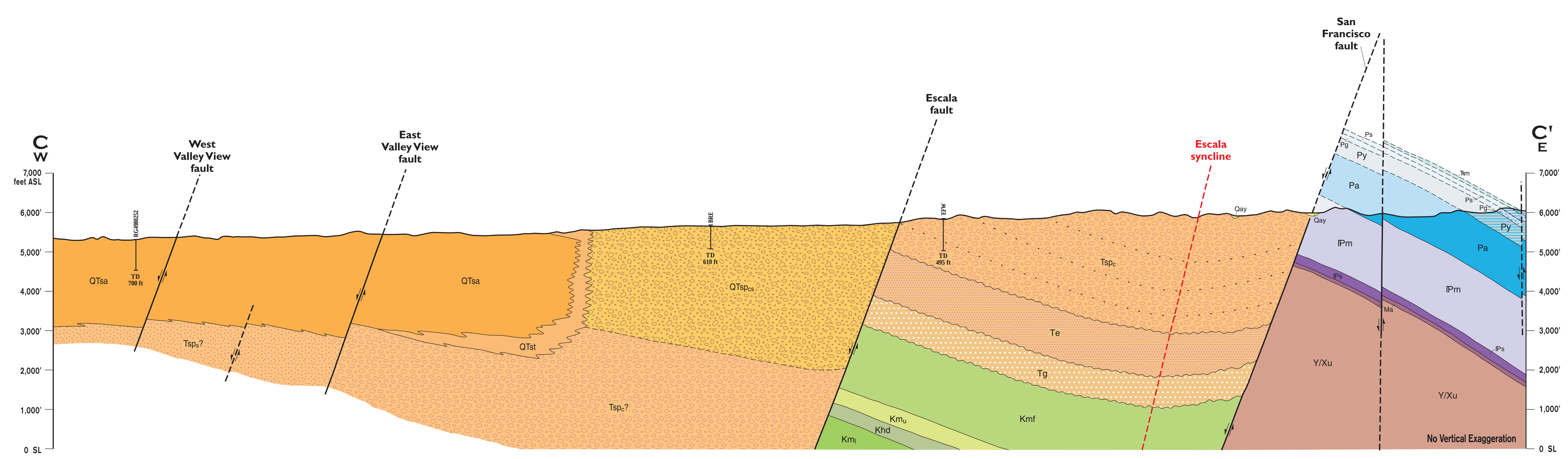


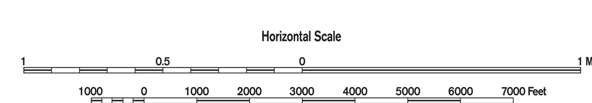
Bernalillo Quadrangle – NMBMMR OF-DM-16 (Connell, 1998)

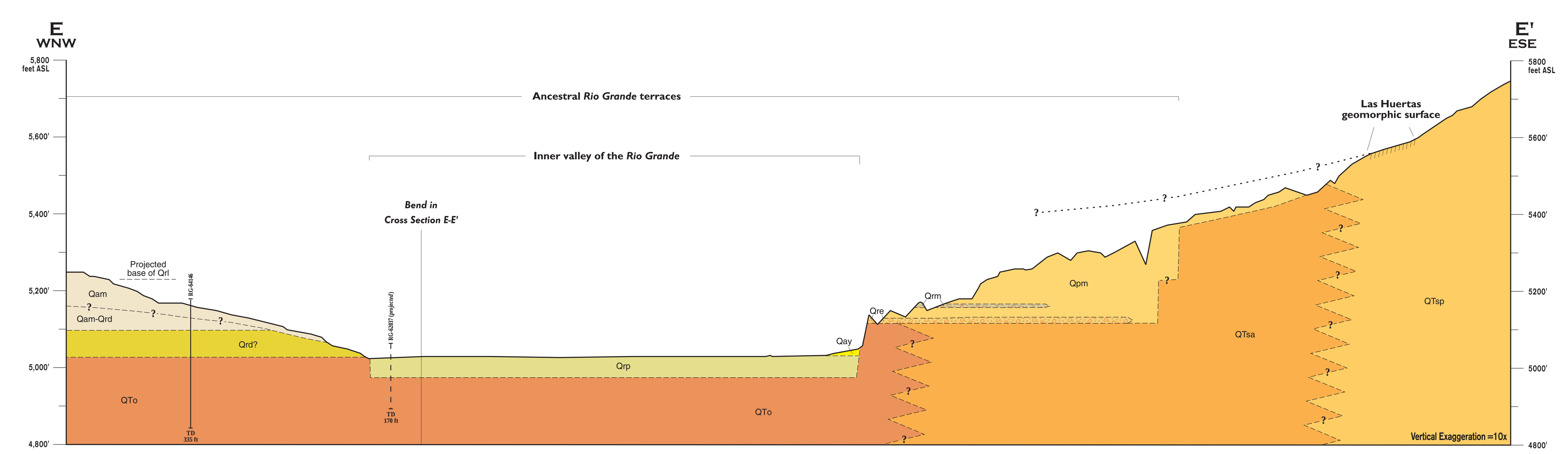
Placitas Quadrangle – NMBMMR OF-DM-2 (Connell, *et al.*, 1995)

Cross sections are constructed based upon the interpretation of the authors made from geologic mapping, and available geophysical (regional gravity and aeromagnetic surveys), 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.









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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

17 February 2000 Revision

Bernalillo quadrangle
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May 1998

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[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

Alluvium

Stream-valley alluvium

Qay, Qay2, Qay1 — 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 (Qay1) and younger (Qay2) 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, Qpy2, Qpy1 — 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 (Qpy1) and younger (Qpy2) 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).

Qpm2, Qpm2a, Qpm2b — 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 Qpm1), 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 (Qpm2a) and younger (Qpm2b) 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 Qpm2b) between *Del Agua Cañon* and *Sandia Wash*. Geomorphic surface Q7 of Connell (1995, 1996).

Qpm1 — 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).

Qpo4 — 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 (Qpo3). Deposit is inset by the Edith Formation (Qre). Approximate thickness is less than 10 ft (3 m).

Qpo3 — 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 (Qpo1), 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).

Qpo2 — 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).

Qpo1 — 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 Pleistocene 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

[...]

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.

[...]

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.

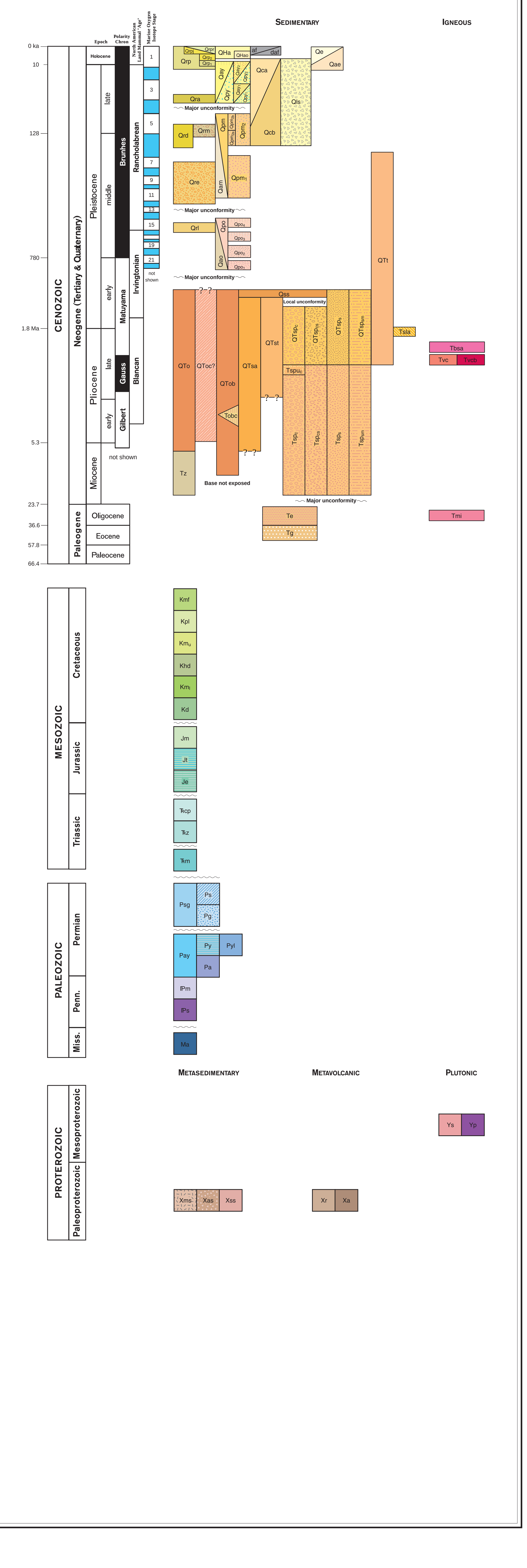
Xa — Amphibolite and amphibole-biotite schist — Massive green amphibole-plagioclase schist with lensoidal bodies of calc-silicate and calc-pelite interlayered with amphibolite and metapelite. Protolith is interpreted to be volcanic.

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

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