Geologic Map of the Ojo Caliente Quadrangle, Rio Arriba and Taos Counties, New Mexico

By

Daniel Koning, Karl Karlstrom, Judson May, Steve Skotnicki, Robert Horning, Dennis Newell, and William R. Muehlberger

May, 2005

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 101

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 06HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

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

GEOLOGIC MAP OF THE OJO CALIENTE 7.5-MINUTE QUADRANGLE, RIO ARRIBA AND TAOS COUNTIES, NEW MEXICO

OF-GM-101

BY

DANIEL KONING[1], KARL KARLSTROM[2], JUDSON MAY[3], STEVE SKOTNICKI[4], ROBERT HORNING[5], DENNIS NEWELL[2], AND WILLIAM R. MUEHLBERGER[6]

May, 2005

[1] New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, 801 Leroy Place, Socorro, NM, 87801; dkoning@nmt.edu
[2] University of New Mexico, Dep. of Earth and Planetary Sciences, Northtrop Hall, MS 032040, Albuquerque, NM 87131-1116
[3] 3508 Lynbrook Dr., Plano, TX 75075; the southwest portion of this map was taken from Dr. May's Ph.D. thesis.
[4] 281 West Amoroso Drive, Gilbert, AZ 85233
[5] P.O. Box 662, Tesuque, NM 87574
[6] Department of Geological Sciences, The University of Texas at Austin, Austin, TX 78712

LIST OF FIGURES

Figure 1. Index map showing areas mapped by the respective authors.

Figure 2. Correlation of map units with respect to age.

ABSTRACT

The Ojo Caliente 7.5-minute quadrangle lies in the general area of the border between the Abiquiu embayment of the Española basin, the San Luis basin, and the southern Tusas Mountains. The area offers a fascinating array of rock types of various ages: from Proterozoic metasedimentary and metavolcanic rocks to Cenozoic basin fill and basalt flows. Distinctive Cerro Colorado, located 3 km northwest of the town of Ojo Caliente, is composed of metarhyolite of the Vadito Group from an interpreted 1.70 Ga caldera complex. The area just northeast of Cerro Colorado consists of complexly deformed metamorphic rocks of the Vaditio Group. The Ortega Quartzite of the Hondo Group (Proterozoic, 1.7 Ga) constitutes the La Madera Mountains on the northeast corner of the quadrangle. This quartzite is folded into a km-scale synclinorium called the La Madera syncline. These rocks have a polyphase deformational and metamorphic history. The La Madera syncline and associated thrusts probably formed during the Mazatzal orogeny at ca. 1.65 Ga. The pervasive S2 and S3 fabrics, together with amphibolite facies metamorphic minerals, record metamorphic conditions of about 650 C and 3.5 kbars reached at about 1.42 Ga. Pegmatites similar to the Pataca pegmatite district intruded deformed metamorphic rocks as a series of WNW striking dikes at ca. 1.38 Ga that form mica "mines" in the north central part of the quadrangle. Paleozoic and Mesozoic strata are not preserved in this area, in part because the area was persistently high during southeast extension of the Ancestral Rockies Uncompahgre uplift and in part because of uplift and erosion in the Laramide orogeny. Cenozoic units associated with sedimentation of the Rio Grande rift were deposited directly on Proterozoic basement and cover most of the quadrangle. These strata generally dip 4-9 degrees east-southeast, and have been displaced by a major west-down normal fault called the Ojo Caliente fault (~ 500 m of throw). Locally flanking the base of Proterozoic-cored hills is 2-80 m of poorly sorted, angular, locally derived colluvium and alluvium of the lower Abiquiu Formation. Above this sediment is tuffaceous sand of the upper Abiquiu Formation (18-22 Ma), part of which may represent fluvially reworked eolian sediment. Coarse volcaniclastic strata (Tesuque Formation; 18-14 Ma) overlie the Abiquiu Formation and grade laterally southwards with the Chama-El Rito Member of the Tesuque Formation. The latter is dominated by pink fine sand that is interbedded with subordinate clay and volcaniclastic gravel beds. A ~22 Ma basalt underlies the basin fill at two localities, and younger mafic intrusions and flows are found higher in the stratigraphic section but appear to predate the Ojo Caliente Sandstone Member of the Tesuque Formation. The Ojo Caliente Sandstone is a very pale brown, fine- to medium-grained eolianite deposited by northeast winds in a vast dunefield. A well-preserved flight of Quaternary terrace deposits flank the Rio Ojo Caliente, a south-flowing river just east of the center of the quadrangle. These terrace deposits are interpreted to range in age from 1.6 Ma to 15 ka.

INTRODUCTION

The Ojo Caliente 7.5-minute quadrangle covers the northeastern Abiquiu embayment. The town of Ojo Caliente, the namesake of the quadrangle, lies 1 km southeast of its center. Through Ojo Caliente flows the Rio Ojo Caliente, a south-flowing perennial river. Most of the quadrangle is covered by the Santa Fe Group. This basin fill is weakly to moderately consolidated, and moderately dissected to create poor to good exposures. Standing tall near the center of the quadrangle is the reddish Cerro Colorado. Immediately east of the Rio Ojo Caliente in the northeastern quadrangle is a 2 km-long segment of the southern La Madera Mountains. The quadrangle is situated near the border of the San Luis and Española basins of the Rio Grande rift, and lies south of the southern end of the Tusas Mountains. A wide suite of Proterozoic and upper Cenozoic lithologic units are found on this quadrangle, and these allow interpretations regarding Proterozoic tectonic evolution of northern New Mexico and Rio Grande rift depositional and structural activity. In addition, a well-preserved flight of terraces flank the Rio Ojo Caliente, and can be used to infer Quaternary erosion rates in this part of the basin (Newell et al., 2004). Detailed unit descriptions are provided below, with brief interpretations regarding their age and depositional environment. We also discuss structural features in this quadrangle and give our preliminary interpretations regarding how geologic features have influenced the locations of both cold and hot springs in the area.

DESCRIPTION OF MAP UNITS

Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term “clast(s)” refers to the grain size fraction greater than 2 mm in diameter. Clast percentages are based on counts of 100-150 clasts at a given locality. Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Surficial units are only delineated on the map if estimated to be at least 1 m thick. Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992) and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999).

Mapping of geologic features was accomplished using field traverses, close inspection of numerous outcrops across the quadrangle, and aerial photographs. Terrace correlations were made using comparison of mapped strath elevations (with aid of terrace profiles), lithologic characteristics, and deposit thickness. Map units are correlated in **Figure 1**.

QUATERNARY AEOLIAN DEPOSITS

Qe **Aeolian sand deposits (middle to late Pleistocene and Holocene) –** Yellowish brown to light yellowish brown (10YR 5-6/4) to reddish yellow (7.5 YR 6/6) and pink (7.5YR 7.4) silty very fine- to fine-grained sand and very fine to fine sand. Sand is well sorted, subrounded to subangular, and arkosic. It may overlie Quaternary sandy gravel deposits less than 1 m thick. This unit is generally massive and overlies Pleistocene and Holocene alluvial deposits and the Tesuque Formation. Correlates in part to unit Qe of Koning (2002), Koning (2004), and Koning and Manley (2003); in the latter the unit is the type locality of the Española Formation of Galusha and Blick (1971). The Española Formation is reported to contain Rancholabrean-age (approximately 10-300 ka; Tedford et al., 2004) fossils that include *Canis dirus*, *Equus*, *Bison*, and *?Camelops* (Galusha and Blick, 1971, p. 80-81). Dethier and Reneau (1995, table 1) report a radiocarbon date of 19 ka from eolian sand overlying Quaternary terrace gravels east of Española. On this quadrangle, the unit clearly overlies upper Holocene deposits so it is also late Holocene in age. Loose to weakly consolidated and 1-7 m thick.

Qe
Qayh **Eolian sediment overlying unit Qayh (upper Holocene)** – The eolian sediment is commonly in isolated, discontinuous low dunes approximately 0.5-2.0 m tall. Sand is very pale brown to yellowish brown to light yellowish brown (10YR 7/3; 10YR 5-6/4), fine-upper to medium-upper, well to moderately sorted, subrounded, and similar in composition to the Ojo Caliente Sandstone and the pink sand of the Chama-El Rito Member of the Tesuque Formation. Loose.

Qe
Tto **Eolian sediment overlying the Ojo Caliente Sandstone (upper Holocene)** – Eolian sediment that mantles the Ojo Caliente Sandstone in the west and northeast pats of the quadrangle, apparently as sand sheets. Dunes are not common. The sand is similar to the Ojo Caliente Sandstone, but loose and commonly redder.

Qes **Aeolian sand deposits and sheetwash deposits (middle to late Pleistocene and Holocene) –** Similar to unit Qe but interbedded locally with some pebbly sediment, and it has a sufficiently long sloping surface to make it susceptible to slope wash processes. 1-7 m thick.

MIXED QUATERNARY ALLUVIUM AND AEOLIAN DEPOSITS

Qae **Mixed alluvium and eolian sediment (middle Pleistocene to Holocene) –** Generally light yellowish brown (10YR 6/4), very pale brown (10YR 7/3-4), or brown to pale brown (10YR 5-6/3) fine- to medium-grained sand; locally minor silt and very fine sand. This unit is present in the southeast corner of the quadrangle, where it overlies the Ojo Caliente Sandstone Member of the Tesuque Formation. Erosion of this Member has contributed most of the sand in this unit. Sand is mostly subrounded, well to moderately sorted, and arkosic. Unit is interpreted to represent local sheetwash and alluvial deposits plus fine eolian sand sheets. Loose. Thickness is 1-4(?) m.

QUATERNARY ALLUVIUM

Qayl **Younger alluvium occupying a low topographic position in valley bottoms (modern-100(?) years old) –** Loose sand and gravel that occupy active channels and associated floodplains; also includes sediment in slightly elevated (less than 2 m) areas adjacent to active arroyos that are probably than 100 years old. Sand is generally planar-laminated or in planar-very thin beds. Local cross-stratification. Gravel is in very thin to thin, lenticular to broadly lenticular beds. Texture composition of the sediment reflects the source. Sparse to no vegetative cover. Very weak to no soil development, with no evident soil carbonate horizon development. Age is based on conversation with local residents and information on USGS topographic maps (such as the stipple pattern). Thickness not known but probably less than 3 m.

Qayi **Younger alluvium occupying an intermediate topographic position in valley bottoms (50-200? years old) –** This unit occupies an intermediate position in valleys between that of units **Qayh** and **Qayl**. Its sediment is similar to these other two units, and in many areas it may represent **Qayh** that has been beveled by stream erosion. Where exposures are sufficient to verify this beveling, particularly exposures that conclusively show a lack of an inset relationship between the two units, such units were then called **Qayh**. In most places, however, exposures are too poor to reveal potential buttress unconformities or inset relations. Soil development may be characterized by a 10-20 cm thick Bw horizon but no apparent calcic horizon (based on observations of same unit in the Lyden quadrangle to the south; Koning, 2004). Generally its surface is covered by grass and shrubs. Age lies between the age ranges of units **Qayl** and **Qayh**. 1-3 m thick.

Qayh **Younger alluvium occupying a high topographic position in valley bottoms (Holocene to upper Pleistocene, greater than 100 years old) –** Sand and gravel that form low, stable terrace deposits on the floors of valleys or arroyos. It generally occupies valley bottoms that have been incised. However, in a given valley or arroyo the deposit may be continuous between areas that have underwent channel incision to areas that have not experienced channel incision. Unit is composed of sand with subordinate pebbly sand and sandy pebbles. Sand is planar-laminated or massive, and locally low-angle, gently cross-laminated (less than 10 cm thick). Sand is mostly fine to medium-grained, pink to very pale brown to light yellowish brown (10-7.5YR 7/4 and 10YR 6/4), subrounded, moderately to well sorted, and arkosic. Medium to very coarse sand is generally associated with light brownish gray to light gray (10YR 6-7/2) gravely beds, and are subrounded, poorly to moderately sorted, and rich in Tertiary volcanic or Proterozoic metamorphic lithic grains. Gravel is generally very fine to very coarse pebbles with locally minor cobbles. It is in very thin to medium, lenticular to broadly lenticular beds. Gravel is clast-supported, subrounded, and poorly sorted. Texture and composition of the sediment reflects the source area. Top soils are marked by a thin A or Bw horizons (together generally less than 50 cm) locally underlain by a weak calcic horizons in lower elevations (up to Stage II carbonate morphology but generally less developed) that generally is less than 50 cm thick. Moderate or strong buried soil deposits are not observed (only buried grayish A horizons about 10-40 cm thick). Possibly correlative deposits in the Rio Tesuque valley bottom (southeast of this quadrangle) are interpreted to have ceased aggrading between 800 to 2,000 years ago (Miller and Wendorf, 1958). 2-7 m thick.

Qao **Older alluvium (middle to upper Pleistocene) –** Sandy gravel that is topographically higher than unit Qayh. The latter is probably inset into unit **Qao**, but no exposures was found to demonstrate this. This unit is most common along the eastern flanks of Cerro Colorado. There, the gravel consists of reddish meta-rhyolite from Cerro Colorado; this gravel is very poorly sorted, angular to subangular, and weakly consolidated.

Qtgu **Undifferentiated, high-level gravelly terrace deposits (middle to upper Pleistocene)** – Sandy gravel preserved on the tops of ridges at various topographic heights relative to the adjoining drainages. Gravel consists of pebbles to cobbles of quartzite (most common in coarse to very coarse pebbles and cobbles) and intermediate to volcanic rocks (more common in the finer gravel); clasts are poorly sorted and subangular to rounded. This unit correlates with Qtg in the Medanales quadrangle to the southwest (Koning et al., 2004a) and unit Qtgh in the Lyden quadrangle to the south (Koning, 2004). Loose and 1-2 m thick.

Qgcc **High-level gravel deposits east of Cerro Colorado (lower to middle Pleistocene) –** Very poorly sorted sandy gravel derived from the vicinity of Cerro Colorado. Gravel range from pebbles to boulders, are angular to subrounded, and consist of meta-rhyolite, amphibolite, amphibolite-bearing gneiss, mica schist and gneiss, and quartzite. Sand is brownish, fine to very coarse, moderately poorly sorted, subangular to subrounded, and rich in volcanic and mafic lithic grains. Weakly consolidated.

QTtm **High-level terrace deposits at the south tip of La Madera Mountains (lower Pleistocene to upper Pliocene) –** Sandy gravel underlying broad surfaces just southeast of the La Madera Mountains. The straths of these deposits overlie units Tgq and Ttpc. The straths are about 140-200 m above the Rio Ojo Caliente to the east, and 69-100 m above the Canon Seco. Gravel includes quartzite pebbles to boulders that are locally- derived from the La Madera Mountains. These terrace deposits are above unit Qt9, which has an inferred age of 1.6 Ma. Thus, they are lowest Pleistocene to upper Pliocene in age. Weakly consolidated and up to 12 m thick.

Tgq **High-level, quartzite gravel deposits at the south tip of La Madera Mountains (Pliocene) –** Reddish, quartzite-rich conglomerate. Contains poorly sorted, gray, angular to subrounded quartzite. Gravel is clast supported and ranges from very fine pebbles to boulders. Matrix is a deep red, poorly sorted quartz sand, silt, and clay. No bedding visible in the few available exposures. Possibly debris flows. Interpreted to be Pliocene-age because unit **QTtm** appears to lie unconformably on top of this deposit. Weakly consolidated and 30-40 m thick.

TERRACE DEPOSITS OF RIO OJO CALIENTE

Six terrace deposits along the Rio Ojo Caliente are sufficiently continuous to correlate along the river. In addition, there are a number of intermediary, strath terrace deposits that are preserved in the area where the Rio Ojo Caliente incises through Proteroozic bedrock in the north-central part of the quadrangle (Newell et al., 2004). This area appears to record an unusually complete record of strath terraces, but many of these were left uncorrelated in this study. Terrace fills generally consist of 2-4 m of sandy cobbles and pebbles deposited by an axial Rio Ojo Caliente. Gravel are clast-supported, subrounded to rounded, poorly sorted, and locally include minor boulders. Clasts include abundant quartzite mixed with felsic to intermediate volcanic rocks; Proterozoic schist, gneiss, granite and metavolcanic rocks are minor. The highest terrace deposits, located east of the Rio Ojo Caliente, may be overlain by 2-5 m of sand. The sand probably represents local alluvium shed from the Santa Fe Group mixed with aeolian sand.

Below, the terrace deposits associated with the Rio Ojo Caliente are listed, and their differences and age interpretations briefly discussed. Following the first two letters ("Q" for Quaternary and "t" for terrace deposit), "oc" stands for the Rio Ojo Caliente. The following numbers represent our interpretation of relative age, with 1 being the youngest and higher numbers being successively older). The "y" following the numeral indicates a slightly lower strath (by a few meters) than the strath of the main correlated terrace deposit. The "s" or "g" following the numeral denote whether deposit is dominated by sand or gravel, respectively, and is only used for Qtoc6.

Qtocu **Non-correlated terrace deposits of the Rio Ojo Caliente (Upper to lower Pleistocene) –** Sandy gravel terrace deposits at various levels that did not appear to correlate with the main six terrace levels. Generally less than 4 m thick.

Qtoc1 **Lowest terrace deposit of the Rio Ojo Caliente (Uppermost Pleistocene) –** Only located ~4 km downstream of the northern quadrangle boundary, where it is largely buried by younger sediment shed from hills to the east. Its strath is ~3 m above the modern Rio Ojo Caliente. The quartzite-rich, axial gravel is less than 6 m thick. Because it is not well-preserved, it is difficult to correlate this terrace deposit downstream of the quadrangle. Near Española, terrace deposits 5-12 m above the modern Rio Chama are interpreted to be 12-45 ka in age based on radiocarbon dating and amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993; Dethier and Reneau, 1995, table 1). The unit on this quadrangle may be of similar age or slightly younger.

Qtoc2y **Lower terrace deposit of the Rio Ojo Caliente (Upper to lower Pleistocene) –** This terrace deposit is similar to that of Qtoc2 (see below), but is much more discontinuous. Its strath is inset about 3 m below the strath of Qtoc2. The unit is found east of the river immediately downstream of Cañada de los Comanches (2 km north of the town of Ojo Caliente) and at the mouth of Arroyo Gavilon (1 km north of the southern quadrangle boundary). It is 24-27 m above the modern Rio Ojo Caliente, and has an interpreted age that is between Qtoc1 and Qtoc2 (45-70 ka).

Qtoc2 Lower-middle terrace deposit of the Rio Ojo Caliente (Upper Pleistocene) – This sandy gravel terrace is the most laterally extensive of the suite along the Rio Ojo Caliente; its strath is 24-30 m above the Rio Ojo Caliente (with height increasing in the area of the bedrock constriction ~3 km south of the northern quadrangle border). The surface of this terrace has the greatest number of archeological sites, including pueblo ruins and agricultural plots. It is generally marked by having a thick fill (up to 18 m) greater than 7 km downstream of the southern boundary of the quadrangle. However, in the map area it is clearly a strath terrace deposit that is 3-5 m thick. Correlates to unit Qt4 of the Lyden quadrangle to the south (Koning, 2004). This deposit may correlate to a terrace deposit near Española that is ~30-39 m above the present-day Rio Chama, which has an inferred age of 70-90 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993; Dethier and Reneau, 1995, table 1). The terrace projects below the travertine sample sites KO3-LM4 and KO3-LM5 (~85-105 ka based on uranium series dating; Dennis Newell, unpublished data), and we make the preliminary interpretation that it is inset below these sites.

Qtoc3 Middle terrace deposit of the Rio Ojo Caliente (Upper to middle Pleistocene) – This terrace deposit is only located between Cañada de los Comanches and the town of Ojo Caliente, on the west side of the river. Its strath lies 45-52 m above the modern river. Maximum thickness is about 12 m. Correlates to unit Qt3 of the Lyden quadrangle to the south (Koning, 2004). Deposits of this height near Española are inferred to be 130-150 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993; Dethier and Reneau, 1995, table 1). This terrace projects to about the same elevation as the travertine sites KO3-LM4 and KO3-LM5 (~85-105 ka).

Qtoc4 Upper-middle terrace deposit of the Rio Ojo Caliente (Middle Pleistocene) – This terrace deposit is located east of the Rio Ojo Caliente south of the town of Ojo Caliente. Its strath is approximately 60-75 m above the modern river. Thickness is about 5-7 m. Unit locally includes two terrace straths, one being inset about 3 m below the other. Where this is recognized, the unit is subdivided into Qtoc6a (higher, older strath) and Qtoc6b (lower, younger strath). Maximum thickness of 7-9 m. Correlates to unit Qt2 of the Lyden quadrangle to the south (Koning, 2004). Deposits of this height near Española are inferred to be 130-280 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993; Dethier and Reneau, 1995, table 1).

Qtoc5 Lower-upper terrace deposit of the Rio Ojo Caliente (Lower-middle Pleistocene) – This terrace deposit is less than 6 m thick and located east of the Rio Ojo Caliente between the town of Rio Ojo Caliente and the southern quadrangle boundary. The unit is also correlated to high-level gravels along the northern border of the map; these form an extensive surface in the southwestern La Madera quadrangle to the north. Its strath lies 105-113 m above the Rio Ojo Caliente. This unit probably correlates to unit Qt1 in the Lyden quadrangle, in which a fine, white ash was located. Analyses of this ash are pending, but we suspect that it correlates to the Lava Creek B ash based on comparisons to this ash where it is present near the Rio Chama. Such a correlation suggests that Qt7 on this quadrangle has an age of about 620-640 ka.

Qtoc6 **Uppermost terrace deposit of the Rio Ojo Caliente (Lower Pleistocene) –** This terrace deposit is common in the map area, but generally not preserved to the south. It is relatively thick (12-18 m). The lower-middle parts of this unit are a sandy gravel (**Qtocg**), but east of the Rio Ojo Caliente the upper 6-12 m generally consists of a sandy sediment (**Qtoc9s**). The latter likely represents local alluvium from the east mixed with eolian sediment. The strath of this unit is located 130-140 m above the modern Rio Ojo Caliente. A pumiceous fine lapilli and coarse ash bed was found in this unit about 4-8 m above the strath (described below). Chemical analyses are pending, but we think it is likely that this coarse pumice correlates to the Guaje pumice of the Otowi Member of the Bandelier Tuff. If that proves correct, this terrace deposit has an age of ~1.6 Ma.

QUATERNARY LANDSLIDE DEPOSITS

Qls **Landslide deposits (Holocene to middle(?) Pleistocene) –** Slumped sediment bodies consisting of unit Ttpc (see descriptions for these units). Unit is marked by contorted bedding and butrress unconformities. 1-10(?) m thck.

MIOCENE SEDIMENTARY ROCKS

TESUQUE FORMATION OF SANTA FE GROUP

The Tesuque Formation was proposed by Spiegel and Baldwin (1963) for Miocene basin fill sediment, primarily pinkish-tan silty arkosic sandstone, deposited in the Rio Grande rift near Santa Fe. Galusha and Blick (1971) later subdivided the Tesuque Formation into several members, the pertinent ones for this quadrangle being the Chama-El Rito, and Ojo Caliente Sandstone Members. Age control for these units was obtained from published dates of tephra found within them in addition to fossil data (the latter is nicely summarized in Tedford and Barghoorn, 1993). In general, the Tesuque Formation units exposed on this quadrangle probably range in age from 18-12 Ma. Geochronologic investigations of the tephras are currently underway, and will later refine the ages listed for the units below.

Tto, Tto_i **Ojo Caliente Sandstone Member of the Tesuque Formation (middle to upper(?) Miocene) –**Extensively cross-laminated sand; massive near base of unit. Sand is generally very pale brown (10YR 8/2 to 7/3 and 7/4), fine-upper to medium-upper in grain size, subangular to rounded (mostly subrounded), and well sorted. The sand is composed of quartz with 15-20% pinkish grains that likely include potassium feldspar grains, and 8-15% (generally 8-12%) volcanic detritus and mafic grains. Cross-stratification is generally tangential. Near base of deposit, grain size is generally fine-upper. Higher in the section, medium-lower and medium-upper sand are abundant. Unit is weakly to moderately consolidated and generally non-cemented. It erodes relatively easily to form rounded hills. Best exposures are in recently incised gullies.

Maximum thickness of 220 m in northwest part of quadrangle. Estimated thickness of 390 m near eastern border of quadrangle.

Locally, the unit label on the map carries an "i" subscript (e.g., **Tto$_i$**). This is used to signify where the Ojo Caliente Sandstone is interbedded with or within the Chama-El Rito Member.

The Ojo Caliente Sandstone represents a vast erg or sand dune field. Its initial deposition may have been as sand sheets whose bedding was disturbed by bioturbation. Shortly afterwards, however, sand dunes dominated. Measurements of steep foresents indicate that they primarily dip to the northeast-east. Thus, the paleowind direction appears to have been from the southwest-west. The source of the sand is still under investigation. The abundance of quartz and presence of potassium feldspar suggests a source west-southwest of the Abiquiu embayment. However, some sand likely came from streams within the embayment, based on the minor presence of volcanic grains in the sand fraction.

Immediately below this unit, and present in Chama-El Rito Member interbeds at the base of the Ojo Caliente Member, are fine white ash beds. These may correlate with the Pojoaque white ash zone to the southeast of Española because of fossil similarities in the strata at either area (Tedford and Barghoorn, 1993; Galusha and Blick, 1971). Preliminary investigations of the Pojoqaque white ash zone suggests that it ranges from 14.3-13.2 Ma (Izett and Obradovich, 2001; Andrei Wojcicki, written communication, 2005; Barghoorn, 1981). Thus, the base of the Ojo Caliente Sandstone appears to be as old as 13-14 Ma. The upper part of the Ojo Caliente Sandstone is thought to have extended into the Clarendonian North American land mammal age (Teford and Barghoorn, 1993). Since the top of the Ojo Caliente Sandstone is not preserved in the quadrangle area, it is not known how young the unit is here. We speculate a minimum age of 12-13 Ma.

Ttoc **Interbedded Ojo Caliente Sandstone Member (dominantly) and the Chama-El Rito Member, Tesuque Formation (middle Miocene) –** Please see descriptions of the Ojo Caliente Sandstone and Chama-El Rito Member. This unit is mapped as part of the gradational contact between the Ojo Caliente Sandstone and underlying Chama-El Rito Member. Here it is designated for strata where very pale brown eolian sediment is more abundant than pinkish fluvial sand and mud beds. The age of this unit is equivalent to the gradational contact between the two members. At least one bed of fine white ash is found in this unit. We suspect that the zone of fine white ashes that are present near the contact correlate to the Pojoaque white ash zone southeast of Española (see above paragraph). If that conjecture is confirmed, then this unit would have an age of 13.2-14.3 Ma (i.e., the age range of the Pojoaque white ash zone, discussed above). 5-20 m thick.

Ttco **Interbedded Chama-El Rito Member (dominantly) and Ojo Caliente Sandstone Member, Tesuque Formation (middle Miocene) –** Please see descriptions of the Chama-El Rito Member and Ojo Caliente Sandstone. This unit is mapped as part of the gradational contact between the Ojo Caliente Sandstone and underlying Chama-El Rito Member. Here, it is assigned to strata where pinkish fluvial sand and mud beds are more abundant than very pale brown eolian sediment. The age of this unit is equivalent to the contact between the two members. At least one bed of fine white ash is found in this unit. We suspect that the zone of fine white ashes that are present near the contact correlate to the Pojoaque white ash zone southeast of Española because of fossil similarities in the strata at either location (Tedford and Barghoorn, 1993; Galusha and Blick, 1971). If that conjecture is confirmed, then this unit would have an age of 13.2-14.3 Ma (i.e., the age range of the Pojoaque white ash zone, discussed above). 10-30 m thick.

Ttcf, Ttcf$_i$ Fine sand of upper Chama-El Rito Member, Tesuque Formation (middle Miocene) – Fluvial deposits of predominately fine sand and subordinate silt and clay. These are interbedded with minor (generally less than 15% by volume) coarser channel deposits of volcanic gravel and sand. The sand in the finer sediment is generally pink (7.5 YR 7/4) to reddish yellow (7.5YR 6-7/6), and in thin to thick (mostly medium to thick), tabular to broadly lenticular beds; these beds are internally planar-laminated or internally massive, with local gentle cross-lamination. Locally, clay rip-ups are present. Sand grains are subrounded (minor subangular), well sorted, and composed of quartz with 15-25% pinkish grains (probably includes potassium feldspar) and 10-15% lithic grains of mafic minerals and intermediate to felsic volcanic detritus. Locally in this sand is minor (1-10%) scattered medium to very coarse sand grains of felsic to intermediate volcanic composition. Clay and mud beds are commonly very thin to thick and tabular, and have a color of light brown (7.5YR 6/4) to pink (7.5YR 7/4) to reddish yellow (7.5YR 6-7/6). The coarser channel sediment is light brownish gray to pale brown (10YR 6/ 2-3) and composed of fine-upper to very coarse-upper sand and gravel. The sand in the coarser channel sediment is subrounded-subangular, moderately to poorly sorted, and a volcanic-rich lithic arenite (medium to very coarse sand is almost all volcanic grains). The gravel is generally pebbles with minor cobbles, clast-supported, subrounded, and moderately to poorly sorted. Clast composition is predominantly intermediate volcanic rocks (dacite?). In the western quadrangle, volcanic rocks also include substantial felsic volcanic flow rocks, volcanic tuff (including Amalia tuff), and less than 10% quartzite and granite. Porphyritic dacite becomes more abundant eastwards, and Amalia tuff decreases eastwards. Coarser channel deposits are in tabular to broadly lenticular channel complexes up to 2 m thick. Within these channel complexes, beds are very thin to medium, lenticular to broadly lenticular to channel-shaped. There is also planar-bedding in the sand fraction, in addition to minor cross-stratification up to 30 cm tall. Channels have scoured to very slightly scoured bases. Paleoflow indicators indicate a southwest to southeast flow direction. Locally, the coarse channel complexes may be weakly cemented by calcium carbonate. Generally, however, the sediment is non-cemented and moderately to well consolidated. Unit is 30-120 m thick; it appears to be thinner near Rio Ojo Caliente than to the west.

Locally on the map, this unit carries a subscript of "i" (**Ttc$_i$**). This is used to denote where the authors believe a certain interval to be interbedded with or within the overlying Ojo Caliente Sandstone. Moderately consolidated and generally not cemented by calcium carbonate. A given interval is generally 1-12 m thick. On the map, interbeds of this unit that are too thin to show as polygons are depicted as lines labeled "cb."

An interpretation was offered in the Medanales quadrangle to the southwest that the fine, pink sediment in the Chama-El Rito Member possibly represents eolian sand blown in from the southwest(?) that was fluvially reworked (Koning et al., 2004). This quadrangle adds support to that interpretation. Middle Miocene strata in the northern half of the quadrangle is dominantly coarse volcaniclastic sediment (see unit Ttpc and Ttvc descriptions). The pink, fine sand only becomes abundant immediately below the gradational contact with the overlying Ojo Caliente Sandstone. The latter is clearly an eolian deposit, and is described above. Using Walther's Law, it follows that the pink, fine sand was deposited at the fringes of an eolian dune field at a slow enough rate to allow fluvial redeposition.

Sediment of the Chama-El Rito is interpreted to have been deposited on a south-sloping alluvial-slope (stream-flow dominated) piedmont. Ekas et al. (1984) intereprets the Chama-el Rito Member as being deposited on a south-sloping distal alluvial fan. However, it is probably more correct to say distal alluvial slope because the sediment shares more affinities with an alluvial slope compared with an alluvial fan (see Smith, 2001, and Kuhle and Smith, 2001 for discussion of alluvial slopes). In particular, the Chama-El Rito Member contains coarse deposits in distinct channel-form geometries surrounded by the aforementioned finer sediment, similar to what is seen in the Skull Ridge Member alluvial slope environment to the east (Kuhle and Smith, 2001). The Chama-El Rito Member also lacks the tabular, planar-bedded couplets of relatively coarse- and fine-grained sediment diagnostic of sheetflood deposits, which themselves are characteristic of alluvial fans (Blair, 1987 and 1999; and Blair and McPherson, 1994). Thus, the depositional environment of the Chama-El Rito Member is interpreted to be one of a medial to distal alluvial slope that was subject to deposition of fine-grained sand eolian sheets, the latter of which were fluvially reworked and mixed somewhat with volcaniclastic sediment.

The Chama-El Rito Member on this quadrangle probably is 16-13 Ma. It lies a short distance below fine white ash beds in units Ttoc and Ttco, which are tentatively correlated to the Pojoaque white ash zone (14.3-13.2 Ma; Barghoorn, 1981; Izett and Obradovich, 2001; Tedford and Barghoorn, 1993). To the south, these fine white ash beds are interbedded in the upper part of the unit. This age range is consistent with fossil data (Tedford and Barghoorn, 1993), K-Ar dates on reworked volcanic clasts (Ekas et al., 1984), and overlying basalt flows and cross-cutting dikes (Dethier et al., 1986). Aldrich and Dethier (1990) argue that this unit pre-dates 12.4 Ma, which is a K/Ar age of a lava flow immediately above the upper Ojo Caliente Sandstone contact at one locality 3 km west of the town of Hernandez (see also Dethier and Manley, 1985).

Ttcc **Coarse channel deposits in the fine sand of the upper Chama-El Rito Member, Tesuque Formation (middle Miocene) –** Grayish channel complexes of sandy pebble-conglomerate and pebbly sandstone that are of sufficient thickness and extent to map. Note that these were not differentiated in the southwest part of the quadrangle. This unit is similar to the description of the coarse channel deposits of unit **Ttcf**, described above.

. **Ttvc** **Undifferentiated coarse volcaniclastic sediment of Tesuque Formation (middle Miocene) –** Grayish channel complexes of sandy pebble-conglomerate and pebbly sandstone. The sand fraction within the channel complexes is commonly planar-laminated. The gravel fraction in the channel complexes are commonly in very thin to ~50 cm-thick, lenticular to broadly lenticular beds or in beveled, 1-4 m-wide, discrete channel fills. Sand is mostly medium-to very coarse-grained, subrounded, moderately to poorly sorted, and a volcanic lithic arenite. Gravel are commonly clast-supported, subrounded, very poorly to moderately sorted, and composed of intermediate, porphyritic gravel (probably dacite) along with welded and non-welded tuff, rhyolite, and <10% granite+ quartzite. Clasts are mostly very fine to medium pebbles, but there are also minor coarser pebbles and cobbles. Maximum clast sizes of b axis is commonly 10-15 cm. Locally, Amalia tuff is observed. Unit is differentiated from unit Ttpc in that it has more welded volcanic tuff clasts in its gravel fraction plus more Amalia Tuff; however, the contact between the two is very gradational. Commonly weakly cemented and well-consolidated. Thickness is not known with certainty. We suggest a possible value of 240-250 m based on the inferred thickness of unit Ttpc to the east.

Unit is found north and west of Cerro Colorado. Compared with the Plaza lithosome of the Tesuque Formation (unit Ttpc), the volcanic clasts in this unit are more varied and contain the Amalia Tuff. We interpret that the sediment reflects erosion of the Los Pinos Formation off of the southern Tusas Mountains. The nature of the bedding is consistent with a high-energy alluvial fan or alluvial slope depositional environment

The unit interfingers southward with the Chama-El Rito Member of the Tesuque Formation. The maximum age of the Chama-El Rito Member is thought to be ~18 Ma based on fossils data (Tedford and Barghoorn, 1993). Based on the age of the upper part of the Chama-El Rito Member that overlies this unit (14-15 Ma), the minimum age for this unit is probably 14-15 Ma.

Ttvc-Ttcf **Unit within the lateral gradational zone of the coarse volcaniclastic unit of the Tesuque Formatin (dominant) with the fine sand of the Chama-El Rito Member of the Tesuque Formation (middle Miocene) –** In the Tesuque Formation in the northwest part of this quadrangle, this unit is demarcated in the lateral transition between coarse volcaniclastic sediment on the north (unit **Ttvc**) with the fine pink sand of the Chama-El Rito Member to the south (unit **Ttcf**). Grayish channel complexes of sandy pebble-conglomerate and pebbly sandstone of unit **Ttvc** is dominant.

Ttcf-Ttvc Unit within the lateral gradational zone of the coarse volcaniclastic unit of the Tesuque Formatin (dominant) with the fine sand of the Chama-El Rito Member of the Tesuque Formation (middle Miocene) – In the Tesuque Formation in the northwest part of this quadrangle, this unit is demarcated in the lateral transition between coarse volcaniclastic sediment on the north (unit **Ttvc**) with the fine pink sand of the Chama-El Rito Member to the south (unit **Ttcf**). Pink sand of unit Ttcf is dominant.

. **Ttpc Coarse volcaniclastic sediment of Plaza lithosome of Tesuque Formation (middle Miocene) –** Grayish channel complexes of sandy pebble-conglomerate and pebbly sandstone. Very thin to medium, lenticular to broadly lenticular beds with minor beveled, 1-4 m-wide, discrete channel fills; local cross-stratification. Pebbles are generally clast-supported, subrounded to subangular, moderately to poorly sorted, and composed of porphyritic dacite with no to trace Amalia Tuff. Minor (10-20%) tuff clasts are present west of the Rio Ojo Caliente, but these seem sparser to the northeast. Cobbles are sparse. Sand is mostly medium-to very coarse-grained, subrounded to subangular, moderately to poorly sorted, and a volcanic lithic arenite In the matrix of the coarser sand is finer sand and clay, which imparts a yellowish red (5YR 5/6) color. Commonly weakly cemented (mostly by clays) and well-consolidated.

Unit is found in east and northeast parts of the quadrangle. The composition of the volcanic gravel appears to be consistent with that of the Plaza lithosome of Ingersoll et al. (1990). The Plaza lithosome is interepreted to be derived from a source near Servilleta Plaza based on marked clast coarsening in that area. Our oboservations of the monolithic character of the volcanic clasts, plus the lack of Amalia tuff, is consistent with this interpretation of Ingersoll et al. (1990). The nature of the bedding is consistent with a high-energy alluvial fan or alluvial slope depositional environment. This unit grades westward into unit **Ttvc**. The contact between the two is very gradational; in general, the part of this unit west of the Rio Ojo Caliente can be thought of as part of this gradation.

This unit interfingers southward with the Chama-El Rito Member of the Tesuque Formation. The maximum age of the Chama-El Rito Member is thought to be ~18 Ma based on fossils data (Tedford and Barghoorn, 1993). Based on the age of the upper part of the Chama-El Rito Member that overlies this unit (14-15 Ma), the minimum age for this unit is probably 14-15 Ma.

Tsf Undifferentiated Santa Fe Group (middle Miocene) – Probably consists of units Ttpc or Ttvc.

LOWER TO MIDDLE MIOCENE MAFIC VOLCANIC ROCKS

Ojo Caliente tuff ring

An intriguing, well-exposed vent complex is located 4-4.5 m southwest of the town of Ojo Caliente, and 1 km south of lowerArroyo El Rito. Judson May first mapped and described these deposits, and the reader is referred to his thesis and subsequent papers (May, 1980 and 1984b). We attempted to further subdivide the volcanic deposits associated with this vent. These include finer (probably older and/or more distal) phreatic and phreatomagmatic surge deposits, coarser (probably younger and/or more proximal) phreatomagmatic surge deposits, crystal tuff, basalt flows, and basalt dikes and small intrustions. We have collected basalt samples for future $^{40}Ar/^{39}Ar$ dating. A bomb from vents in a possibly similar stratigraphic position alongside El Rito creek to the west has returned a K/Ar age of 15.3 Ma. We think it is likely that the Ojo Caliente tuff ring may also be 15.0-15.5 Ma in age.

Toct **Calcified crystal tuff near the center of the tuff ring –** Dark rusty brown to medium gray (fresh and weathered), massive to very faintly bedded, very well sorted, non-graded, calcite impregnated, silica-cemented, basaltic crystal tuff. Consists of glass, of which 20-95% has been altered to rusty-red clay (60-80 %); interstitial and crack-filling calcite (5-15%); black, equant olivine (tr-2%); clear, black, prismatic <0.2mm long, amphibole (0-tr); fractured quartz (0-2%); clear, colorless, vitreous, H>3, insoluble in HCl, void-filling analcime (3-15%); vesicles (0-10%). The unit has been highly fractured into lapilli-size masses, with calcite filling the fractures. The unit is interpreted to be a late stage eruptive facies.

Tobi **Basaltic intrusive rocks –** Dark gray to black (fresh), dark to medium gray to brownish-gray (weathered), microporphyritic, amygdaloidal, massive to blocky fracture, basaltic lava. Matrix (70-80% of rock) is glassy to microgranular. Phenocrysts include black, prismatic to acicular habit, vitreous luster, hackly-fracture pyroxene(?) (1–7% of phenocrysts); black to orange-black, equant habit, vitreous luster, conchoidal fracture olivine (15-20% of phenocrysts); and colorless, tabular habit plagioclase(?) (0-2% of phenocrysts). Alteration of olivine to iddingsite is near zero in some dikes. Amygdules (trace to 2% of rock) range in size from submillimeter to 4mm in maximum dimension, are rounded in dikes and plugs, and are filled with calcite. (All mineral identifications are tentative.)

Tobe **Basaltic extrusive rocks –** Dark gray to black (fresh), dark to medium gray to brownish-gray (weathered), microporphyritic, amygdaloidal, massive to blocky fracture, basaltic lava. Matrix (70-80% of rock) is glassy to microgranular. Phenocrysts include black, prismatic to acicular habit, vitreous luster, hackly-fracture pyroxene(?) (1–7% of phenocrysts); black to orange-black, equant habit, vitreous luster, conchoidal fracture olivine (15-20% of phenocrysts); and colorless, tabular habit plagioclase(?) (0-2% of phenocrysts). Alteration of olivine to iddingsite is essentially complete in a flow located in Arroyo el Rito north of the tuff ring. Amygdules (trace to 2% of rock) range in size from submillimeter to 4mm in maximum dimension, are flattened, and are filled with calcite. (All mineral identifications are tentative.)

Tobei **Basaltic extrusive intrusive or rocks –** Dark gray to black (fresh), dark to medium gray to brownish-gray (weathered), microporphyritic, amygdaloidal, massive to blocky fracture, basaltic lava. Matrix (70-80% of rock) is glassy to microgranular.

Phenocrysts include black, prismatic to acicular habit, vitreous luster, hackly-fracture pyroxene(?) (1–7% of phenocrysts); black to orange-black, equant habit, vitreous luster, conchoidal fracture olivine (15-20% of phenocrysts); and colorless, tabular habit plagioclase(?) (0-2% of phenocrysts). Amygdules (trace to 2% of rock) range in size from submillimeter to 4mm in maximum dimension, are flattened, and are filled with calcite. (All mineral identifications are tentative.) This unit is applied to basalt where we cannot determine if it is extrusive or intrusive.

Tobc **Basaltic conglomerate –** Medium rusty gray brown (fresh and weathered), massive to wavey thickly bedded, matrix supported, blocky jointed, argillaceous basaltic conglomerate. Unit contains flattened basaltic bombs ≤10m long. Groundmass around these bombs includes orange clay fragments (altered basaltic tuff) (50-90%); amygdaloidal basaltic lapilli, mostly altered to clay (5-45%); calcite filling joints and amygdules (≥5%); and broken mafic mineral grains, including black, prismatic, amphibole (tr). The unit is interpreted to represent relatively low energy phreatomagmatic explosions.

Tosc **Coarse surge deposits –** Buff to yellowish buff (fresh and weathered), fine and coarse grained, very poorly sorted, thin to very thick planar and wavey bedded, medium to well-indurated, tuff breccia. Nearest the volcanic center and low in the exposed section, this unit includes a >4m thick pile of interbedded fine and coarse-grained layers organized into types C and D regressive pyroclastic surge bedforms (Allen, 1982, as cited in Cas and Wright, 1988) with multimeter wavelengths. These dunes contain cognate and accidental bombs and blocks to 45 cm, some with bomb sags. Farther out, and higher in the section, beds become planar, finer grained, and thin to medium bedded.

These dunes consist of alternating fine and coarse grained members. Fine grained layers contain about 85% vfL matrix. Typical analyses of the matrix, performed in the field, yield unidentified grains (probably altered ash) (68%), pink feldspar (15%), quartz (10%), mafic grains (1%), green chlorite or epidote (1%), disseminated calcite (5%). Matrix supported sand and granules (15% of total) include accidental lithic fragments (60%), quartz (20%), feldspar (5%), unidentified green clots (probably chlorite and/or clay) (13%), mafic minerals (2%).

Coarse layers within the dunes consist of 40-70% matrix with composition similar to the fine layers. Lapilli, pebbles, cobbles, bombs, and blocks make up 30-60% of this rock and typically include basalt (20-50%), intermediate igneous clasts (15-60%), quartzite and phyllite (tr-5%), sandstone (tr-10%), unidentified green clots (5-40%), granite (tr).

Farther from the eruptive center, and higher in the section, Totsc thins and becomes yellow-buff to reddish-buff, thinly to medium planar-bedded, calcite-cemented, devitrified lithic crystal tuff-breccia and lapilli-tuff. Groundmass consists of white and orange clay(?), sparry and disseminated calcite, and milky opal(?). Mineral grains include magnetite, pyroxene(?), quartz, and pink feldspar. Clasts include rounded accessory and juvenile black to reddish orange coarse ash and fine lapilli, partially altered to orange clay and hematite, as well as accessory sandstone, intermediate igneous clasts, some of which are vesiculated, granite, and assorted metamorphic lithologies. Basaltic bombs and blocks are locally present. Still farther from the volcanic center, Totsc grades into Totsf. Totsc is interpreted to represent highly energetic phreatomagmatic explosive eruptions.

Tosf **Fine surge deposits –** Buff (fresh and weathered), upper fine grained (vfL - vcL), poorly sorted, subangular, medium induration, thickly laminated, plane parallel bedded, carbonate cemented, erodable sublitharenite. Although the unit is generally planar bedded, it locally exhibits sand waves with amplitudes in excess of 6m. The rock consists of frosted, subrounded quartz (80%), granitic lithic fragments (7%), mafic lithic fragments (3%), pink feldspar (7%), mafic minerals (2%), and miscellaneous phases (1%). The unit is interbedded with, and grades into Ttc (away from the volcanic center) and Totsc (toward the volcanic center). It is interpreted to record early stage phreatic explosions, and to be a distal component of coarser-grained surge deposits.

Lower Miocene to Oligocene basalt flows and intrusive rocks

Southwest, west, and northwest of Ojo Caliente, on the footwall of the Ojo Caliente fault, are basalt flows and intrusives exposed near the base of the Tertiary basin fill. These are subdivided into the three following units:

Cerro Negro volcano

Tcnbi **Basaltic lava of Cerro Negro volcano and adjacent plugs and dikes –** Black (fresh), dark greenish gray (weathered), porphyritic to microporphyritic, massive with blocky jointing and local, poorly developed, decimeter-scale columnar jointing and flow striae, basaltic lava. Groundmass (70-98% of rock) is granular to microgranular. Groundmass contains black, vitreous, equant unidentified grains (50-60% of groundmass); black, prismatic, vitreous amphibole(?) (0-2% of groundmass); and colorless to white, hackly fracture feldspar(?) (40-50% of groundmass). Phenocrysts include black, equant habit, conchoidal fracture; <3mm diameter olivine(?) (40-50% of phenocrysts) and black, subequant habit, hackly to platey fracture/cleavage, vitreous, <1.5mm length pyroxene(?) (40-50% of phenocrysts). (All mineral identifications are tentative.) One intrusion immediately south of Cerro Negro returned a K/Ar age of 18.9 Ma (Baldridge et al., 1980). This sample locality was reported as a flow by Baldridge, but we have observed reddening/baking in the sediment on either side of this rock, and therefore regard it to be a sill.

Tcnsc **Coarse tuff breccia of Cerro Negro volcano –** Greenish gray (fresh), brownish green (weathered), very poorly sorted tuff breccia consisting of basaltic and accidental clasts in a matrix of felsic ash with ~2% altered basaltic grains, a trace of biotite, 10% unidentified grains, and a trace of white, biotite-bearing pumice. Two exposures exist.

The first is a near-vertical, ~3m wide, layer adjacent to a basaltic dike within the Cerro Negro eruptive center. It is filled with the matrix just described surrounding angular basaltic lapilli altered to brown clay. This outcrop is interpreted to be the fissure through which the breccia erupted. The second outcrop is a ~20m × 30m knob surrounded by basaltic talus. This outcrop contains the material of the fissure as well as angular to rounded, altered basaltic bombs and angular to very well rounded accidental clasts ranging from pebbles to small boulders. The rock is faintly wavey bedded, with the bedding orientation suggesting that the rock was deposited within the Cerro Negro crater.

Tbj **Jarita(?) basalt of May (1980) –** Alternating and interbedded basaltic flows, tuff breccias, pillow(?) lavas, and minor sandy upper Abiquiu Formation. See May (1980) for more detailed description of this unit. Dated at 22 Ma by Baldridge et al. (1980).

Tbcns: Ultramafic(?) sill found on south slopes of Cerro Negro. This unit returned a K/Ar age of 18.9 Ma (Baldridge et al., 1980). This sample locality was reported as a flow by Baldridge, but we have observed reddening/baking in the sediment on either side of this rock, and therefore regard it to be a sill.

It is composed of black (fresh), dark greenish gray with black spots (weathered), porphyritic, spheroidal weathering, olivine nephelinite(?). Groundmass (98% of rock) contains an unidentified vitreous phase that alters to a rusty, vitreous mineral; a clear, colorless, vitreous foid(?), and an unidentified milky-blue, dull to waxey luster phase that occurs in irregular patches. Phenocrysts (2% of rock) include a black, hackly fracture, subequant unidentified phase, probably olivine.

Other basalt units

Tbc **Purplish dark gray basalt exposed immediately east of Cerro Colorado –** Basalt appears to thicken northwards from ~5 m in its southernmost exposure to ~12 m near the Joseph Mine. It does not appear to extend to Arroyo Rancho. This unit consists of lapillistone and basalt flows. The proportion of the former seems to increase southwards.

Tb **Basalt flows northeast of Ojo Caliente (middle Miocene?)–** Thick, stacked basalt flows north of unit Tbcc that appear to originate from vents immediately north of the San Texas mine. At one locality 0.5 km northeast of this mine, these flows appear to overlie undifferentiated Santa Fe Group (unitTsf). Their topographic position is higher than, and east of (down-dip) of, unit Tbcc, suggesting this unit is younger than unit Tbcc. Thickness is on the order of a few 10s of meters.

ABIQUIU FORMATION

The base of the Tertiary basin fill is exposed on the footwall of the Ojo Caliente fault between Arroyo El Rito and Cerro Colorado. We have subdivided this lower fill into two units. One unit consists of angular to subangular, locally derived clasts. Above this unit is generally a tuffaceous sand with very minor pebble lenses consisting of Tertiary volcanic clasts. The composition of the clasts appears to be similar to that of unit **Ttvc**. However, we feel that differentiating this unit from **Ttvc** is warranted because of its overall finer texture (i.e., generally a sand as opposed to a sandy gravel or gravelly sand). Immediately south of Cerro Negro, the sandy upper unit has been intruded by unit **Tbcni**, one intrusion of which was dated at 18.9 Ma. Therefore, the sandy upper unit pre-dates 18.9 Ma. The sandy upper unit is interbedded in the Jarita(?) basalt flow (unit Tbj), which has been dated at 22 Ma. Thus, the age range of the sandy upper unit is 19-22 Ma, and is consistent with that of the Abiquiu Formation (Smith et al., 2002). We consequently call the lower rift basin fill here the Abiquiu Formation, and differentiate the lower and upper members of this Formation observed near Abiquiu (Smith, 1938; Vazanna, 1980; Vazanna and Ingersoll, 1981; Smith et al., 2002).

. **Tau** **Upper member of Abiquiu Formation (lower Miocene) –** Predominately a very pale brown to light gray (2.5Y 7/2) sand and silty sand, with subordinate white or reddish silty-clayey sand. Sand is tuffaceous in areas. The white sand is in a well consolidated interval that erodes to form "tepee" shapes. Reddish clayey-silty sand is in thin to thick, tabular beds. The sand is generally massive and very fine to fine grained, weakly to moderately consolidated, subrounded to subangular, well sorted, and arkosic. Interbedded in this sand are minor pebble beds. The pebble beds consist of angular, poorly sorted, locally derived detritus near Proterozoic exposures. On the immediate footwall of the Ojo Caliente fault, the pebbles consist of volcanic clasts that are similar in composition to unit **Ttvc**. Thin beds of this unit are interbedded with the Jarita(?) basalt flow (unit **Tbj;** K/Ar age of 22 Ma from Baldridge et al., 1980). Ultramafic(?) intrusions of unit Ttcni at Cerro Negro cross-cut the upper member of the Abiquiu Formation, one of which has been dated by K/Ar methods and returned an age of 18.9 Ma (Baldridge et al., 1980). Thus, this member is interpreted to have an age range of 19-22 Ma.

Tal **Lower member of Abiquiu Formation (lower Miocene to Oligocene)** – Exposures southwest and south of Cerro Colorado consist of angular to subangular, very poorly sorted, matrix- to clast-supported pebbles and cobbles adjacent to Proterozoic-cored structural highs. The matrix is a clayey, poorly sorted sand. The sand is very fine to very coarse, angular to subangular, very poorly sorted, and arkosic(?). The clay in the matrix commonly imparts a reddish color to the deposit (5YR 6/4 and 5/6). The deposit is massive. Very minor medium beds of reddish, clay-rich, very poorly sorted, subangular to angular, very fine to very coarse (mostly medium to very coarse) sand. The composition of the gravel is very similar to the adjoining Proterozoic bedrock, and we interpret that the gravel was deposited as colluvium, talus cones, or small alluvial fans adjacent to these highs. Gravel in exposures southeast of Cerro Colorado may be more hetereolithic and rounded than gravel seen in the western exposures; also, these exposures appear to have a more grayish color. We tentatively interpret that at least some of the gravel in the eastern exposures were transported a few kilometers and deposited by streams or rivers.

‘

TEPHRAS

Guaje(?) pumice – The tephra is in a thick bed and consists of pumice, 0.1-4 mm in diameter, mixed with ~5% quartz and 0.5-1% hornblende or pyroxene and also biotite. It is not significantly mixed with detrital sand where sampled. The tephra is pale yellow (2.5Y 8/2). We suspect it may correlate to the Guaje pumice bed based on its position in such a high terrace deposit and coarseness. Sampled at site with the following UTM coordinates: 4018020 N, 408370 E (zone 13, NAD 27).

Fine white ash in the gradational contact between the Chama-El Rito and Ojo Caliente Sandstone Members of the Tesuque Formation – At a given locality, this tephra consists of a single, medium to thick (up to about 50 cm), tabular bed of fine white to grayish white ash with generally 1-3% biotite. The ash is altered to clay and greasy in feel. The ash was noted in three different localities in a roughly similar stratigraphic position; we do not know for sure, however, whether this is the same ash bed or separate ashes of similar appearance. The ash is similar in appearance to ashes in the Pojoaque white ash zone east-southeast of Española. Furthermore, the ashes are probably of similar age based on the similarity of fossils collected in the upper Chama-El Rito Member with that of the middle Pojoaque Member (where the Pojoaque white ash zone is located). Thus, we think it is likely that the fine white ash bed mapped in this quad correlates to one of the ash beds in the Pojoaque white ash zone (14.3-13.2 Ma; Barghoorn, 1981; Tedford et al., 2004; Izett and Obradovich, 2001). Chemical analyses proving this correlation will be difficult, if not prohibitive, because of the intense diagenesis of the fine white ash on this quadrangle.

PROTEROZOIC IGNEOUS AND METAMORPHIC ROCKS

Yp Pegmatite (Mesoproterozoic) Potassium feldspar + quartz + plagioclase+muscovite+ biotite pegmatite. Large books of muscovite up to 5-cm in diameter. Occurs as dikes, sills, and pods cutting metasedimentary and metavolcanic rocks. Not strongly foliated, but dikes and sills are variably boudinaged and folded

Hondo Group (Paleoproterozoic)

Xqs- quartzite rich schist interlayers within Ortega Quartzite, locally contains kyanite, andalusite, and sillimanite

Xq- Ortega Quartzite—mature, crossbedded hematite-rich quartz arenite

Xqv- viridine-bearing quartzite from the lower Ortega Group

Vadito Group (Paleoproterozoic)

Xmq- micaceous trough cross-bedded quartzite in gradational transition from Vadito to Hondo groups

Xa Amphibolite – Consists of amphibole + plagioclase feldspar; grades into areas rich in tourmaline. Massive, foliated, and lineated varieties. Foliation defined by inter-layered amphibole and plagioclase feldspar-rich layers. Occurs as pods, dikes, and continuous layers within metavolcanic and metasedimentary rocks. Primary textures are absent, but may include both metabasaltic flows and hypabyssal intrusive sills and dikes.

Xbg --garnet biotite schist and Xbs --biotite schist; gradationhal with foliated metaryolite; interpreted to be volcanogenic rocks.

Xc- metaconglomerate—stretched and folded pebble conglomerate with clasts of vein quartz (up to 10 cm diameter), chert (ellipsoidal shapes) and volcanic rock fragments (preserved as wafers with aspect rations up to 10 cm X 2 cm X <1 cm); may correlate with Big Rock Quadrangle to the north

Xcd- cordierite schist—interlayered with Xk

Xms- mica schist—includes quartz-muscovite-biotite schist and gneiss

Xst- staurolite schist—and garnet-staurolite-sillimanite schist (qmps of Trieman, 1977) and garnet-biotite-staurolite schist (grouped with qb of Trieman, 1977).

Xs- sillimanite schist including sillimanite pod rock

Xk—kyanite schist, kyanite-sillimanite-andalusite schist (qbk of Trieman, 1977) and kyanite-plagioclase-cordierite schist grouped with qp and qb of Trieman, 1977)

Xr- metarhyolite—schistose to massive metarhyolite. Includes the Cerro Colorado metarhyolite in the central part of the quadrangle; dated at ~1.70 Ga based on zircons (Lanzirotti personal communication 1996; L.T. Silver, personal communication)

Xrp- porphyritic metarhyolite with quartz and feldspar phenocrysts of mm to cm scale

Xrs- schistose metarhyolite

STRUCTURE

Three major generations of penetrative deformation have been identified in the Cerrp Colorado area. These are identified as D1, D2, and D3, with associated folds F1, F2, and F3, and related axial plane foliations S1, S2, and S3. F1 folds are isoclinal in style and are found at the mesoscopic scale as intrafolial folds of compositional layering (S0). F2 folds are tight to isoclinal folds with a well developed axial plane schistosity that forms the dominant fabric in the quadrangle. F2 folds occur at scales ranging up to macroscopic folds defined by amphibolite layers just north of Cerro Colorado and the La Madera syncline of La Madera Mountain. An L2 stretching lineation is defined by stretched pebbles, streaked micas, aligned amphiboles, sillimanite and other prismatic minerals. L2 lineations plunge shallowly north-south. D2 fabrics are refolded by a large F3 antiform cored by Cerro Colorado rhyolites. This fold plunges about 30 degrees towards the east. S3 is weakly to moderately developed as a crenulation cleavage and as axial planes to mesoscopic folds of S2. Porphyrobalst-matrix microstructural studies did not identify any metamorphic porhyroblasts that grew during D1. Possibly early garnet, kyanite, and staurolite grew during D2, and most porphyroblast growth took place after D2 and during D3 (Bishop, 1997). D3 is constrained to have taken place at about 1.4 Ga based on the presence of ca. 1.43 monazites within syn-S3 porphyropblasts and the alignment of weakly deformed ca. 1.4 Ga pegmatites parallel to the S3 axial plane.

Strata of the Tertiary basin fill dip 4-9 degrees to the east-southeast. The steepest dips (5-9 degrees) appear to be in the older strata (units **Tau**, **Ttvc**, and **Ttpc**), whereas beds dip slightly shallower (4-7 degrees) in younger strata (units **Ttcf** and **Tto**). This slight change in dip magnitudes from older to younger strata is consistent with deposition of basin fill during tilting associated with rift tectonism. However, it is evident that tectonic tilting continued after the deposition of the lower Ojo Caliente Sandstone Member of the Tesuque Formation.

The Ojo Caliente fault is the longest and most prominent structure on this quadrangle. It extends approximately north-south just west of center. May (1980) terminated this fault just north of Canada Ancha in a zone of multiple fault splays. However, we interpret that slip transfers west from these splays to the prominent fault located immediately west of Cerro Negro and Cerro Colorado. South-dipping beds in this zone of multiple fault strands north of Canada Ancha is consistent with a south-dipping ramp located in this left stepover. The Ojo Caliente fault is a relatively discrete structure near Cerro Negro and Cerro Colorado. Northwest of Cerro Colardo, the fault has a northeast strike. Where it crosses Canoncito Madera, it has a north strike for ~2 km before bending northeastward near the northern quadrangle boundary. The Ojo Caliente fault is a west-down normal fault. Cross-section A-A’ indicates a throw value of about 500 m.

We interpret a west-down normal fault along the west side of La Madera Mountains. This fault is inferred by the juxtaposition of the Ojo Caliente Sandstone against the Ortega Quartzite and a relatively smooth, straight mountain front. Between this fault and the northern Ojo Caliente fault strata dip 3 to 11 degrees to the northeast – this area may be a structural ramp between these two faults.

There possibly may be a buried fault along the Rio Ojo Caliente. North of Canada de los Comanches, strata dip **westward** towards the Proterozoic rocks northeast of Cerro Colorado. These strata may be tilted along a fault immediately east of the Proterozoic bedrock. This fault may possibly extend southward to the town of Ojo Caliente, as inferred by May (1980) and Muehlberger (unpublished data, 1960). Southwest of the town of Ojo Caliente, the Proterozoic bedrock forms a remarkably linear ridge with a relatively smooth eastern face. There may possibly be a fault buried under the Tesuque Formation immediately to the east of this ridge.

HYDROGEOLOGIC INFERRENCES

There is a spatial association of springs with the Ojo Caliente fault near the northern quadrangle boundary. There are also springs located along the fault bounding the western face of the La Madera Mountains. Travertine deposits are present in springs along both of these faults, but are much more abundant alongside the La Madera Mountains. The Ojo Caliente fault may be acting as a groundwater barrier to south-southeastward (?) flowing groundwater in the Tesuque Formation, elevating groundwater levels sufficiently that groundwater can drain into deeply incised arroyos as springs. However, this explanation for springs may not suffice for groundwater discharge alongside the western La Madera Mountains because these springs are located about 60 m above, and to the southeast, of the Rio Ojo Caliente. The latter runs on top of the Tesuque Formation between the springs and the Tusas Mountains to the north (probably a major source of groundwater recharge). The springs alongside the La Madera Mountains may be discharging water from significant depths alongside fractured rock adjacent to the fault zone there. A similar phenomena may explain the presence of hot springs near Ojo Caliente, assuming our inferred, buried faults there are real.

ACKNOWLEGMENTS

We wish to thank the UNM summer field courses for their work on the Proterozoic near Cerro Colorado.

REFERENCES

Aldrich, M.J., and Dethier, D.P., 1990, Stratigraphic and tectonic evolution of the northern Española basin, Rio Grande rift, New Mexico: Geological Society of America Bulletin, v. 102, p. 1695-1705.

Baldridge, W.S., Damon, P.E., Shafiqullah, M., and Bridwell, R.J., 1980, Evolution of the central Rio Grande rift, New Mexico -- New Potassium-Argon ages: Earth and Planetary Science Letters, vol. 51, p. 309-321.

Barghoorn, S., 1981, Magnetic-polarity stratigraphy of the Miocene type Tesuque Formation, Santa Fe Group, in the Española Valley, New Mexico: Geological Society of America Bulletin, v. 92, p. 1027-1041.

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

Bishop, J.L., 1997, The determination of a quantitative P-T-t-D history for Proterozoic rocks of the Cerro Coloraod area, north central New Mexico: MS thesis, University of Massachusetts, Amherst Ma, 174 p.

Blair, T.C., 1987, Sedimentary processes, vertical stratification sequences, and geomorphology of the Roaring River alluvial fan, Rocky Mountain National Park: Journal of Sedimentary Research, v. 57, p. 845-862.

Blair, T.C., 1999, Sedimentary processes and facies of the waterlaid Anvil Springs Canyon alluvial fan, Death Valley, California: Sedimentology, v. 46, p. 913-940.

Blair, T.C., and McPherson, J.G., 1994, Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages: Journal of Sedimentary Research, v. A64, p. 450-489.

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

Dethier, D.P., Aldrich, M.J., Jr., Shafiqullah, M., 1986, New K-Ar ages for Miocene volcanic rocks from the northeastern Jemez Mountinas and Tejana Mesa, New Mexico: Isochron/West, no. 47, p. 12-14.

Dethier, D.P., and Manley, K., 1985, Geologic map of the Chili quadrangle, Rio Arriba County, New Mexico: United States Geological Survey, Miscellaneous Field Studies Map MF-1814, scale 1:24000.

Dethier, D.P., and McCoy, W.D., 1993, Aminostratigraphic relations and age of Quaternary deposits, northern Española Basin, New Mexico: Quaternary Research, v. 39, p. 222-230.

Dethier, D.P., and Reneau, S.L., 1995, Quaternary History of the western Española Basin, New Mexico: New Mexico Geological Society, 46th Field Conference Guidebook, Geology of the Santa Fe Region, p. 289-298.

Ekas, L.M., Ingersoll, R.V., Baldridge, W.S., and Shafiqullah, M., 1984, The Chama-El Rito Member of the Tesuque Formation, Española Basin, New Mexico: New Mexico Geological Society Guidebook, 35th Field Conference, Guidebook, p. 137-143.

Galusha, T., and Blick, J.C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: Bulletin of the American Museum of Natural History, v. 144, 127 p.

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

Ingersoll, R.V., Cavazza, W., Baldridge, W.S., and Shafiqullah, M., 1990, Cenozoic sedimentation and paleotectonics of north-central New Mexico: Implications for initiation and evolution of the Rio Grande rift: Geological Society of America Bulletin, v. 102, p. 1280-1296.

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

Izett, G.A., and Obradovich, J.D., 2001, $^{40}Ar/^{39}Ar$ ages of Miocene tuffs in basin-fill deposits (Santa Fe Group, New Mexico, and Troublesome Formation, Colorado) of the Rio Grande rift system: The Mountain Geologist, v. 38, no. 2, p. 77-86.

Koning, D.J., 2002, Geologic map of the Española 7.5-minute quadrangle, Rio Arriba and Santa Fe Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM-54, scale 1:24000.

Koning, D.J., 2004, Geologic map of the Lyden 7.5-minute quadrange, Rio Arriba and Santa Fe counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM-83, scale 1:24,000.

Koning, D.J., and Manley, K., 2003, revised Sep-2004, Geologic map of the San Juan Pueblo 7.5-minute quadrangle, Rio Arriba and Santa Fe counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM-70, scale 1:24,000.

Koning, D., May, J., Aby, S., and Horning, R., 2004a, Geologic map of the Medanales 7.5-minute quadrange, Rio Arriba county, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM-89, scale 1:24,000

Kuhle, A.J., and Smith, G.A., 2001, Alluvial-slope deposition of the Skull Ridge Member of the Tesuque Formation, Española Basin, New Mexico: New Mexico Geology, v. 23, p. 30-37.

May, J., 1980, Neogene geology of the Ojo Caliente-Rio Chama area, Española Basin, New Mexico [Ph.D. thesis]: Albuquerque, New Mexico, University of New Mexico, 204 p.

May, J., 1984a, Miocene stratigraphic relations and problems between the Abiquiu, Los Pinos, and Tesuque formations near Ojo Caliente, northern Española Basin: New Mexico Geological Society, 35th Field Conference, Guidebook, p. 129-135.

May, J., 1984b, Exhumed mid-Miocene volcanic field in the Tesuque Formation, northern Española Basin, New Mexico: New Mexico Geological Society, 35th Field Conference, Guidebook, p. 171-178.

Miller, J.P., and Wendorf, F., 1958, Alluvial chronology of the Tesuque Valley, New Mexico: Journal of Geology, v. 66, p. 177-194.

Munsell Color, 1994 edition, Munsell soil color charts: New Windsor, N.Y., Kollmorgen Corp., Macbeth Division.

Newell, D.L., Koning, D.J., Karlstrom, K.E., Crossey, R.J., and Dillon, M., 2004, Plio-Pleistocene incision history of the Rio Ojo Caliente, northern Espanola basin, and overview of the Rio Grande system in northern New Mexico: New Mexico Geological Society Guidebook, 55th Field Conference, Geology of the Taos Region, p. 300-313.

Smith, H.T.U., 1938, Tertiary geology of the Abiquiu quadrangle, New Mexico: Journal of Geology, v. 46, p. 933-965.

Smith, G.A., 2001, Recognition and significance of streamflow-dominated piedmont facies in extensional basins: Basin Research: v. 12, p. 399-411.

Smith, G.A., 2002, Assessing roles of volcanism and basin subsidence in causing Oligocene-lower Miocene sedimentation in the northern Rio Grande rift, New Mexico, U.S.A.: Journal of Sedimentary Research, v. 72, no. 6, p. 836-848.

Soil Survey Staff, 1992, Keys to Soil Taxonomy: U.S. Department of Agriculture, SMSS Technical Monograph no. 19, 5th edition, 541 p.

Spiegel, Z., and Baldwin, B., 1963, Geology and water resources of the Santa Fe area, New Mexico: U.S. Geological Survey Water-Supply Paper 1525, 258 p.

Tedford, R.H., and Barghoorn, S.F., 1993, Neogene stratigraphy and mammalian biochronology of the Española Basin, northern New Mexico: Vertebrate paleontology in New Mexico, New Mexico Museum of Natural History and Science, Bulletin 2, p. 159-168.

Tedford, R. H., L. B. Albright, III, A. D. Barnosky, I.Ferrusquia-Villafranca, R. M. Hunt, Jr., J. E. Storer, C. C. Swisher, III, M. R. Voorhies, S. D.Webb, and D. P. Whistler. 2004. Mammalian biochronology of the Arikareean through Hemphillian interval (late Oligocene through early Pliocene epochs). Pp. 169-231 in M. O. Woodburne (editor), Late Cretaceous and Cenozoic mammals of North America: Biostratigraphy and Geochronology. Columbia University Press, New York, 391 p.

Treiman, A.H., 1977, Precambrian geology of the Ojo Caliente quadrangle, Rio Arriba and Taos Counties, New Mexico: MS thesis, Stanford University, Stanford California, 93 p.

Udden, J.A., 1914, The mechanical composition of clastic sediments: Bulletin of the Geological Society of America, v. 25, p. 655-744.

Vazzana, M.E., 1980, Stratigraphy, sedimentary petrology, and basin analysis of the Abiquiu Formation (Olig-Miocene), north-central New Mexico [unpublished M.S. thesis]: Albuquerque, University of New Mexico, 115 p.

Vazzana, M.E., and Ingersoll, R.V., 1981, Stratigraphy, sedimentary petrology, and basin analysis of the Abiquiu Formation (Olig-Miocene), north-central New Mexico: Geological Society of America, v. 92, pt. 1, 990-992.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377-392.

COMMENTS TO MAP USERS

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

The 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. The contents of the report and map 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 expressed or implied, of the State of New Mexico, or the U.S. Government. Cross-sections are constructed based upon the interpretations 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.