Geologic Map of the Medanales Quadrangle, Rio Arriva County, New Mexico

By

Daniel Koning, Judson May, Scott Aby, and Robert Horning

May, 2004

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 089

Scale 1:24,000

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GEOLOGIC MAP OF THE MEDANALES 7.5-MINUTE QUADRANGLE, RIO ARRIBA COUNTY, NEW MEXICO

BY

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May, 2004

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INTRODUCTION

The Medanales 7.5-minute quadrangle is located in the Abiquiu embayment of the northwestern Española Basin, which is one of many north-south trending basins formed by the Rio Grande rift. Important geographic features in this quadrangle include the confluence of the Rio Chama with the El Rito and a vast area of well-exposed badlands called the Rincon del Cuervo. The Miocene geologic features on this quadrangle are important because they provide insight into the development of the Rio Grande rift, and the younger geologic features, namely Quaternary terrace deposits, provide a record of the erosional and aggradational history of the basin. Detailed unit descriptions are provided below, with brief interpretations regarding their age and depositional environment. Then, we offer general structural and sedimentologic interpretations.

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. New mapping was conducted by Daniel Koning, Scott Aby, and Robert Horning. The map was compiled by Daniel Koning, and the area covered by each respective worker is shown in **Figure 1**. Most of the land in the northwest corner of the quadrangle is privately owned as 5-40 acre parcels. The geologic mapping of May (1980) was generally used for this privately owned land, although much of this previous work was re-examined by publicly accessible roads. The volcanic center by El Rito was re-examined by Robert Horning. Terrace correlations were made by Daniel Koning using comparison of mapped strath elevations (most heavily used), lithologic characteristics, and deposit thickness. Map units are correlated in **Figure 2**.

ANTHROGENIC DEPOSITS

af **Artificial fill (recent) –** Compacted sediment, consisting primarily of sand, used for highway fill.

QUATERNARY AEOLIAN DEPOSITS

Qe **Aeolian sand deposits (middle to late Pleistocene and Holocene) –** Yellowish brown to light yellowish brown (10YR 5-6/4) silty very fine- to fine-grained sand and fine to medium sand. This unit is generally massive and commonly overlies Pleistocene and Holocene alluvial deposits. Correlates to unit Qe of Koning (2002) 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., 1987) 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 (probably this unit) east of Española. On this quadrangle, the unit clearly overlies upper Holocene deposits so it is also late Holocene in age. Older, higher deposits tend to be red with well developed calcic and cambic soil horizons. Loose to weakly consolidated and 1-3 m thick.

Qe/Qayh **Eolian sediment overlying unit Qayh (upper Holocene) –** The eolian sediment is commonly in isolated, discontinuous low dunes approximately 0.5-1.0 m tall. Sand is yellowish brown to light yellowish brown (10YR 5-6/4), fine-upper to medium-upper, well to moderately sorted, subrounded, and similar in composition to the Ojo Caliente Sandstone of the Tesuque Formation. Loose. . This unit is only mapped where it is necessary to clarify what unit underlies the eolian sediment.

Qe/Tto **Eolian sediment overlying the Ojo Caliente Sandstone (upper Holocene) –** The eolian sediment is commonly in hummocks on the side of hills in terrain underlain by the Ojo Caliente Sandstone. The hummocks are 0.5-6 m tall. The sand is similar to the Ojo Caliente Sandstone, but loose. This unit is only mapped where it is necessary to clarify what unit underlies the eolian sediment.

QUATERNARY PLAYA DEPOSITS

Qpl **Lagunita playa deposit (Holocene) –** Light brownish gray (10YR 6/2) silt and mud. Hard when dry and well consolidated. Organic rich below about 10 cm. Light yellowish brown (10YR 5/4) silt and very fine sand is prevalent towards the margins of the lake. Thickness is unknown.

QUATERNARY LANDSLIDE DEPOSITS

Qls **Undifferentiated landslide deposits (Holocene to late Pleistocene) –** Mass wasting deposits of jumbled volcaniclastic material near the vents west of El Rito

QUATERNARY ALLUVIUM

Qam **Modern alluvium (less than approximately 20 years old) –** Sand and gravel that occupies active arroyos. Sand is generally planar-laminated or in planar-very thin beds. Gravel is in very thin to thin, lenticular to broadly lenticular beds. Texture composition of the sediment reflects the source area (Chama-El Rito Member versus Ojo Caliente Sandstone of the Tesuque Formation versus gravelly Quaternary terrace deposits). No soil development, and none to sparse vegetative cover. Loose. Thickness not known, but in small to intermediate arroyos probably only a few meters thick.

Qayl **Younger alluvium occupying a low topographic position in valley bottoms (approximately 20-100 years old) –** Sand and gravel that occupy floodplains or slightly elevated (less than 2 m) areas adjacent to active arroyos. Sand is generally planar-laminated or in planar-very thin beds. Gravel is in very thin to thin, lenticular to broadly lenticular beds. Texture composition of the sediment reflects the source area (Chama-El Rito Member versus Ojo Caliente Sandstone of the Tesuque Formation versus gravelly Quaternary terrace deposits). Loose. Sparse vegetative cover and very weak to no soil 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 only 1-2 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, then both units were called **Qayh**. In most places, however, exposures are too poor to reveal potential buttress unconformities. Soil development is marked by a 10-20 cm thick Bw horizon but no apparent calcic horizon. Generally its surface is covered by grass and shrubs. 1-3 m thick. Age not well-constrained.

Qayh **Younger alluvium occupying a high topographic position in valley bottoms (Holocene, greater than 100 years old) –** Sand and gravel that form low, stable terrace deposits on the floors of valleys or arroyos. It is composed of sand with subordinate pebbly sand and sandy pebbles. Sand is planar-laminated or massive. 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, well sorted, and arkosic. Medium to very coarse sand is generally associated with gravely beds, and are subrounded, poorly to moderately sorted, and a rich in volcanic lithic grains. Gravel is generally very fine to very coarse pebbles with 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 (Chama-El Rito Member versus Ojo Caliente Sandstone of the Tesuque Formation versus gravelly Quaternary terrace deposits). Top soils are marked by a thin (5-10 cm-thick) A horizon underlain by a Bw horizon (20-40 cm) underlain by a very weak calcic horizon (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. 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 generally deposited by tributaries to the Rio Chama and El Rito.

Qgh **High-level gravel deposits (middle to upper Pleistocene) –** Sandy gravel preserved on the tops of ridges. These are only 1-2 m thick and their identification with current drainages are uncertain. This unit correlates with **Qgth** on the Lyden quadrangle to the east.

TERRACE DEPOSITS OF CAÑON LA MADERA

Qtm **Terrace deposits along Cañon la Madera (upper Pleistocene) –** Sand and gravel deposited along Cañon la Madera in the southwest portion of the quadrangle. Sand is laminated or in very thin to medium, planar to lenticular beds. Sand is subrounded to rounded and mostly derived from erosion of the Ojo Caliente Sandstone. Gravel is mostly pebbles to cobbles, with minor boulders, and generally composed of basalt from the Lobato Formation; minor quartzite may locally be present. Gravel is subrounded and poorly sorted. Loose. Up to 12 m thick.

TERRACE DEPOSITS OF THE RIO OJO CALIENTE

Qtroc **Terrace deposits along the Rio Ojo Caliente (upper Pleistocene) –** Sand and gravel deposited along the Rio Ojo Caliente in the extreme southeastern part of the quadrangle. No good exposure of the sediment. Gravel is predominately quartzite, but volcanic clasts are significant in the pebble fraction. Clasts are subrounded to rounded and poorly sorted. Sand is mostly similar to fluvial- or wind-reworked Ojo Caliente Sandstone (fine-lower to coarse-lower, subrounded to rounded). Loose. Less than 6 m thick.

TERRACE DEPOSITS OF THE RIO CHAMA

Seven terrace deposits can be differentiated that were deposited by the Rio Chama and its southern tributaries. The thicker terrace deposits share a general upward trend in that the lower

1-8 m of the terrace sediment was deposited by the axial Rio Chama; the middle to upper portions, however, are generally derived from tributaries south of the Rio Chama.

The sediment deposited by the axial Rio Chama consists of sandy gravel channel deposits in addition to subordinate floodplain deposits of silt and very fine sand. The gravel consists of pebbles and cobbles with minor boulders that are generally clast-supported, subrounded to rounded, and poorly sorted. Gravelly beds are medium to thick and tabular. The clasts are mostly quartzite, basalt derived from the Lobato Formation, and intermediate to felsic rocks derived from the San Juan Mountains and reworking of Miocene volcaniclastic sediment. There are minor amounts of vein quartz, porphyritic hypabyssal intrusives (felsic to intermediate), yellowish-orangish quartzose sandstone (probably from Paleozoic and Mesozoic formations), gneiss, and granite. Clast count data from four locations are summarized in Table 1 below.

Table 1. Clast count data from Rio Chama terraces

Rock type	Terrace Qtcu, Site ML-761, n=100	Terrace Qtc3 Site ML-518, n=109	Terrace Qtc3 Site ML-804 N=120
Quartzite	65 - 65%	38 - 35%	28 - 23%
Foliated quartzite	4 - 4%	1 - 1%	5 - 4%
Intermediate to felsic volcanic rocks	25 - 25%	18 - 17%	58 - 48%
Basalt	0	42 - 39%	20 - 17%
Vein quartz	1 - 1%	0	2 - 2%
Mylonite	1 - 1%	0	0
Chert	2 - 2%	0	0
Paleozoic-Mesozoic(?) sandstone	0	3 - 3%	1 - 1%
Hypabyssal intrusives	1 - 1%	1 - 1%	3 - 3%
Unidentified black mafic-rich rock	1 - 1%	1 - 1%	O

Gneiss	0	0	1 - 1%
Granite	0	6 - 6%	2 - 2%

The sand associated with the axial deposits is generally pale brown, fine-upper to very coarse-upper, subangular to rounded, poorly sorted, and a mix of volcanic sand and sand similar to that in the Ojo caliente Sandstone. Floodplain deposits of silt to very fine sand are planar-laminated or in very thin to thick, tabular beds; their color is commonly pale brown to pale yellow (10YR-2.5Y 7/3). 1-8 m thick.

Tributary deposits are mostly fluvially reworked Ojo Caliente Sandstone (fine- to coarse-grained, subrounded to rounded, well sorted). There are subordinate medium to thick, lenticular beds of sandy gravel. The gravel is subrounded, poorly sorted, commonly clast-supported, and composed of basalt from the Lobato Formation with 5-10% clasts of quartzite. Up to 16 m thick.

Note: Much previous work has been done on these terrace deposits and the Quaternary incisional history of the Rio Grande; pertinent publications include Dethier et al. (1988), Dethier and McCoy (1993), Dethier and Reneau (1995), and Reneau and Dethier (1996). Dethier and Reneau (1995) provide a map of the terrace deposits, which they correlate primarily according to height above the modern floodplain.

Below, the seven terrace deposits are listed and differences are expounded.

Qtcu Non-correlated terrace deposits of the Rio Chama (Upper to lower Pleistocene)

Qtc7 Lowermost terrace deposit of the Rio Chama (Upper Pleistocene) – The terrace deposit is generally less than 4 m thick, but northwest of the confluence of the Rio Chama and El Rito it is up to 10-15 m thick. Probably correlates to the 15-6 m-high terrace of Dethier and Reneau (1995, fig. 2), which has an inferred age of >26 ka based on radiocarbon dating.

Qtc6 **Lower terrace deposit of the Rio Chama (Upper Pleistocene) –** A fill terrace that is 4-12 m thick. Maximum clast sizes average 27-35 x 22-27 cm (a and b axes from quartzite clasts). This deposit correlates to the 26-35 m-high terrace of Dethier and Reneau (1995, fig. 2), which has an inferred age of 40-70 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993).

Table 2. Maximum clast sizes of Rio Chama terrace deposits
All measturements are from quartzite clasts, and are of a x b axes in centimeters

Qtc6	Qtc6	Qtc6	Qtc3	Qtc3	Qtc2	Qtc1
0.5 km SE of Medanales	1 km NW of Medanales	2.25 km southeast of Medanales	mouth of Arroyo del Toro (site ML-804)	1 km southeast of Cañon la Madera		
35x27 31x30 35x30 39x22	29x23 22x21 25x18 35x24 25x24	25x20 28x21 30x25 24x22 32x28 50x47 37x27	30x16 29x23 30x19 30x24 25x18	36x23 22x15 28x23 31x27	23x23 26x16 20x17 33x20 21x18 25x16 23x14 18x15 18x12 18x12	12x10 14x13 17x14 13x12 15x14
Avg:35x27	Avg: 27x22	Avg: 32x27	Avg: 35x20	Avg: 29x22	Avg: 23x16	Avg: 14x13

Qtc5 **Lower-middle terrace deposit of the Rio Chama (Upper to middle Pleistocene) –** A strath(?) terrace less than 6 m thick. It correlates to the 43-50 m-high terrace of Dethier and Reneau (1995, fig. 2), which has an inferred age of 70-130 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993).

Qtc4 **Middle terrace deposit of the Rio Chama (Middle Pleistocene) –** A discontinuous terrace deposit 9-12 m thick. It correlates to the 82-93 m-high terrace of Dethier and Reneau (1995, fig. 2), which has an inferred age of 250-400 ka based on amino-acid ratios of fossil gastropods (Dethier and McCoy, 1993).

Qtc3 **Upper-middle terrace deposit of the Rio Chama (Middle Pleistocene) –** An extensive fill terrace that contains the Lava Creek B ash, the latter of which was mapped. This terrace deposit is commonly 8-15 m thick and correlates to the 105-117 m-high terrace of Dethier and Reneau (1995, fig. 2). Maximum clast sizes average 29-35 x 20-22 cm (a and b axes of quartzite, in cm). The Lava Creek B ash is generally in a white to pale yellow, single bed 40-70 cm-thick that is associated with floodplain deposits. The ash is generally extensively reworked with silt and very fine sand, and locally cemented by calcium carbonate. The ash seems least reworked and altered between Arroyo Pinavetes and Cañon la Madera. The Lava Creek B ash has an Ar-Ar age of 620 ka (Sarna-Wojcicki et al., 1987), and the restriction of this ash to a single bed in the terrace deposit strongly suggests that it was fluvially reworked and deposited immediately after 620 ka.

Qtc2 **Upper terrace deposit of the Rio Chama (Lower Pleistocene) –** Located 1 km south of Arroyo del Toro in the south-central portion of the quadrangle, this deposit is 11 m thick and approximately 165 m above the Rio Chama. Maximum clast sizes average 23x16 cm (a and b axes of quartzite, in cm). Oddly, Dethier and Reneau show this terrace as 172 m above the Rio Chama and thus being older than Qtc1. Its age is between that of Qtc3 and Qtc1, which would be 620-1600 ka.

Qtc1 **Uppermost terrace deposit of the Rio Chama (Lower Pleistocene) –** Located 1 km west of Cañon la Madera in the southwest part of the quadrangle, this deposit contains the Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff. The deposit contains 2-2.5 m of clast-supported sandy gravel overlain by 16 m of reworked Ojo Caliente sand and basaltic gravel. Maximum clast sizes average (a and b axes of quartzite, in cm). The Guaje Pumice has been dated at 1.6 Ma (Izett and Obradovich,

1994) and is in a single 1.2-1.5 m thick bed that fines-upward. The restriction of this pumice to a single bed in the deposit strongly suggests fluvial reworking almost immediately after the deposition of the pumice. Thus, the age of this terrace is 1.6 Ma.

TERRACE DEPOSITS OF THE EL RITO

Terrace deposits along the El Rito are generally thin and composed of sandy gravel. Floodplain deposits are sparse, as can be observed from available exposures. The gravel is generally composed of cobbles and pebbles that are clast-supported, subrounded to rounded, and poorly sorted. A clast count of the lowest terrace indicates subequal felsic to intermediate volcanic rocks compared to quartzite. There are also minor mylonitized quartz and comparably very sparse clasts of granite, schist, and felsic hypabyssal intrusives. The sand is pale brown to light gray (10YR 6/2-3), subrounded, poorly sorted, and has more volcanic lithic grains compared to pinkish potassium feldspar. Deposits are loose and have a noticeably flat and broad tread surface.

Qtr4 **Lower terrace deposit of El Rito (upper Pleistocene) –** The strath of this deposit is 18-24 m above the modern El Rito channel. Maximum clast sizes 4 km from the mouth of El Rito are: 29x18, 33x20, 33x19, 27x12, and 28x27 (a and b axes of quartzite clasts, in cm). This appears to project to the Qtc6 deposit, which has an inferred age of 40-70 ka. 5-8 m thick.

Qtr3 **Lower-middle terrace deposit of El Rito (upper-middle Pleistocene) –** The strath of this deposit is 40-43 m above the modern El Rito channel. This may correlate with the Qtc5 terrace based on projections of the strath and height above the modern channel. If this is correct, than Qtr3 would have an inferred age range of 70-130 ka. Thickness is less than 6 m.

Qtr2 **Upper-middle terrace deposit of El Rito (upper-middle Pleisotcene) –** The strath of this strath terrace is approximately 60 m above the modern El Rito channel. It may possibly correlate with the Qtc4 terrace based on projections of the strath. The terrace may also represent a localized strath terrace which projects between that of Qtc4 and Qtc5. These considerations would suggest an age range of 130-400 ka. 6-25 m thick.

Qtr1 **Upper terrace deposit of El Rito (middle Pleistocene)) –** The strath of this deposit is 60-75 m above the modern El Rito channel, and 10-15 m above the strat of Qtr1. It may correlate with the Qtc4 terrace based on projections of the strath. It probably does not correlate with Qtc3 because it is thinner and lacks the Lava Creek B ash. If this correlation is correct, then Qtr3 would have an inferred age range of 250-400 ka. Thickness is 4-12 m.

MIOCENE SEDIMENTARY ROCKS

TESUQUE FORMATION

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 were obtained from published dates of tephra found within them in addition to fossil data. In general, the units exposed on this quadrangle probably range in age from 16-11 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 Member of the Tesuque Formation (middle to upper Miocene)** –Extensively cross-stratified sand. Sand is generally very pale brown (10YR 8/2 to 7/3) to white (10YR 8/1), fine-upper to coarse-lower in grain size, subrounded to rounded (minor subangular), and moderately to well sorted. The sand is composed of quartz with 12-18% pinkish potassium feldspar grains, 10-15% lithic grains of volcanic detritus, mafics, chert and red- to green-colored quartz. Cross-stratification is tangential, with some exposures showing trough-cross-stratification. Unit coarsens from a fine-upper and medium-lower sand upwards to a medium-lower to coarse-lower sand. Furthermore, foreset heights increase upwards in the unit from approximately 1-2 m to over 6 m. Lower part of member exhibits medium to thick, tabular to irregular zones of strong cementation by calcium carbonate; these occupy and estimated 1-10% of the sediment volume. Additionally, the lower part of the member is commonly moderately to well consolidated, perhaps because of minor cementation by gypsum (this has yet to be confirmed). Higher in the member the sediment is weakly consolidated and strong calcium carbonate cement is lacking. A stratigraphic section to the east of this quadrangle by the Rio Ojo Caliente and the western slope of Black Mesa gives a thickness of 210 m May (1980). However, an east-west cross-section through this area and the Velarde graben suggests a thickness of 500-530 m (Koning, 2004, in press). Cross-section B-B' shows a thickness of approximately 450 m, but this value is not well-constrained due to uncertainty of bedding attitudes over much of the area underlain by this unit.

Locally, the unit label on the map carries an "i" subscript. This is used to signify where the Ojo Caliente Sandstone is likely interbedded with or within the Chama-El Rito Member.

The Ojo Caliente Sandstone represents a vast erg or sand dune field. Early in its deposition, relatively low-energy streams were able to flow through this erg. Close inspection and mapping of some of these stream deposits (unit Ttci) reveals that some were eventually ponded by dunes; specifically, the above-described sediment grades laterally into reduced(?), greenish silty very fine to fine sand beds that pinch out in dune deposits. Later in time (i.e., higher in the Ojo Caliente Sandstone deposit), the lack of Ttci deposits indicates that the dunes were of sufficient size that they blocked virtually all stream flows. We hypothesize that fluvial systems draining the Tusas Mountains flowed around the erg. Near State Highway 84 in the immediate hangingwall of the unnamed, east-down fault between the El Rito and Madera Cañon faults (see structure discussion below), are noticeably more reddish brown clay beds within the middle Ojo Caliente Sandstone. Perhaps these reflect movement along this fault during deposition of the Ojo Caliente Sandstone that preferentially influenced the path of these fluvial systems to the immediate hangingwall.

Consistent with past studies, we assign a middle-late Miocene age to the Ojo Caliente Sandstone. The Conical Hill fossil quarry west of Cañon Madera is located in the uppermost part of the gradation between the Chama-El Rito and Ojo Caliente Members. This quarry yielded fossils of latest Barstovian age (Tedford and Barghoorn, 1993), and thus the base of the Ojo Caliente Sandstone is interpreted to be 12-14 Ma (probably 12-13 Ma). To the south of the quadrangle, the top of the Ojo Caliente Sandstone is capped by basalt flows of the Lobato Formation (Goff et al., 1989), which are generally 9-10 Ma. The Ojo Caliente Sandstone on this quadrangle is thus interpreted to have an age range of 14-10 Ma, which is consistent with age interpretations by Galusha and Blick (1971), May (1980 and 1984), Aldrich and Dethier (1990), and Koning et al. (in press).

Ttco **Interbedded Ojo Caliente Sandstone Chama-El Rito Member), Tesuque Formation (middle to upper Miocene) –** Please see descriptions of the Ojo Caliente Sandstone and Chama-El Rito Member. This unit is designated for areas where these two units are interbedded so that they are approximately subequal in volume (plus or minus 20%).

Ttc **Chama-El Rito Member, Tesuque Formation (middle Miocene) –** Fine sand and minor mud to clay that is interbedded with subordinate coarser channel deposits of volcanic gravel and sand. The sand in the finer sediment is generally pink (7.5YR 7/3-4), with minor reddish yellow (7.5YR 6/6) and very pale brown (10YR 7/3-4), and in thin to thick, tabular to broadly lenticular beds. Sand grains in the finer sediment are fine-lower to fine-upper in size, subrounded (minor subangular), well sorted, and composed of quartz with 15-25% pinkish potassium feldspar grains and 10-15% lithic grains of mafic minerals, intermediate to felsic volcanic detritus, and chert plus green- to red-colored quartz(?). Clay and mud beds are commonly very thin to medium and tabular, and have a color of light brown (7.5YR 6/4) to reddish brown (5YR 5/4). 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, 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 poorly sorted. Clasts are composed of intermediate to felsic volcanic flow rocks with 10-25% volcanic tuff, 0.5-2% vesicular basalt, and less than 10% quartzite and granite. Coarser channel deposits are in tabular to broadly lenticular channel complexes up to 8 m thick, but generally 0.5-2.0 m thick, and locally fine-upward. Within these channel complexes, beds are very thin to medium, lenticular to broadly lenticular to channel-shaped. Channels have scoured to very slightly scoured bases with up to 150 cm of relief (but generally less than 70 cm). The tops of the channels are commonly gradational with overlying finer sediment. Maximum clast size is generally 10-16 x 6-12 (a and b axes). Paleoflow indicators indicate a southwest to southeast flow direction. There are sparse beds of fluvially reworked ash in thin to medium, laterally extensive beds that have been mapped within the Chama-El Rito Member. Locally, the coarse channel complexes may be weakly to strongly cemented by calcium carbonate. Generally, however, the sediment is non-cemented and weakly to moderately consolidated. Unit seems to become paler within 0.5 km of the Madera Canon fault, and here sand similar to the Abiquiu Formation seems to increase. Perhaps this reflects reworking of the Abiquiu Formation into the Chama-El Rito across an active fault during the middle Miocene, but this requires further investigation. The base of this member is not exposed on this quadrangle, so its thickness is uncertain. May (1984) estimates a thickness of 450-550(?) m.

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 Oj Caliente Sandstone. Where this is the case, the unit commonly is composed of very fine-lower to medium-lower sand and silty sand, with minor claystone beds and very minor very fine to medium pebble beds. Sand is generally in medium to thick, tabular to lenticular beds. Clay is in very thin to thick, tabular to broadly lenticular beds. Pebbly beds are thin to medium and lenticular, and associated with fine- to very coarse-grained, volcanic-rich sand. Outside of these very sparse pebbly beds, the sand is pink to light brown (7.5YR 6-7/4), subrounded, high-moderately to low-well sorted, and composed of quartz, 12-18% pinkish potassium feldspar, and 10-15% lithic grains of mafic minerals, volcanic detritus, and chert or red- to green-colored quartz. Local mm-scale rip-ups of clay are present in the sand beds. Clay beds are commonly 5YR 5/4 or 7.5YR 6/4. 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.”

Because of the pronounced difference in the sand composition between the coarser channel sediment and finer sediment, we interpret that the fine sand in the latter is derived from a different provenance. The well sorting and general subrounded texture of this fine sand suggest an eolian origin from sources to the west containing potassium feldspar in addition to quartz and chert.. Because cross-stratified sand is sparse in the Chama-El Rito Member below its gradation with the overlying Ojo Caliente Sandstone, this eolian sand was deposited as sand sheets as opposed to dunes, and most of it was reworked by fluvial processes (as indicated by local clay rip-ups and ripple marks in the fine sand beds). Based on the nature of the bedding, this fine sand was fluvially reworked into broad, shallow channels or as tabular sheets. Confined, relatively deeper channels of volcanic pebbles and sand locally scoured into this fine sand as these coarser channels migrated across the area. Past interpretations (Ekas et al., 1984; May, 1984) that the arkosic fine sand was deposited due to input or mixing from the arkosic parts of the Pojoaque or Skull Ridge Members of the Tesuque Formation – that is, lithosome A of Cavazza, 1986 – is not possible. This is because the Chama-El Rito Member is separated from lithosome A by the south-southwest flowing fluvial system of lithosome B, which is slightly more lithic-rich than arkosic (Koning, 2003; Koning, 2002; Koning and Manley, 2003) and whose clasts and sand grains are not observed in the Chama El Rito Member.

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 fine sand, like 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 (Bull, 1972; Blair, 1987 and 1999; and Blair and McPherson, 1994). Thus, we envision the depositional environment of the Chama-El Rito Member to be one of a medial to distal alluvial slope that was subject to much deposition of fine-grained sand eolian sheets, the latter of which were generally fluvially reworked.

The Chama-El Rito Member has been assigned an approximate age of 11-18 Ma. The upper age limit is based on 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). A minimum age of ~12 Ma is preferred by May (1984) because that is the minimum age of the Cordito(?) Member. 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 Dethier and Manley, 1985). The lower age limit is supported by fossil data (Tedford and Barghoorn, 1993) and correlation with the Cordito Member of the Los Pinos Formation, which has an age range of 18-12 Ma (May, 1984). K-Ar dates of a basalt bomb (15.3 ± 0.4 Ma) from a dike near the volcanic center at El Rito is consistent with this age range (Ekas et al., 1984).

Ttce **Chama-El Rito Member mixed with volcanic detritus from the El Rito vents –** Olive to pale olive (5Y 4-6/3) pebble conglomerate in very thin to medium, tabular to irregular beds. Clasts are matrix-supported, subrounded, and poorly sorted. Clast assemblage is monolithic, and composed of basalt to basaltic andesite inferred to be derived from the El Rito volcanic vents. This conglomerate is interbedded with subordinate light olive brown (2.5 YR 5/4) fine-lower to very coarse-upper sandstone and light brown (7.5YR 6/4) very fine sandstone to siltstone-mudstone. The very fine and fine sand is arkosic, but the coarser sand is volcanic. In places, the unit is massive and very poorly sorted; this may represent a debris flow deposit from a proximal volcanic vent. Unit is moderately to well cemented by calcium carbonate, and may be associated with ephemeral seeps in arroyos. 4-40(?) m thick, and becomes thinner to south away from the El Rito vents.

$\mathbf{Ttce_m}$ **Marker bed of Chama-El Rito Member mixed with volcanic detritus from the El Rito vents –** As desribed above, but forms a distinctive marker interval in the extreme northwest part of the quadrangle.

EL RITO VOLCANIC VENTS

Two basaltic, tuffaceous spatter cones are exposed on the north-central quadrangle boundary 12 km southwest of Ojo Caliente, along either side of El Rito Creek. They were first described by May (1980, 1984). Ekas et al. (1984) report a K-Ar age of 15.3 ± 0.4 Ma from a basalt bomb derived from the vent on the east side of El Rito.

Tea **Basaltic agglutinate –** Welded lapilli and ash; basaltic.

Tep **Basaltic phreatomagmatic deposits –** Poorly sorted deposits comprised of basalt detritus.

Tev1 **Basaltic volcanic deposits consisting primarily of pyroclastic tuff breccia**

Tev2 **Basaltic volcaniclastic tuff and lapilli tuff**

LOBATO FORMATION

Tld **Dikes of basalt to basaltic andesite(?) (upper Miocene) –** Dikes of dark gray to very dark gray to dark greenish gray (N/3-4 to 10Y 4/1) basalt to basaltic andesite(?). Dikes are 0.5-3.0 m wide and commonly discontinuous at 10^0-10^3 m scale. These locally occur in the southwest corner of the quadrangle at the head of Arroyo del Toro. One dike 0.3 m-wide is also found in upper Arroyo Pinavetes. 10-15% green olivine up to 0.8 mm in diameter, and 20-70% plagioclase laths. The rock is hard and forms prominent rib-like ridges in the landscape. To the south of this quadrangle, similar dikes have been dated by K-Ar methods to yield ages of about 10-11 Ma (Aldrich and Dethier, 1990).

ABIQUIU FORMATION

The Abiquiu Formation was first applied as “Abiquiu Tuff” to light gray, tuffaceous sandstone and minor volcaniclastic conglomerate exposed near the town of Abiquiu (Smith, 1938).

Ta **Abiquiu Formation (lower(?) Miocene) –** White (2.5Y 8/1) fine-grained sandstone with subordinate medium to very coarse sand. Bedding is generally medium (minor thick) and tabular. Well consolidated but generally no effervescence when HCl is applied. The white color, tabular beds, and consolidation make this a distinctive unit that commonly forms cliffs. The sand is subrounded to subangular, moderately sorted, and rich in volcanic grains. Very minor medium to thick, approximately tabular beds of pebbly sandstone to sandy pebble-conglomerate. Pebbles are very fine to coarse, subrounded, and moderately to poorly sorted. Clasts are composed of felsic to intermediate volcanic rocks, with an estimated 5-10% being Amalia Tuff. The clast assemblage seems similar to those of the overlying Chama-El Rito Member of the Tesuque Formation. Several studies indicate a late Oligocene to early Miocene age for the Abiquiu Formation (May, 1980 and 1984; Baldridge et al., 1980; Manley and

Mehnert, 1981; Manley, 1981; Lipman, 1975 and 1989; Ingersoll and Cavazza, 1991; Moore, 2000; Smith et al., 2002). Seismic studies suggest a total thickness of 150-180 m on the western margin of the quadrangle (Baldridge et al., 1994), but measured sections to the west indicate a total thickness of greater than 600 m (Smith et al., 2002).

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SUBSURFACE UNITS DEPICTED ONLY ON CROSS-SECTION

Pzu **Undivided Paleozoic strata (Mississippian to Permian) –** Limestone, sandstone, siltstone, and shale.

STRUCTURE

May (1980) reviews the structure of the northern quadrangle in detail, and subdivided it into four structural domains bounded by faults. In a gross sense, the structure in the quadrangle may be thought of as a broad graben (called the Medanales graben by Gonzales and Dethier, 1991) between two prominent faults: the east-down El Rito fault on the east and the west-down Ojo Caliente fault on the west (seen in the extreme southeast corner of the quadrangle). East of the Ojo Caliente fault, strata dip very uniformly to the southeast towards the Velarde graben. This southeast stratal dip direction is still present for about 4 km northwest of the Ojo Caliente fault in the southeast part of the map; this 4 km-wide area forms a band marked by several relatively short, northeast-trending faults parallel to the Ojo Caliente fault that dip mostly to the northwest. This band is bounded on the west by a long east-down fault that passes through Canada de Ancha and lower Arroyo del Cerrito (labeled “fault 10”, following May, 1980). The area between faults 10 and 9 narrows to the south, and contains the gradational contact between the Ojo Caliente and Chama-El Rito Members. We distinguish a “fault 8a” and a “fault 8b”, both of which are west-down and strike north. Between them is a 1-1.5 km zone of primarily west-down, relatively small faults that strike parallel to these larger faults. The “fault 8b” projects across the Rio Chama to another west-down fault, the latter which extends less than 2 km to the south. Except for local possible drag effects adjacent to normal faults, the area between faults 8a and 8b generally dips 3-8 degrees to the southwest.

Because it extends across the entire quadrangle, we apply the name El Rito fault to the prominent east-down fault that May (1980) called “fault 7.” North of the Rio Chama, this fault strikes parallel to, and within a kilometer of, the El Rito Creek. South of the Rio Chama, the fault has a north-strike and is within a kilometer of Cañon la Madera. South of the Rio Chama, the El Rito fault is marked by numerous splays and some step-overs. This may also be the case for north of the Rio Chama, where this fault is largely buried by Quaternary alluvium. Thus, the El Rito fault is likely segmented, and the throw value along the fault is likely to be variable. May (1980) interprets a range of 150-300 m of throw along this structure. Between the El Rito fault and fault 8a, strata dip 2-11 degrees to the southwest.

An unnamed fault, best observed on the adjacent Abiquiu quadrangle to the west, passes into this quadrangle at State Highway 84. This fault juxtaposes the Chama-El Rito and the Ojo Caliente Sandstone Members and is east- to southeast-down. It is uncertain where this fault goes in this quadrangle beneath the late Quaternary alluvium of the Rio Chama, but we suspect it may link with a north-striking, east-down fault just north of State Highway 96. Strata dip 4 to 8 degrees west to northwest between this fault and the El Rito fault to the east.

The Madera Cañon fault is a major structure that juxtaposes the Abiquiu Formation against the Chama-El Rito Member of the Tesuque Formation. It is estimated to have 395-485 m of throw (May, 1980). This fault is generally considered to be in the eastern part of the broad zone of faults that define the western Rio Grande rift margin in this area. On its hangingwall, strata dip steeply 7-18 degrees to the southeast. North of the Rio Chama, a south-plunging syncline has developed between this fault and the El Rito fault. Whether this syncline is related to the aforementioned unnamed fault is not known. The syncline may be related to drag-related folding in the hangingwall of the Madera Cañon fault.

SEDIMENTOLOGIC TRENDS

The volcanic clasts in much of the upper Abiquiu Formation are interpreted to be at least partly derived from the same source area as those in the coarse channels of the Chama-El Rito Member (Smith, in press). The main difference between the two units is the presence of the pink to very pale brown fine sand in the Chama-El Rito Member. As noted in the Chama-El Rito Member description, we interpret that this pink to very pale brown, fine sand is a fluvially reworked eolian sheet sand. It cannot be derived from arkosic sediment of lithosome A in the Pojoaque and Skull Ridge Members of the Tesuque Formations southeast of Española. This is because of the intervening, south- to southwest-flowing fluvial sediment of lithosome B (Cavazza, 1986; Koning, 2002; Koning, 2003; Koning and Manley, 2003), which is not significantly arkosic. If this interpretation is correct, then the timing of initiation of Chama-El Rito deposition may coincide with an environmental or climatic change in which eolian sedimentation dramatically increased. Perhaps this change was due to the middle Miocene optimum, which seemed to have began around 17 Ma based on $\delta^{18}O$ and δ^{13} C curves Zachos et al. (2001, fig. 2).

The only noticeable difference (inspecting many samples with a handlense) in the composition of the sand between the Chama-El Rito and Ojo Caliente Sandstone Members is that there is slightly less pinkish potassium feldspar in the latter. Moreover, the sand coarsens only very slightly in the gradation between the two members (mostly fine-lower to fine-upper in the Chama-El Rito to mostly fine-upper to medium-lower in the lower Ojo Caliente Sandstone). The main difference between the two members is the arrival of cross-stratified dune deposits. This signals another marked environmental change from a predominately fluvial, medial-distal alluvial slope environment to a sand dune field (erg) on this alluvial slope.

At the beginning of the initiation of this sand dune field (14-12 Ma), streams were able to progress southwards several kilometers into the dune field. In addition, preserved dune heights in the lower part of the Ojo Caliente Sandstone are relatively low (1-2 meters). In the middle to upper Ojo Caliente Sandstone, fluvial deposits are much sparser, and correspondingly preserved foreset heights increase to greater than 6 m and general grain size increases to medium-lower and medium-upper. Apparently, dune heights increased sufficiently during this time to block southward stream flows. Whether streams from the Tusas highlands flowed east or west (or both east and west) around this dune field is under investigation. Because the western part of lithosome B during this time becomes richer in volcanic detritus (Daniel Koning, unpublished data), at least some of the streams appear to have gone east around the dune field and emptied into the lithosome B fluvial system north of Española.

Lastly, clast size data in Table 2 show a trend of increasing gravel size with younger terraces associated with the Rio Chama. Although more data are needed to make it a more robust set, what data we have supports casual field observations that post- 700 ka terrace deposits have noticeably coarser gravel than pre- 700 ka terrace deposits, by a factor of approximately 1.5. After approximately 700 ka, global climate oscillations between glacial and interglacial periods seem to become more pronounced, as reflected in an increase in amplitude of the marine oxygen isotope curves (Karner et al., 2002). Perhaps this clast size increase may reflect a climate signal related to glacial-interglacial transitions in the middle to late Pleistocene.

HYDROGEOLOGIC AND ENVIRONMENTAL IMPLICATIONS

There may not be an appreciable difference in hydraulic conductivities between the lower Ojo Caliente Sandstone and the upper Chama-El Rito Member because their overall sand grain sizes are grossly similar. The coarse channel complexes in the Chama-El Rito Member may not be of appreciably higher permeability compared to the fine sand; this is because of lower sorting and slightly higher cementation in the coarse channel deposits compared to the well sorted, lesser cemented sand. However, more detailed hydrogeologic study is needed to confirm these two postulations. Faults are likely to influence groundwater flow because of features associated with sand deformation bands, clay cores, and local cementation. The general grain size increase up-section in the Ojo Caliente Sandstone, and thus permeability may also increase up-section in this unit. However, the middle to upper parts of the Ojo Caliente Sandstone probably lie mostly above the saturated zone in the study area.

Geologic mapping has recognized several late Holocene eolian deposits discontinuously overlying unit Qayh and Tto in the southwest part of the map (unit Qe/Qayh and Qe/Tto). Furthermore, at least three eolian-related “blow-outs” were discovered. Presently, these dunes are generally stable. However, in times of prolonged drought, such as New Mexico is presently in, caution must be exercised in land management so that the sand dunes do not become reactivated. In particular, activities such as grazing and off-road vehicle use, which reduce the stabilizing effect of vegetation, should be well-regulated.

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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.