

Geologic Map of the Chili Quadrangle, Rio Arriba County, New Mexico

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May, 2005

**New Mexico Bureau of Geology and Mineral Resources
*Open-file Digital Geologic Map OF-GM 103***

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.



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

BY

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May, 2005

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Paleocurrent directions are shown by heavy black arrows (scaled in proportion to number of measurements, 10 per bin), and relative clast composition is shown by pie diagrams to the right. Diagonal line from the top of the Gaucho Section to the base of the Hernandez section ties the middle beds of the Chamita lower tuffaceous zone. Explanations for clast composition pie graphs, unit shading, symbols, and fill textures are given in the **Figure 4** caption. UTM coordinates of base: 3,985,332 N, 398,325 E (Zone 13, NAD 27).

Figure 4. Arroyo de la Presa stratigraphic section, showing the lower, finer part of the Hernandez Member overlying a Lobato Formation basalt flow dated at 11.9 ± 0.3 Ma (Dethier et al., 1986). This flow provides a lower age limit for the Hernandez Member. Explanations for clast composition pie graphs, fills, unit shading, and symbols are shown to the right. Abbreviations used in descriptions are: w = well, modly = moderately, mw = moderately well, p = poorly, vp = very poorly, lt = light, v = very, rnd = rounded, subrnd = subrounded, subang = subangular, ang = angular, int = internally, lamin = laminated, tab = tabular, lentic = lenticular, med = medium, vf = very fine, f = fine, cs = coarse, vc = very coarse, kspar = potassium feldspar. Sand sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are abbreviated as follows: vfL = very fine, lower; vfU = very fine, upper; fL = fine, lower; fU = fine, upper; mL = medium, lower; mU = medium, upper; cL = coarse, lower; cU = coarse, upper; vcL = very coarse, lower; vcU = very coarse, upper. UTM coordinates are in NAD 27 and zone 13.

Appendix 1. Descriptive data for Gaucho and Hernandez stratigraphic sections. Abbreviations follow those in Figure 4.

ABSTRACT

The Chili quadrangle lies about 5-10 km northwest of the city of Española in the Rio Grande rift of New Mexico. It covers a scenic area with an outstanding variety of exposed, rift-related geologic features as old as the middle Miocene. These features include a complicated array of normal and strike slip faults, a relatively complete set of middle to upper Miocene and Pliocene rift basin fill units, upper Miocene basaltic intrusions and flows, and a well-preserved set of Quaternary terraces. The most important geologic structure is the Santa Clara fault, which strikes NE-SW across the southeastern part of the quadrangle. We interpret this fault as having oblique motion (east-down and left-lateral slip). The Santa Clara fault makes a 2-3 km right step southwest of Cerro Romano, with a probable southwest-dipping structural ramp in this stepover. Intersecting the Santa Clara fault at this stepover is the NW-striking Cañada del Almagre fault zone; this fault zone has evidence of right lateral slip and east-down normal throw. The broad, north-northwest striking Puye fault zone (east-down normal fault) meets the Santa Clara fault in

the southeast part of the map and there is likely a transfer of slip between the two fault zones. The Ojo Caliente fault (southwest-down normal fault) traverses the northeast tip of the map and appears to merge with the Santa Clara fault. North of the Santa Clara fault and east of the Cañada del Almagre fault zone is a multitude of relatively short, small-magnitude oblique-slip and dip-faults (throw less than 200-250 m). At least some of the northwest-striking faults here have a component of right-lateral slip, and at least some of the northeast-striking faults have a component of left-lateral slip. The central and northwestern part of the quadrangle is underlain by the Chama-El Rito and Ojo Caliente Members of the Tesuque Formation (generally middle Miocene), interpreted to have been deposited during rift-related subsidence. Pink fine sand and subordinate volcanoclastic sediment of the Chama-El Rito Member was deposited by southeast-to southwest-flowing streams during the middle Miocene. This member coarsens noticeably upwards. High-energy, gravelly fluvial sediment in its upper part of the unit (~13-14 Ma) appears to be more abundant in the western part of the quadrangle, perhaps suggesting that the main south-flowing river traversing the Abiquiu embayment flowed there at this time. The very pale brown, extensively cross-stratified Ojo Caliente Sandstone gradationally overlies the Chama-El Rito Member; this unit reflects a vast sand dune field that existed from 13.5-11 Ma. Over the Ojo Caliente Sandstone lies brown to reddish fluvial strata of the Chamita Formation. The Chamita Formation has recently been subdivided into five members, four of which are mapped on this quadrangle. The Vallito Member generally lies at the base of the formation. The lower contact may have pedogenic features near the town of Chili and perhaps is an unconformity there, but to the south the contact appears to be gradational. Above the Vallito Member lies the interfingering Cejita and Hernandez Members (12 – 6 Ma). The former was derived from the Sangre de Cristo Mountains to the northeast, and is marked by having a clast composition dominated by Paleozoic sandstone, siltstone, and Proterozoic quartzite. The latter was derived from the Abiquiu embayment and Tusas Mountains to the north-northwest, and is characterized by having a gravel fraction dominated by volcanoclastic gravel. There are many volcanic flows, dikes, and small stocks related to an episode of basaltic volcanism at 12.5-9.5 Ma. The basalt flows are generally interbedded in the Hernandez and Cejita Members of the Chamita Formation. In the northwest part of the quadrangle is a dike swarm that has intruded into the Ojo Caliente and Chama-El Rito Members of the Tesuque Formation. Lastly, the presence of various tephra beds within Quaternary terrace deposits provides age control; these ages indicate overall incision of the area during the Quaternary.

INTRODUCTION

The Chili 7.5-minute quadrangle is located in a structurally complex area of the Española basin about 5-10 km northwest of the city of Española, north-central New Mexico. This basin is one of many structural depressions in the Rio Grande rift in the state. Here, there are a myriad of faults with various types of motion. Previous mapping and work by Dethier and Martin (1984), Dethier and Manley (1985), and Aldrich and Dethier (1991) advanced the stratigraphy of the area from that presented in Galusha and Blick (1971), and later workers used that stratigraphy to form new structural interpretations of the basin (e.g., Aldrich, 1986; Gonzales, 1993). However, with recent advances in our understanding of the stratigraphy of the basin fill to the east and northwest (Koning and Manley, 2003; Koning, 2003; Koning et al., 2004a; Koning, 2002), we

thought it would be fruitful to revisit this quadrangle. In particular, we have high aspirations that the knowledge gained from this re-mapping will greatly aid new structural studies in this part of the rift.

This quadrangle straddles two different regions of the Española basin. To the northwest is a structural area referred to as the Abiquiu embayment. The Abiquiu embayment lies between the Embudo fault system and Santa Clara faults to the east and several east-down faults near Abiquiu to the west. The Tusas and Jemez Mountains (in particular, the Jemez lineament; S. Baldrige, personal commun., 2004) probably bound the embayment to the north and south, respectively. Abiquiu embayment has a basin fill thickness of about 1 km and approximates a structural bench (Baldrige et al., 1994) broken by numerous north-south normal faults. The other structural region, extending into the southeast part of the quadrangle, is a relatively deep part of the Española basin near the Velarde and Santa Clara inner grabens (Koning et al., 2004b); basin fill thickness here is as much as 3-5 km (Cordell, 1979; cross-sections of Kelley, 1978, Koning, 2003, Koning and Aby, 2003, and Koning and Manley, 2003). These two regions are separated by a major fault zone called the Santa Clara fault by (Harrington and Aldrich, 1984 and Koning et al., 2004b) and the Embudo fault by Aldrich (1986) and Machette et al. (1998) – for reasons outlined in Koning et al. (2004b) we use the term Santa Clara fault. Faults from the Abiquiu embayment and the deeper part of the Española basin extend towards the Santa Clara fault from the northwest and southeast, respectively.

There are several important topographic features found in the Chili quadrangle. In the northeast part of the quadrangle is the intersection of three important rivers: the southwest-flowing Rio Ojo Caliente from the Tusas Mountains, the southeast-flowing Rio Chama from the Abiquiu area, and northeast-flowing Rio del Oso from the Jemez Mountains. The south tip of Black Mesa is immediately east of the northeast corner of the quadrangle. In the southwest part of the quadrangle are outliers of the Jemez Mountains: Santa Clara Peak and Cerro Roman. To the east of these peaks extends the northern reaches of the Pajarito Plateau.

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. The map was compiled by

Daniel Koning, and the area covered by each respective worker is shown in **Figure 1**. Map units are correlated in **Figure 2**. Stratigraphic sections of the Chamita Formation are given in **Figures 3 and 4**. The appendix gives the descriptive data for two of these sections (the Gaucho and Hernandez sections in **Figure 3**).

ANTHROGENIC DEPOSITS

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

QUATERNARY AEOLIAN DEPOSITS

Qed **Aeolian sand dune deposits (middle to upper Holocene)** – Pale brown sand (10YR 6/3) in dunes up to about 2 m tall. Internal bedding not exposed. Sand is subrounded to rounded, well sorted, and consists of quartz with 12-15% pinkish grains (probably mostly potassium feldspar) and 10-12% mafic and volcanic lithic grains. Loose. Dunes parallel the stream channels and appear to be composed of sand blown up from these channels. No evidence of cohesive soil horizons nor were calcic soil horizons observed.

Qes **Aeolian sand deposits, locally reworked by slopewash (middle to late Pleistocene and Holocene)** – Strong brown (7.5YR 5/6) fine to medium sand and silty very fine to medium sand. Sediment is in planar or slightly wavy laminations. Silty sand may be in very thin to thin, tabular to broadly lenticular beds. Sediment may also be massive. Sand is subrounded to rounded, well sorted, and consists of quartz with minor potassium feldspar and volcanic and mafic grains. Commonly overlies thin Pleistocene and Holocene alluvial deposits. Correlates to unit Qe of Koning (2002) and Koning and Manley (2003); in the latter 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. Loose to weakly consolidated and 1-3 m thick.

Qes
xxx **Eolian sediment and slopewash overlying another map unit (middle to upper Holocene)** – The eolian and slopewash sediment is generally only 1-3 m thick.

QUATERNARY LANDSLIDE DEPOSITS

Qls **Landslide deposits (upper to middle? Pleistocene)** – Landslide complexes on the north side of Cerro Roman and the east side of Santa Clara Peak. These complexes are marked by hummocky topography and by younger, smaller slides inset into older, larger slides. The sediment in these complexes consists of poorly sorted boulders to pebbles of Lobato Formation basalt in a disturbed matrix of sand. Probably not stratified. The slides appear to have formed where at least 60 m of weakly to moderately consolidated Santa Fe Group (commonly Ojo Caliente Sandstone of the Tesuque Formation together with the Vallito and/or Hernandez Members of the Chamita Formation) underlie at least 30 m of Lobato Formation basalt flows on a steep slope. Thickness is on the scale of 10s of meters.

QUATERNARY ALLUVIUM

Qayl **Younger alluvium occupying a low topographic position in valley bottoms (0-100(?) years old)** – Sand and gravel that occupy modern channels, floodplains, or slightly elevated (about 1 m or less) areas adjacent to active arroyos. Sand is generally planar-laminated or in planar-very thin beds. Gravel is in very thin to medium, lenticular to broadly lenticular beds. Composition and texture of the sediment reflects the source area. Loose. Sparse vegetative cover and very weak to no soil development. Age is based on information on USGS topographic maps (such as the stipple pattern), and observations of sedimentation in parts of this unit during heavy rainfall events. 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 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 (upper Pleistocene to Holocene, greater than 100 years old)** – Sand, subordinate silty sand, and subordinate gravel that form low, stable terrace deposits on the floors of valleys or arroyos. Sandy sediment is commonly massive or in vague, very thin to medium, tabular beds or planar-laminations. Minor low (less than 10 cm) tangential cross-lamination. Also minor channel fills of fine to very coarse sand and gravel. Nature of sand varies across the quadrangle. Where sand is eroded from the Chama-El Rito and Ojo Caliente Sandstone Members of the Tesuque Formation, it is very pale brown to pale brown (10YR 7/3-4 and 10YR 6/3), generally fine- to medium-grained, subrounded to rounded, well to moderately sorted, and arkosic; coarser sand is generally volcanic. Sand derived from volcanic terrains is more rich in lithics and more

angular. Gravel also varies according to source area, but it is generally clast-supported, poorly sorted, and volcanic. Clast sizes range from pebbles (mostly) to boulders. Unit may locally have buried, weakly developed soil horizons (three seen at one locality) that are grayish brown to light gray (10YR 5-7/2), perhaps due to high organic content; these soils have only weak ped structure and generally no discernable calcic horizon. Soil at surface is also weakly developed, locally with slight reddening in upper 30 cm of profile (Bw horizon). A calcic horizon (Bk) is either absent or has only stage I carbonate morphology. 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.

- Qae** **Mixed and/or interbedded alluvium with eolian sediment (middle to upper Pleistocene and Holocene)** – Pale brown to brown (10YR 5-6/3) or very pale brown to light yellowish brown (10YR 6-7/4) silt and very fine to fine sand. Near south boundary of quadrangle may be 5-10% scattered pumice and dacitic, coarse to very coarse sand and very fine to medium pebbles. Commonly massive and moderately hard. Generally has darkened A soil horizon (10-40 cm thick) but noticeable calcic horizon was not observed (although we suspect these are locally present). Unit generally occupies valleys in areas of low-relief that receive eolian input of silt and very fine to fine sand. 1-5(?) m thick.
- Qao** **Older alluvium (middle to upper Pleistocene)** – Sandy gravel marked by having abundant boulders of Lobato Basalt. Strath is commonly 1-3 m above the modern stream, but in some drainages the modern stream climbs over the strath of this deposit in an upstream direction (i.e., the modern stream is on top of Qao). Has a soil with a calcic horizon with a stage I+ to stage II carbonate morphology and root casts. This may correlate with unit Qtro5 downstream. 2-4 m thick.
- Qaob** **Older alluvium adjacent to Cerro Roman with abundant basalt gravel (Pliocene to lower-upper Pleistocene)** – Unit is like that of Qao described above, but gravel is dominantly basalt and soil development may be greater. Unit overlies, and is interbedded with, the Puye Formation adjacent to Cerro Roman.
- Qpc** **Piedmont sandy gravel on top of Puye Formation with 0.5-3% obsidian clasts (lower to middle Pleistocene)** – Sandy gravel that overlies the Puye Formation in the southern part of the quadrangle. Gravel are subrounded, poorly sorted, and consist of pebbles, cobbles and boulders of Tschicoma dacite with very minor rhyolite, obsidian clasts (0.5-3%), and pumice. Correlates to unit QTc (Cerro Toledo interval) on the Puye quadrangle to the south (Dethier, 2003).
- Qpu** **Undifferentiated piedmont gravel on top of Puye Formation (lower to middle Pleistocene)** – Like unit Qpc but we could not confirm whether there was obsidian clasts in the deposit due to land access restrictions.
- Qtgu** **Uncorrelated gravel deposits (lower to middle Pleistocene)** – Sandy gravel and gravelly sand in terrace deposits adjacent to drainages; their straths are as much as 40-

48 m above the adjoining drainages. Gravel includes pebbles and cobbles. Found below the ridge-capping gravel of QTgh and is interpreted to be younger. Gravel is generally dominated by Lobato Basalt and is subrounded and poorly sorted. Sand is similar to sand in the Chama-El Rito and Ojo Caliente Members of the Tesuque Formation. Soil development is variable. Thickness is generally 3-9 m

QTgh High-level gravel deposits (upper Pliocene to middle Pleistocene) – Sandy gravel preserved on the tops of ridges about 80-120 m above adjoining drainages. Gravel is clast-supported, poorly sorted, subrounded, ranges in size from pebbles to boulders (mostly cobbles and boulders), and composed primarily of Lobato Basalt and intermediate volcanic rocks. This unit correlates with **Qgth** on the Lyden quadrangle to the east (Koning, 2004). Interbedded in one deposit is a thick, discontinuous, pumice lapilli deposit that is physically similar to the Guaje pumice (UTM coordinates: 3994750N , 388820E, zone 13, NAD27; on peak labeled 6828 ft). If this is the Guaje pumice, than these deposits are as old as 1.6 Ma. Undersides of clasts coated with calcium carbonate as much as 3 mm-thick in upper 2 m of deposit (Dethier and Manley, 1985). A ~1 m-thick soil with a calcic horizon having stage III to III+ carbonate morphology is present on top of this deposit 1 km west of the quadrangle boundary. Dethier and Demsey (1984) report that stripped stage IV calcic horizons underlie soils with stage III calcic horizons on the surface of this unit. Weakly consolidated and 3-15 m thick.

CORRELATED TERRACE DEPOSITS ALONG MAJOR DRAINAGES

This quadrangle has several levels of terraces along the Rio Chama, Rio del Oso, and Rio Ojo Caliente. Terrace deposits are labeled according to their associated drainage because the lithologic types in the gravel fraction vary noticeably between drainages. Each drainage has five or six main levels of terraces (although along the short stretch of the Rio Ojo Caliente on this quadrangle only the lower three are preserved). We've attempted to correlate these levels based on relative heights of the straths above the stream at a given locality. However, over long distances (km-scale) these heights vary noticeably; in particular, the straths seem to converge upstream. Age control for these six levels is summarized in a table following the descriptions.

Qtrc1-6 Terrace deposits along the Rio Chama (lower to upper Pleistocene): Sandy gravel axial channel deposits of the Rio Chama in addition to minor floodplain deposits of silt and very fine sand. The gravel consists of pebbles and cobbles that are generally clast-supported, subrounded to rounded, and poorly sorted. The clasts are mostly quartzite, basalt derived from the Lobato Formation, intermediate to felsic volcanic rocks, minor granite, and minor Mesozoic to Paleozoic sandstone. Sand is pale brown to yellowish brown (10YR 6/3-5/4), medium- to very coarse-grained, moderately to poorly sorted, subrounded (minor rounded), and rich in lithic grains. Floodplain deposits are pale brown to light yellowish brown (10YR 6/3-4) silt and very fine- to fine-grained sand; sand is well-sorted and weakly to moderately consolidated; medium to thick, tabular beds. It is commonly observed that sandy gravel and sand reworked from the Santa Fe

Goup (especially the sand and very fine to medium pebble fraction), the Lobato Formation (basaltic coarse pebbles, cobbles, and boulders), and the Tshicoma Formation (dacite gravel) overlie the axial sediment; this is interpreted to represent local piedmont deposits. The sand in these piedmont deposits are light yellowish brown (10YR 6/4), massive, mostly fine- to medium-grained, well sorted, subrounded, and has a composition comparable to that of the arkosic, fine- to medium sand of the Tesuque Formation in the local area. Weakly consolidated.

Qtoc4-6 Terrace deposits along the Rio Ojo Caliente (middle to upper Pleistocene) – Sand and gravel deposited along the Rio Ojo Caliente in the extreme northeastern 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. Loose.

Qtro1-6 Terrace deposits along the Rio del Oso (lower to upper Pleistocene) – Sandy gravel deposited along the Rio del Oso, mostly to the north of this drainage. Beds are thin to thick, vague, and lenticular. Gravel are clast-supported, include a well-graded mixture of pebbles through cobbles, and are subrounded. Surface characteristics for these deposits are discussed in Dethier and Demsey (1984); their Q2 surface correlates to surfaces on our Qtro1 and Qtro2, and their Q3 and Q4 surfaces correlate to surfaces on our Qtro3 and Qtro4. Loose to weakly consolidated.

Table 1. Age control for terraces along the Rio del Oso, Rio Chama, and Rio Ojo Caliente

Terrace level	Approx ht of strath (m) near confluence ¹	Measured ht of top of quartzite-rich, axial gravel for terraces with age control (m) ²	Material used for dating ³	Estimated age of axial river sediment, in ka ⁴	Remarks	Interpreted age of this terrace level (ka)
Qt__6	10-14	N/d	Charcoal, gastropods	12-45	Deposit does not extend far up Rio del Oso or Rio Ojo Caliente;<6 m thick	12-45
Qt__5	24-33	38	gastropods	70	As much as 35-36 m thick' common bouldery piedmont sediment in middle-upper	60-70

					part	
Qt_4	40-49	47	gastropods	130	5-7 m thick	130
Qt_3	64-69	63-75	gastropods	150-280	5-7 m thick	150-250
Qt_2	85	84-91	gastropods	280-350	10-15 m thick	280-350
Qt_1	95-100	110	Lava Cr B ash	620	6-17 m thick	550-650

Notes:

N/d = Not differentiated as a separate terrace deposit in Dethier and Reneau (1995, fig. 3).

1. Heights measured using the topographic contour lines.
2. Heights are from Dethier and Reneau (1995, fig. 3)
3. From Dethier and Reneau (1995; table 1) and Dethier and McCoy (1993). Methods include C-14 dating of charcoal, amino acid racemization of gastropods, and chemical comparison with the Lava Creek B ash.
4. Values are from age estimations and related data presented in Dethier and Reneau (1995, table 1).

Table 2. Correlation chart for terraces along the Rio del Oso, Rio Chama, and Rio Ojo

Caliente

Terrace level on this quadrangle	Approx ht of strath (m) near confluence of the three drainages	Measured height of top of quartzite-rich, axial gravel for terraces with age control (m) ¹	Correlative terrace in Lyden quadrangle (Koning, 2004)	Correlative terrace in Medanales quadrangle (Koning et al., 2004)	Correlative terrace in San Juan Pueblo quadrangle (Koning and Manley, 2003)
Qt_6	10-14	N/d	None	Qtc7	Qtcg4
Qt_5	24-33	38	Qt4	Qtc6	Qtcg3
Qt_4	40-49	47	Qt3	Qtc5	Qtcg2c
Qt_3	64-69	63-75	none	none	Qtcg2b or 2a
Qt_2	85	84-91	Qt2	Qtc4	Qtcg2a
Qt_1	95-100	110	Qt1	Qtc3	Qtcg1

PLIOCENE ALLUVIUM

Tp Puye Formation (Plicoene) – Mostly medium- to thick-bedded and locally thinly bedded gravel, gravelly sand, and minor sand. Most beds are very planar and only locally show minor channel fills. Overall, discrete channel fills are sparse except at

basal contact. Trough cross-stratification is likewise sparse; where present, it is defined by trains of relatively well-sorted dark grains. Gravel consists mostly of Tschicoma Dacite (70-90%): dark gray, crystal-rich dacite containing 10-15% subhedral to euhedral plagioclase phenocrysts up to 1 cm across as well as hornblende and biotite. The remainder of the clasts (10-30%) are massive to vesicular basalt and pumice. Clasts are subangular to subrounded and very in size from granules to 2 m-long boulders. Gravelly beds are locally both relatively well sorted to poorly sorted, although beds containing cobbles and boulders are everywhere poorly sorted. Beds containing pumice clasts typically contain pumice and are exposed as slightly lighter-colored marker beds 20 to 30 cm thick. Matrix in all beds is sand composed of feldspar and volcanic lithics, as well as very pale brown to light yellowish brown silt. Unit forms resistant plateaus capped by brown, gravelly soil 20-30 cm-thick, steep slopes, and locally cliffs. Many slopes are mantled by coarse debris lag that commonly covers the underlying Santa Fe Group as well. Unit overlies the Santa Fe Group with angular unconformity; the basal contact is well exposed in road-cuts along Forest Service Road 144 in the south part of the quadrangle. Unit is overlain by the Otowi Member of the Bandelier Tuff and by units Qpc and Qpu (probably across an unconformable contact).

LATE CENOZOIC VOLCANIC ROCKS

BANDELIER TUFF

Qbo Otowi Member of the Bandelier Tuff (lower Pleistocene) – White to grayish white pumiceous lapilli and coarse ash; clast- to matrix-supported, moderately to poorly sorted, and subrounded. Commonly mixed with minor volcanic detritus and massive. Interpreted as a fall deposit (Guaje pumice) except for upper part, which is a poorly-welded ignimbrite (called Otowi ignimbrite). Unit appears to fill a paleovalley based on map pattern. Currently being mined near the center of this paleovalley, where the deposit is greater than 12 m thick. Unit thins to north and south from the center of the paleovalley. Moderately to well consolidated.

LOBATO FORMATION

Tlb Basalt flows of Lobato Formation (middle to upper Miocene) – Dark gray to very dark gray (N 3/ to 4/), mostly fine-grained basalt. Contains mafic minerals mostly altered to red opaques (iddingsite) that are both rectangular and diamond-shaped (pyroxene + olivine?). Mafic minerals occur both as tiny grains in the matrix and as subhedral phenocrysts 1-2 mm-wide. Plagioclase in matrix is fresh and lath-shaped. Abundant vesicles are commonly filled with calcite. See Goff et al. (1989) for more discussion and descriptions of these Lobato Formation flows. K/Ar ages from the flows in this quadrangle range from 9.6 ± 0.2 Ma to 12.4 ± 0.4 Ma (Dethier et al., 1986; Dethier and Manley, 1985). The basalt flows are classified as olivine-phyric tholeiite

and hawaiite (Dethier and Manley, 1985; Aldrich and Dethier, 1990; Goff et al., 1989). Individual flows are on the order 2-6 m thick. At Cerro Roman, stacked flows are as great as 180 m thick.

- Tlbi** **Intrusive basalt bodies of Lobato Formation (upper Miocene)** – Dark gray to gray (N 4/ to 5/) basalt that weathers brown (7.5YR 5/2-3). Composed of abundant plagioclase and unidentified mafic minerals (no biotite). Crystals are 1-2 mm long and elongated. This unit constitutes dikes or small stocks (the latter being less than 60 m in diameter). The dikes are 0.5-3.0 m wide and commonly discontinuous at 10³ m scale. These dikes are prevalent in the northwest quadrant, where they generally trend north-south. The basalt in these dikes is hard and forms prominent rib-like ridges in the landscape. These dikes have been dated by K-Ar methods to yield K/Ar ages of about 9.7 ± 0.3 to (Baldrige et al., 1980) in addition to 10.7± 0.3 Ma, 10.6 ± 0.3 Ma, and 10.6 ± 0.3 Ma. These are mapped as lines labeled “bd” where less than a pencil width on the map.
- Tlg** **Intrusive gabbro bodies of Lobato Formation (upper Miocene)** – Gray intrusive of gabbro that is as coarse as medium-grained. Found in roadcut along Forest Service Road 144 at western boundary of quadrangle.
- Tla** **Andesitic intrusion of Lobato Formation (upper Miocene?)** – Description modified from Dethier and Manley, 1985): Gray to grayish-green andesitic intrusive rock. Flows not confirmed by us. Thickness of 60 m.
- Tlp** **Phreatomagmatic deposits associated with the Lobato Formation (middle to upper Miocene)** – Very thin to medium beds of very poorly sorted, fine to very coarse sand and very fine to very coarse pebbles of basalt. ~5% basaltic cobbles. Sand consists of Ojo Caliente Sandstone stained pale yellow to yellow (5Y 7/3-7/6) in addition to 30-50% basalt fragments and tephra stained orange to yellow. Well consolidated and moderately cemented by calcium carbonate. Deposits are as thick as 15 m.

SANTA FE GROUP BASIN FILL

The Tesuque Formation of the Santa Fe Group 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. Galusha and Blick (1971) called the brown to pink sand, silty sand, and gravel above the Tesuque Formation and under Pliocene basalts as the Chamita Formation. The type section for the Chamita Formation lies about 2 km west of the northern part of the eastern quadrangle boundary. Earlier work in the western part of the San Juan Pueblo to the east recognized distinct lithologic units within the Chamita Formation. We see these same units on this quadrangle, and feel they are worthy of the member-rank status proposed by Koning and Aby (in press). Earlier age estimates for these units, based solely on paleontologic data (e.g., Galusha and Blick, 1971), were later supplemented from

radiometric dates of tephra and lava flows interbedded within the Santa Fe Group (Manley, 1976a and 1976b, 1979; Aldrich and Dethier, 1991; Barghoorn, 1980). In general, the units exposed on this quadrangle probably range in age from 16-6 Ma. Additional geochronologic investigations of the tephra are currently underway, and will later refine the ages listed for the units below.

CHAMITA FORMATION, SANTA FE GROUP

Tch Hernandez Member of the Chamita Formation (middle to upper Miocene) – Interbedded floodplain deposits and coarse channel fills. The floodplain deposits commonly are grayish brown (10YR 6-7/2; 2.5Y 5-7/2) to light yellowish brown (10YR 6/4) to very pale brown (10YR 7/3) in color and composed of silt, clay, and very fine- to fine-grained sand. The channel fill deposits consist of sandy gravel with subordinate pebbly sand. Internal bedding of these channel complexes is marked by planar laminations in the sand fraction and very thin to thick, lenticular beds and channel-forms in the gravel fraction. Planar- to tangential- cross-bedding and trough cross-bedding is locally present (up to 70 cm thick). The gravel is clast-supported, subrounded-rounded, and poorly to moderately sorted. Clast types are a mixture of a mixture of dacite and andesite, with subordinate granite (0-15%), basalt (1-13%), rhyolite (2-7%), welded tuff (2-3%), and quartzite (2-27%). Maximum gravel sizes range from 5 to 18 cm (intermediate clast axis). Sand in the coarse channels is gray to brownish gray to grayish brown (2.5Y-10YR 5-6/1-2; 7/2), medium- to very coarse-grained, subrounded, moderately to poorly sorted, and composed of quartz, dark volcanic lithics, and minor (estimated less than 15%) pink-orange potassium feldspar. Abundant channel trend and clast imbrication data indicate a predominantly south-southeast flow direction. The upper contact is an angular unconformity beneath the Puyé Formation. Nine to ten kilometers up Rio del Oso, on the immediate footwall and hanging wall of the Cañada del Almagre fault (UTM coordinates: 3990225 N, 388650 E; zone 13; NAD 27), the Hernandez Member lies below, and also is interbedded with, Lobato Formation basalt flows. Beneath one Lobato Formation basalt flow, 70 cm of pebbly sand of the Hernandez Member overlies the Ojo Caliente Sandstone. The unit interfingers with the Cejita Member to the northeast and gradationally overlies the Vallito Member north and east of the diatomaceous earth mine near the center of the quadrangle.

The lower part of the Hernandez Member is illustrated in the Gaucho section (**Figure 3**) and the Arroyo de la Presa section (**Figure 4**). The Hernandez stratigraphic section (**Figure 3**), located on the immediate hanging wall of the Santa Clara fault, contains the upper, coarser part of the Hernandez Member -- where the type section has been designated by Koning and Aby (in press).

We interpret the Hernandez Member to reflect deposition by a river draining the Abiquiu embayment, which can be thought of as an ancestral Rio Chama. The relatively large clast sizes in the Hernandez Member (see Koning and Aby, in press, fig. 12), particularly in its upper part where there is common clast imbrication, indicates relatively high stream power.

The Hernandez Member ranges in age from 10-12 Ma to less than 6.5-7 Ma. In the Arroyo de la Presa section (**Figure 4**), the base of the Hernandez Member lies immediately above a basalt flow dated by K-Ar methods at 11.9 ± 0.3 Ma (Dethier et al., 1986; Dethier and Manley, 1985). One of the basalts interbedded in the lower Hernandez Member 9-10 km up Rio del Oso, on the footwall of the Cañada del Almagre fault, returned a K-Ar date of 10.3 ± 0.3 Ma (Dethier and Manley, 1985; Dethier et al., 1986). The base of the member lies approximately 16 m below a projection of a 9.6 ± 0.2 Ma basalt flow in the Gaucho section (K/Ar age from Dethier and Manley, 1985; Dethier et al., 1986). A white coarse ash located at 150 m in the Hernandez stratigraphic section is correlated with the Chamita upper tuffaceous zone (6.8-6.9 Ma; McIntosh and Quade, 1995; Izett and Obradovich, 2001) because it contains 20-25% coarse pumice and lacks the colored volcanic lithics observed in the coarse white ash zone.

Tcc **Cejita Member of the Chamita Formation (middle to upper Miocene)** – This unit extends from the Tesuque Formation east of the Rio Grande to the Chamita Formation west of the Rio Grande, as proposed by Koning and Aby (in press). It is composed of light brown to light yellowish brown (7.5-10YR 6/4) to very pale brown (10YR 7/3-4) floodplain deposits of silt-clay and fine sand that are interbedded with various proportions of coarser channel deposits of sand and pebble-dominated gravel. The channel deposits are commonly part of thick, tabular channel complexes. Bedding within the channel complexes has local planar- to tangential- cross-stratification. Paleoflow measurements from clast imbrication and channel trends indicate a general southwest flow direction. Channel gravel is composed of 35-60% quartzite and 15-45% green-gray Paleozoic limestone, sandstone, and siltstone (with 0-15% vein quartz, 0-10% felsic to intermediate volcanic rocks, and 0-15% granite). The gravel is clast-supported, locally imbricated, subrounded to rounded, poorly to moderately sorted, and consists of pebbles and fine cobbles. Maximum clast sizes are typically 3-6 cm in the quadrangle. Channel sand may be in planar laminations. This channel sand is typically pale brown to very pale brown (10YR 6-7/3) or light gray (10YR 7/2) or pale yellow (2.5Y 7/3), fine- to very coarse-grained, subrounded to subangular, well to poorly sorted, and contains common grains of mafic, metamorphic, and Paleozoic lithics (these are generally more abundant than orange-pink potassium feldspar). Unit interfingers with the Hernandez Member to the southwest and gradationally overlies the Vallito Member. The Chamita Formation type section and cross-sections in Koning et al. (2004c) indicate an approximate thickness of 150-200 m for the unit.

Based on clast composition and paleflow direction, unit is interpreted to be derived from the Sangre de Cristo Mountains near the Truchas Peaks. In its westernmost extent, the Cejita Member has some interbeds of sand and gravel likely derived from the San Luis basin. An example of these beds is unit H-9d in **Figure 3** and **Appendix 1**, which lacks limestone and has 5% slightly greenish, white siliceous porphyry with quartz phenocrysts. The lack of Paleozoic limestone and the presence of ~20% Paleozoic sandstone, plus this quartz phenocryst-bearing porphyry, are similar to what is seen in the Vallito Member near the Embudo section. Like the Vallito Member, we

interpret these particular beds in the Cejita Member as being derived from the San Luis basin.

Age of unit is interpreted to be similar to that of the Hernandez Member with which it interfingers: approximately 12-6 Ma.

- Tchc Interfingering Cejita and Hernandez Members of the Chamita Formation (middle to upper Miocene)** – See descriptions of the individual units. Individual members in this interfingering zone are generally more than 3 m thick.
- Tcvu Vallito Member of the Chamita Formation, undivided (middle to upper Miocene)** – Very pale brown, light yellowish brown, light brown, and pink sand and silty sand, with minor lenses of very fine to medium pebbles. In most places, this member can be subdivided into a lower and upper part. The lower part has interbeds of very pale brown, cross-stratified sand similar to the Ojo Caliente Sandstone. The upper part is redder in color and appears to be strictly fluvial. These two parts are described separately below. Unit lies below 9.6 Ma basalt flow (age from Baldrige et al., 1980) near the town of Chili and includes the coarse white ash zone (11-13 Ma). Thus, the age range of the unit is 13-9.6 Ma. Unit is as much as 60 m thick where adequately exposed.
- Tcv Upper fluvial part of Vallito Member of the Chamita Formation (middle to upper Miocene)** –Medium to very thick, tabular beds of silty sand; pink to very pale brown (7.5-10YR 7/4) and light yellowish brown (10YR 6/4). Sediment is also massive. Sand is very fine to very coarse (mostly fine-upper to medium-upper), subrounded (mostly) to subangular, moderately sorted, and composed of quartz, 15-25% pink grains (probably stained quartz and potassium feldspar), and 12-18% lithics grains (volcanic, mafic, and locally green sandstone (latter only in lithosome B sediment)). Locally up to 5% ash grains from the coarse white ash zone is mixed in with sand; local rhizoliths are present. Unit locally has thin, lenticular beds containing Paleozoic sandstone and limestone plus Proterozoic quartzite (Cejita Member, unit **Tcc**) as well as medium to very coarse, volcanic sand beds. The latter locally has scattered very fine to medium, felsic-intermediate volcanic pebbles. Volcaniclastic channel fills become more abundant to the west. Moderately to well consolidated and generally non- to weakly cemented. Locally, there is strong cementation of channel fills. 10-30 m thick.
- Tcve Lower part of Vallito Member of the Chamita Formation, contains interbeds of eolian sandstone (middle to upper Miocene)** – Generally massive or in medium to thick, tabular beds. Internal bedding is massive or else planar-laminated to very thin beds; local cross-laminations (tangential and generally no more than 10 cm thick). Sand is very pale brown to pink (7.5-10YR 7/3-4), fine- to coarse-grained, subrounded (mostly) to subangular, moderately to well sorted, and composed of quartz with 15-25% pinkish grains (probably stained quartz and potassium feldspar), and 10-15% mafic and volcanic lithics. Minor pebbly sand beds that are commonly very thin to medium and lenticular; pebbles may also be scattered in a relatively massive deposit. Pebbles are very fine to coarse, subrounded to rounded, moderately sorted, and

composed of felsic to intermediate volcanic clasts with 0-2% green Paleozoic clasts and 0-2% greenish quartz-porphyry. Eolian intervals consist of laminated to very thin, tangential cross-stratified, medium-lower to coarse-lower sand; foresets are 50-70 cm-thick and face northeast. Sand in the eolian intervals is very pale brown (10YR 7/3-8/2), subrounded (minor subangular), well sorted, and composed of quartz, 12-15% possible Kspar, and ~15% volcanic (mostly) and mafic lithics. Weakly to moderately consolidated. Generally non-cemented except for near base, which may be locally weakly to moderately cemented. A 20-50? cm-thick zone at base of unit, at a location 1 km south of Chili, is marked by reddening, having a silty-clayey sand texture, lack of stratification (possible bioturbation), and local cementation – this zone may be a paleosol and mark an unconformity there. Such a paleosol is not present to the south; near and south of Arroyo de la Presa the base of the Vallito Member appears to grade into the underlying Ojo Caliente Sandstone. Lower contact is gradational over 2-3 m. 6-60 m thick.

- Tcu** **Undifferentiated Chamita Formation (middle to upper Miocene)** – Inferred Vallito, Cejita, or Hernandez Members of the Chamita Formation in areas of very poor exposures. Estimate 60-90 m thick.
- Tc-Tlb** **Undifferentiated Chamita Formation interbedded with Lobato Basalt (middle to upper Miocene)** – Inferred Vallito, Cejita, or Hernandez Members of the Chamita Formation that are interbedded with Lobato Basalt flows in areas of very poor exposures. Approximate thickness of 50-70 m. Not shown in Figure 2.
- Td** **Diatomite (middle Miocene)** – White to light gray, chalky-textured, diatomite that is laminated or in very thin-thin beds; locally relatively massive. Local interbeds of gray, fine ash up to 30 cm thick. Exposed as a crescent-shape 2 km southeast of the center of the quadrangle; with overlying strata removed, the exposure would probably be more circular. The diatomite becomes progressively more interbedded with detrital sediment away from the center of the unit. The interbedded detrital sediment consists of silt and fine sand towards the center (composed of quartz, 12-14% pinkish potassium feldspar or stained quartz, and 20% basalt that is subrounded to subangular and well-sorted). Interbeds of detrital sediment are more abundant, coarser (fine- to very coarse-grained sand), and contain more basaltic detritus towards the margins of the deposit; here, the diatomite is more green in color and more silty than near the center of the deposit. Phreatomagmatic deposits (unit **Tlp**) lie adjacent and below this unit to the west. We interpret these relations, in addition to the circular geometry of the unit, to indicate that the diatomite slowly filled a maar crater following a phreatomagmatic explosion, consistent with interpretations by Dethier and Manley (1985). The crater must have been filled by a lake during this deposition. As deposition progressed, detritus from the margins of the crater was transported a short distance into the crater by probable small-scale mass wasting along the rim. The deposit is overlain by 9-12 m of sand of the Vallito Member of the Chamita Formation (unit **Tcv**), which in turn is overlain by a basalt flow dated at 11.9 ± 0.3 Ma using K/Ar methods (Dethier et al., 1986; Dethier and Manley, 1985). The diatomite abuts (and probably on-laps) a lower basalt flow on its northeastern margin. This basalt flow has not been directly dated, but we suspect it

correlates to a basalt flow 2 km to the northeast that has been dated by K/Ar methods at 12.4 ± 0.4 Ma (Dethier et al., 1986; Dethier and Manley, 1985). Because the lower basalt appears to pre-date the diatomaceous earth, we give an age range of 12.0 - $12.4 \pm$ Ma for this unit. 36-45 m thick.

TESUQUE FORMATION, SANTA FE GROUP

Tto Ojo Caliente Sandstone 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, rounded to subangular (mostly subrounded), and moderately to well sorted. The sand is composed of quartz with 15-18% pinkish grains (probably stained quartz and potassium feldspar) and 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. Foreset heights also increase upwards in the unit from approximately 1-2 m to over 4 m. Lower part of member tends to be less cross-stratified (i.e., more massive) and exhibits medium to thick, tabular to irregular zones of strong cementation by calcium carbonate; these occupy and estimated 1-10% of the sediment volume and are in medium to thick, tabular to broadly lenticular zones. 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 to moderately 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). Cross-section A-A' on this quadrangle indicates that the Ojo Caliente Sandstone is greater than 180 m near Rio del Oso. An east-west cross-section through the eastern quadrangle (cross-section C-C' in Koning et al., 2004c) indicates a thickness of about 360 m.

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 sparseness of Ttci deposits indicates that the dunes were of sufficient size that they blocked virtually all stream flows in the eastern quadrangle. However, there are noticeably more Ttci beds present in the western part of the quadrangle; perhaps this was near the western margin of the dune field and was subject to sporadic fluvial activity.

Consistent with past studies, we assign a middle-late Miocene age to the Ojo Caliente Sandstone. About 3 km north of the northwestern quadrangle boundary lies the Conical Hill fossil quarry. This quarry 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), which according to Woodward et al. (2005) is ~13.2 to 12.5 Ma. A few km east of the center of the quadrangle, a Lobato Basalt flow (K/Ar age of 12.4 ± 0.4 Ma; Dethier et al., 1986; Dethier and Manley, 1985) overlies the Ojo Caliente Sandstone. On the west slope of Black Mesa 2-3 km northeast of the northeastern quadrangle boundary, the uppermost part of the Ojo Caliente Sandstone has an interbed of fine white ash that has been correlated to a 11.3 Ma Trapper Creek tephra (Nelia Dunbar, written commun., 2005). Near the town of Chili, interbeds of the coarse white ash zone are present in the uppermost Ojo Caliente Sandstone; these have been dated by Ar-Ar methods near Española between 12-13 Ma. We use these data to assign a 13.2-11.2 Ma age range (probably mostly 13.2-12.5 Ma) to the Ojo Caliente Sandstone in this quadrangle.

Ttc **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. Thickness not well constrained, probably around 20-40 m.

Ttc **Chama-El Rito Member, Tesuque Formation (lower to middle Miocene)** – Pink to very pale brown (7.5-10YR 7/3-4), very fine to medium sand (mostly fine sand) and silty sand interbedded with minor volcanoclastic sandy pebbles and pebbly sand; there are also local silt and clay beds (these are more abundant lower in the section). The unit coarsens up-section.

The lower, finer part of the Chama-El Rito Member is found on the immediate footwall of the Cañada del Almagre fault and is distinctive in its lack of coarse channel fill deposits. Here, sediment is pink (7.5YR 7/3-4) (minor very pale brown beds) and composed of well-consolidated, very fine- to medium-grained sandstone in medium to thick, tabular to broadly lenticular beds; subordinate beds of silty very fine- to fine-grained sandstone and siltstone that are in very thin to medium, tabular to broadly lenticular beds; 1-20% very thin to medium, planar, light reddish brown (5YR 6/4) clay beds. In the lower interval of the member are local 1-2 m-thick beds of silty very fine to medium sand that are white (10YR 8/1) and have abundant rhizoliths; these beds are weakly cemented by calcium carbonate and have laminated to very thin, wavy beds (3-10 cm amplitude); the rhizoliths are both vertical (in-situe) and reworked. These particular rhizolith-rich beds are interpreted as spring mound deposits and are differentiated on the map (see Explanation of Map Symbols). Cross-section A-A' suggest a cumulative thickness for the Chama-El Rito Member of 790 m, although this is not constrained well due to uncertainties in the thickness of the underlying Abiquiu Formation. Considering that the upper part is 190 m, the lower, finer part may be approximately 300-600 m thick.

The upper, coarser part of the unit is approximately 190 m thick. It is found below the Ojo Caliente Sandstone along the western quadrangle border, in addition to exposed outcrops of this member east of the Cañada del Almagre fault. It differs from the lower

part of the Chama-El Rito Member by having subordinate channel deposits with very coarse volcanic sand and volcanic pebbles. Near the top of the section are common fine to medium, weakly consolidated, very pale brown sand beds that have subordinate coarse to very coarse volcanic grains scattered throughout. The contact between the finer, lower part and the coarser, upper part of the Chama-El Rito Member was so gradational that it was not mapped.

Throughout the Chama-El Rito Member, the very fine to medium sand is in medium to thick, tabular beds that are internally massive, planar-laminated to very thinly bedded, or tangential cross-stratified (generally less than 10 cm). The sand in the finer sediment is well sorted, subrounded-subangular (mostly subrounded), and composed of quartz with 15-25% pink grains (probably stained quartz and potassium feldspar), and 12-18% volcanic and mafic lithic grains. The coarser sediment is in broadly lenticular to tabular channel complexes that are generally up to 0.5-2 m thick (some are as thick as ~ 3 m) and locally fine-upward. In these channel complexes the sediment is planar to broadly lenticular to cross-stratified (up to 1.5 cm thick), and beds are laminated to thin. The lithologic character of the coarse to very coarse sand in the channel complexes is almost wholly volcanic and imparts a grayish color; sand is subangular to subrounded and moderately to poorly sorted. Pebbles are mostly very fine to medium, subrounded, moderately to poorly sorted, clast-supported, and are a mix of intermediate and felsic volcanic rocks, basalt, and tuff. Amalia tuff is present in minor amounts (1-5%), and is more abundant to the west. Near the western quadrangle boundary, coarse and very coarse pebbles and cobbles are locally abundant in the uppermost part of the unit (e.g., in Arroyo del Palacio and south of Rio del Oso. Largest b axes of clasts are 10-20 cm. Paleocurrent directions from channel trends suggest a SW to SE flow, consistent with Dethier and Martin (1984). Clay beds have a reddish brown, light brown, or pink color and are commonly in very thin to thick, tabular to broadly lenticular beds. Moderately to well consolidated; many coarse channels are weakly to moderately cemented by CaCO₃ or clay.

A subscript of “i” (**Ttc_i**) on the unit label is used to denote where this unit is interbedded with or within the Ojo Caliente Sandstone. Where this is the case, the unit commonly is composed of very fine to very coarse sand and silty sand, with minor clay beds. Sand is generally in medium to thick, tabular to broadly lenticular beds that are internally planar-laminated; sand is also massive. Clay is in very thin to thick, tabular to broadly lenticular beds. The sand is pink (7.5YR 7/3-4 and 8/3) to very pale brown (10YR 7-8/3), fine- to medium-grained, subrounded (minor subangular), well sorted, and composed of quartz, 15-20% pink grains (probably stained quartz and potassium feldspar), and 12-15% lithic grains of mafic minerals, volcanic detritus, and chert or green-colored quartz. Local mm-scale rip-ups of clay are present in the sand beds. Locally, there sparse coarse to very coarse sand and very fine pebbles of intermediate to felsic volcanic detritus (subrounded and moderately sorted). Clay beds are commonly reddish brown to light brown (5YR 5/4 to 7.5YR 6/4). Moderately consolidated and generally not cemented by calcium carbonate. A given interval is generally 1-20 m thick. On the map, interbeds of pink fluvial sand, similar to that described above, that are too thin to show as polygons are depicted as lines labeled “cb.”

Sediment of the upper Chama-El Rito on this quadrangle is interpreted to have been deposited on the distal part of a south-sloping alluvial-slope (stream-flow dominated piedmont). Ekas et al. (1984) interprets 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 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). The fine, pinkish sand may be fluviually reworked eolian sand sheets (see discussion of this unit under Koning et al., 2004

Where exposed near the western quadrangle boundary, the lower, finer part of the member appears to have been deposited on a basin floor because of its fine texture and interpreted spring deposits.

Interbedded ash beds in the upper part of the unit are similar to the ashes in the Pojoaque white ash zone, and fossils are similar between the upper Chama-El Rito Member and the Pojoaque Member. The presence of both gray and white ash beds in the lower part of the unit adjacent to the western quadrangle boundary (on footwall of Cañada del Almagre fault) is reminiscent of the tephros observed in the Sull Ridge Member of the Tesuque Formation. In addition, we suspect that the Rio del Oso ash correlates to a similar thick, fine, white ash to the southeast of Española; the latter is called White Ash #4 and is in the Skull Ridge Member. Based on these preliminary ash correlations, we interpret the exposed Chama-El Rito Member on this quadrangle is of the same general age as the Pojoaque and Skull Ridge Members of the Tesuque Fm southeast of Española. This is consistent with the fossils collected near Rio del Oso and in similar strata near the head of La Madera Canyon (a couple of km east of the northwest quadrangle boundary) (Tedford and Barghoorn, 1993). Considering this correlation and the interpreted age of the overlying Ojo Caliente Sandstone Member of the Tesuque Formation, we assign an age range of 13-16 Ma to the exposed Chama-El Rito Member on this quadrangle.

TEPHRAS

Fine white ashes in Tesuque Formation:

Fine white (2.5Y-10YR 8/1) ash beds. Ash beds are tabular where interbedded in fine- to medium-grained sand of the Chama-El Rito Member and lenticular where interbedded in fine- to medium-grained sand of the Ojo Caliente Sandstone Member of the Tesuque Formation. Ashes are individually 9-60 cm thick, and internally planar-laminated to very thinly bedded. Ashes contain 0-5% biotite up to 0.3 mm-long. Commonly altered to clays,

as manifested by a soapy to talc-like texture; otherwise silty-textured and rich in glass shards. Those found near the upper Chama-El Rito Member contact may correlate with the Pojoaque white ash zone southeast of Española based on their appearance and their occurrence in strata having fossil species similar to those found in the proximity of the Pojoaque white ash zone east and southeast of Española (Tedford and Barghoorn, 1993). The Pojoaque white ash zone is 14.3 to 13.2 Ma (Barghoorn, 1981; Tedford and Barghoorn, 1993; Cande and Kent, 1995; Izett and Obradovich, 2001). Fine white ash beds found lower in the Chama-El Rito Member, such as those exposed near the western quadrangle boundary south of Rio del Oso, may possibly correlate to fine white ash beds in the Skull Ridge Member of the Tesuque Formation.

Rio del Oso ash

In upper Rio del Oso, immediately east of the western quadrangle boundary, is a 1-2 m-thick, fine white ash within pink, very fine- to fine-grained, arkosic sandstone and silty sandstone of the lower Chama-El Rito Member. We informally refer to this ash as the Rio del Oso ash because of its prominence in the sediment here. Within this thick ash bed are planar-laminations to very thin beds. The ash is rich in glass shards, silty-textured, and has 3-5% biotite crystals up to 0.5 mm-long. It still has a gritty texture and does not appear to be significantly altered. Hard and generally forms ledges. The thickness of this ash and its physical characteristics lead us to suspect that this ash may correlate to the White Ash #4 in the Skull Ridge Member of the Tesuque Formation. Positive confirmation of this correlation through chemical comparison is still pending.

Fine gray ash 2-5 m above Rio del Oso ash

15-35 cm-thick gray ash within pink, fine sandstone. Ash is light gray (N 7/), has 0-0.5% biotite (up to 0.4 mm-long), and has abundant glass shards. North of Rio del Oso, an ash 5 m above the Rio del Oso ash is correlated to this unit because of its stratigraphic position and physical features; north of Rio del Oso, however, this ash is white.

Undifferentiated fine gray ashes

In the lower Chama-El Rito Member south of the Rio del Oso are beds of gray ashes in scattered exposures; some are grayish white in color. For the most part, these ash beds do not correlate with each other. These ashes are in beds up to 50 cm-thick, rich in glass shards, fine (silt to very fine compared to sand grain size), and have trace to 1% mafic minerals (mostly biotite). These ashes are generally not altered.

Coarse white ash zone:

The coarse white ash zone contains as many as six similar-looking ash beds that are recognized over a stratigraphic interval of approximately 50-65 m. These grayish to greenish white tephra consist of consolidated ash with abundant plagioclase. In addition, there are minor grains of altered pink to gray volcanic lithic fragments, biotite, and quartz. Age constraints described by Koning et al. (2004) and Koning and Aby (in press); most of this zone is 10.9-12.8 Ma, but some beds are as young as ~10 Ma.

Chamita lower tuffaceous zone:

Near the eastern quadrangle boundary, there are two beds that are similar in appearance to the lower and middle intervals of the Chamita lower tuffaceous zone found in the Chamita Formation type section to the north (Galusha and Blick, 1971; Koning et al., 2004c; Koning and Aby, in press). The lowest bed consists of gray, coarse ash to fine lapilli (1-8 mm in diameter) of probable dacitic composition. The middle bed is approximately 13 m above the lower near the Santa Clara fault (base of Hernandez section) and in the Chamita Formation type section. This bed consists of white coarse ash and fine lapilli that is laminated to very thin, planar-bedded. Tephra of the middle bed is composed of consolidated white ash, 1-10 mm in size, with 7-20 percent gray (and minor pink, green, and black) dacite(?) lithics that are 1-15 mm-long. An $^{40}\text{Ar}/^{39}\text{Ar}$ age of 7.7 ± 0.3 Ma from a tephra bed in the lower part of the CLTZ in the Chamita Formation type section, and revision of the Chamita Formation stratotype magnetostratigraphy of MacFadden (1977) by McIntosh and Quade (1995), indicates an age range of 7.7-8.4 Ma for this zone (Koning et al., 2004c). We favor an age of 8.0-8.5 Ma, which is consistent with revision of the magnetostratigraphic data of MacFadden (1977) by McIntosh and Quade (1995) using the revised geomagnetic polarity time scale of Cande and Kent (1995).

Chamita upper tuffaceous zone (Peralta Tuff):

A single, 15 cm-thick bed consisting of pumiceous, coarse, white ash altered to clay. Only present in the upper Hernandez Member in the Hernandez stratigraphic section (unit 11A of **Appendix 1**). Its pumiceous texture and lack of pink lithic fragments and biotite is not consistent with the coarse white ash zone. The stratigraphic position of this unit high in the Chamita Formation, and above the Chamita lower tuffaceous zone, supports its correlation to the Chamita upper tuffaceous zone in the Chamita type section, 5-7 km to the northeast. There, three samples of this tephra have been dated ($^{40}\text{Ar}/^{39}\text{Ar}$) between 6.75 ± 0.05 and 6.93 ± 0.05 Ma (McIntosh and Quade, 1995) and geochemically correlated to the 6.8-6.9 Ma Peralta Tuff (Koning et al., 2004c). The Peralta Tuff is a member of the Bearhead Rhyolite, a late Miocene eruptive in the southeastern Jemez Mountains (Goff and Gardner, 2004).

Guaje Pumice bed of Otowi Member, Bandelier tuff

White pumice-lapilli belonging to the fall-out facies of the Otowi Member of the Bandelier Tuff. Commonly has a 0.2- 2 m-thick cap of poorly welded Otowi ignimbrite. Massive, clast-supported, and weakly consolidated. 1- 3 m thick.

Lava Creek B ash

A powdery, shard-rich white ash interbedded in the Qtrc1 terrace deposit as two separate beds. The lower bed is 15 cm-thick, and 2 m above it is a 2 m-thick interval of reworked Lava Creek B ash. Dethier et al. (1990) provide more descriptive information on this ash and discuss its correlation.

SUBSURFACE UNITS DEPICTED ONLY ON CROSS-SECTION

Ta **Abiquiu Formation (lower Miocene and Oligocene)** – Not known if this unit extends to the line of cross-section A-A'. If it does, it may be a whitish sand with minor felsic-intermediate pebble beds (based on exposures of this unit near Abiquiu).

Mz-Pz **Undivided Mesozoic and Paleozoic strata (probably mostly Triassic and Mississippian to Permian)** – Sandstone, limestone, siltstone, and shale.

STRUCTURE

Numerous faults and folds are found on this quadrangle. These are discussed separately below. Strata dip to the west-northwest in the eastern part of the quadrangle, on the hanging wall of the Santa Clara fault. On western sides of the Cañada del Almagre and Santa Clara faults near the western border of the quadrangle, beds dip southwest to northwest. North of the Santa Clara fault and east of the Cañada del Almagre fault, bedding tilt directions are variable. Cross-section A-A' and the common presence of the Ojo Caliente – Chama-El Rito contact suggests that, in general, the strata here form a bench typical of the gross form of the Abiquiu embayment to the north (see Baldrige et al., 1994). However, two to three km southwest of the Ojo Caliente fault there appears to be two northeast-facing monoclines.

SANTA CLARA FAULT

Perhaps the most important structure on the quadrangle is the Santa Clara fault. “Santa Clara fault” was the first name applied to this structure (Harrington and Aldrich, 1984). Many subsequent workers (e.g., Aldrich, 1986; Aldrich and Dethier, 1991; Gonzales, 1993; Machette et al., 1998) used the name Embudo fault because the fault strikes NE like the southern extent of the Embudo fault system and earlier maps (i.e., Kelley, 1978) had the two faults as a continuous structure. However, recent work indicates that the two structures are not continuous, but rather there is a structurally complicated right step between these two structures at and east of the south tip of Black Mesa (Koning et al., 2004b). Furthermore, the sense of throw (northwest-down versus southeast-down) reverses in this step-over. We feel it is justified to use a separate name when referring to this fault, and other workers have recently re-adopted the name “Santa Clara fault” as well.

This fault extends NE-SW across the southeastern part of the quadrangle. The fault zone of the Santa Clara fault is marked by a relative wide zone (hundreds of meters) of steeply southeast-dipping beds (30 degrees to vertical, some overturned). Within this zone are one or more northeast-striking faults. In a good exposure on the south side of Arroyo Palacio (about 1 km up-canyon), the fault zone has a slight zig-zag in its trace. Overall, the fault zone strikes about N70-80E, but at least one segment at this locality (and probably additional segments to the north) strike about N30E. In the aforementioned exposure, we have confirmed that slickenside lineaments have a northward rake in that locality. Further kinematic work is planned, but we

disagree with previous interpretations by Aldrich (1986) and Aldrich and Dethier (1991), who argue that this fault has a component of right lateral slip. Rather, we interpret an east-down, left-lateral oblique fault. This sense of offset is compatible with kinematic data of smaller, northeast-striking faults to the north, as discussed below. Cross-section C-C' of Koning et al. (2004c) traverses this fault and indicates a throw of 480-495 Ma using offset of a Lobato Basalt flow. This throw value is the most of any faults on the quadrangle, confirming that this is a major structure. We agree with the interpretations of Baldrige et al. (1994) that this fault (called the Embudo fault zone in that work) bounds the southeast side of the structurally shallow (~1 km of basin fill) Abiquiu embayment to the northwest.

Faults within the steeply SE-dipping beds of the fault zone become more difficult to locate immediately south and east of the diatomaceous earth mine, probably because exposure is particularly poor in that area. Using the few exposures available, it appears that there is a slight (600 m), left-step of the fault about 1 km south of this mine where it intersects the northern terminus of one of the faults of the Puye fault zone (the latter is probably a NE-facing monocline at this locality). South of this left-step, there are no more good exposures of the fault zone, and we used stratigraphic relations (namely, where ~10 Ma Lobato Formation basalt is laterally adjacent to the Pliocene Puye Formation) and fault scarps in the Puye Formation to carry this fault to the southwest. For example, between the pumice mines and Cerro Roman is a NE-striking scarp of approximately 9-15 m height. This fault appears to offset the Otowi Member of the Bandelier Tuff by 9-12 m (this throw value is complicated by the fact that the Otowi Member fills a paleovalley), and in its immediate hanging wall the Puye Formation has a east dip (in contrast to its typical west-dip). South of Cerro Roman, there appears to be a 2-3 km right-step in the Santa Clara fault, with the aforementioned fault to the southeast and a fault ~1 km south of Clara Peak to the northwest. The area between these faults may be a south-west tilted ramp that is cross-cut by a northwest-striking, southwest-down fault on the south flanks of Cerro Roman (where the Pliocene Puye Formation is laterally adjacent to ~ 10 Ma Lobato Formation basalts). The northern, northeast-striking fault in this step-over joins with the north-striking Pajarito fault near Santa Clara Canyon to the south and has formed a prominent scarp on the western edge of the Pajarito plateau.

OJO CALIENTE FAULT

A primarily normal fault (Koning et al., 2004b, where it is called the Chili fault) that has an overall northwest strike skirts the lower southwest slopes of Black Mesa. This fault has displaced the Chamita Formation approximately 150-180 m down to the southwest. The trace of the fault on the ground appears to zig-zag because of short NE-striking segments. In roadcuts along the road to Chamita, there is at least one NE-striking fault that dips 70 degrees to the NW. Perhaps there are more of these NE-striking faults that intersect and displace the main NW-trending fault to create this fault trace pattern. The fault strikes 324° at the northernmost exposure of this fault along the slopes of Black Mesa. We interpret that this fault joins with the Ojo Caliente fault to the northeast (see Koning et al., 2004a; Koning, 2004) and thus the name Ojo Caliente fault should be applied on this quadrangle as well. The previous name of Chili fault by Koning et al. (2004b) should be rejected because of this correlation.

CAÑADA DEL ALMAGRE FAULT

The Cañada del Almagre fault of Aldrich and Dethier (1991) appears to intersect the Santa Clara fault where the latter steps to the right southwest of Clara Peak. The trace of the fault is obvious in the field because it juxtaposes very pale brown, weakly to moderately consolidated Ojo Caliente Sandstone (Tesuque Formation) against older, relatively well consolidated, pink, tabular beds of the lower part of the Chama-El Rito Member (Tesuque Formation). In addition, its fault zone is strongly cemented and forms a fin. Cross-section A-A' suggests a 400-500 m, east-down throw along this fault (where there is some constraint on the base of basin fill from the SAGE Rio del Oso seismic line (Ferguson et al., 1995). This fault bends northwards near Rio del Oso from a N-strike to a NW-strike. North of this bed, on the immediate footwall of the fault, are numerous steeply dipping faults whose slickenside lineaments are more horizontal than vertical. On the main Cañada del Almagre fault north of Rio del Oso, we agree with interpretations by Aldrich and Dethier (1991) that a dike of Lobato Formation basalt is offset in an apparent right-lateral manner. We thus interpret that the main fault along with the smaller, steeply dipping faults in its immediate footwall have a significant component of right-lateral slip. This is consistent with kinematic indicators of smaller faults to the north, where northwest-striking faults have northwest-raking slickenside lineaments.

PUYE FAULT ZONE

The Puye fault zone is a name applied to a group of N-NW striking, east-down faults that traverse the eastern part of the Pajarito plateau and commonly offset the Pliocene Puye Formation (La Forge and Anderson, 1988; Wong et al., 1995). Four strands of this fault are present in the southeast part of the quadrangle, where they form east-facing scarps on the upper surface of the Puye Formation that are typically about 7-12 m tall (heights are estimated). The two western strands extend to the Santa Clara fault near the diatomaceous earth mine. The western of these two strands appears to end as a fault-tip monocline and coincides with a 0.6 km left step in the Santa Clara fault.

FAULTS IN NORTHERN AND NORTHWESTERN PART OF QUADRANGLE

There are a multitude of faults in the area north of the Santa Clara fault and east of the Cañada del Almagre fault. These have offset the Chama-El Rito and Ojo Caliente Sandstone Members of the Tesuque Formation by as much as 180-210 m (cross-section A-A'). These faults strike NW south of Arroyo del Palacio, but appear to bend north-northeast north of Arroyo del Palacio as they enter a structural domain to the north dominated by north-northeast-trending faults (May, 1980; Koning, 2004; Koning et al., 2004a). Most are normal faults, but a few have a reverse sense of throw. Near Arroyo del Palacio, many of the northwest-trending faults (both east-down and west-down) have a right-lateral component of slip. About one km south of Arroyo del Palacio (UTM coordinates: 3995350 N, 390600 E; zone 13; NAD27) is an important exposure showing two conjugate faults. Both are normal faults with an east-down sense of throw. One fault strikes 346 degrees and has southeast-raking slickenside lineations (indicating east-down,

right-lateral oblique motion). Another fault strikes 040 degrees and has northeast-raking slickenside lineations (indicating east-down, left-lateral oblique motion). This exposure seems to exemplify the general trends observed elsewhere in this area. Namely, northeast-striking faults may have a left-lateral sense of oblique slip, like that seen in the Santa Clara fault, and northwest-striking faults may have a right-lateral sense of oblique slip, like that interpreted for the Cañada del Almagre fault. One is left with the impression that the sigma 1 component of stress is orientated N-S in this area, and sigma 3 is orientated E-W. Further work is planned to test that interpretation.

FOLDS

Changes in stratal tilt direction indicate subtle folds that trend at relatively high angles to the faults. Most of these folds are so broad, or significantly broken by faults, that they are difficult to define on the map. However, the upper part of Rio del Oso and Arroyo del Palacio seem to follow anticlinal fold axes west of a point about 4.5 km upstream of their mouths (these folds are not shown on the map). In both of these drainages, strata on the south side have a general southward dip, and on the north the strata have a general northward dip. In an exposure about midway between these two drainages (UTM coordinates 3994980 N, 390950 E; zone 13; NAD27), a synclinal axis was mapped for a short distance which seems to parallel the northeast-trend of the Rio del Oso and Arroyo del Palacio. These fold axes seem to be perpendicular to the dominant NW trend of faults south of Arroyo del Palacio.

Two northeast-facing monoclines are observed near the mouth of Rio del Oso. The western one is associated with an unnamed, east-down fault about 2 km above the mouth of this canyon. This monocline has a structural relief of about 470-500 m, and is also observed in seismic reflection data on the eastern end of the SAGE Rio del Oso seismic reflection line (Ferguson et al., 1995). The other monocline is readily observed in the Lobato Formation basalt flows south of the town of Chil. This basalt flow is almost horizontal in its southwestern extent, but immediately southwest of the Rio Chama valley it dips 9 to 20 degrees to the northeast and appears to plunge beneath Quaternary alluvium of the Rio Chama. Both of these monoclines parallel the Ojo Caliente fault on this quadrangle, and are probably related to this fault. Perhaps they indicate shallowing of the dip of the Ojo Caliente fault at depth.

On the immediate hangingwall of the Santa Clara fault, two anticlines and one syncline, have been mapped. These trend approximately east-west, parallel to the major Chamita syncline to the northeast (Koning et al., 2004b). We suspect that these folds relate with transpression or transtension along the Santa Clara fault because they seem to coincide with bends or steps in the trace of the Santa Clara fault.

HYDROGEOLOGIC IMPLICATIONS

Because the basin fill thickens 400-500 m eastward across the Santa Clara fault (cross-section C-C' of Koning et al., 2004c), the basin fill aquifer will correspondingly be thicker to the east of this structure. In the northern and northwest part of the quadrangle, particularly in the Rio del

Oso and Arroyo de Palacio drainages, relatively more abundant cottonwood trees and even springs are located on the immediate upstream side of many faults. These faults in the Chama-El Rito and Ojo Caliente Members of the Tesuque Formation appear to be acting as groundwater barriers in that region. Specifically, fault clay cores or relatively impermeable damage zones in these faults appear to be creating higher groundwater levels on their upstream (western) sides. It follows that any new wells drilled in that area should be located on the western sides of any nearby faults. Relatively widespread and strong silicic cementation in the Chama-El Rito and Ojo Caliente Members (Tesuque Formation) just north of the confluence of the Rio Chama, Rio Ojo Caliente, and Rio del Oso will likely create many zones of decreased hydraulic conductivity values in the subsurface of that area. There, water flow in fractures is probably significant. The two previously mentioned monoclines south of Chili appear to create higher groundwater levels on their western sides. Due west of the mouth of Rio del Oso, the Ojo Caliente Sandstone affected by the western monocline and its associated fault is strongly cemented, creating relatively impermeable conditions. This may be responsible for the springs in Arroyo del Ojitos. Likewise, steeply tilted Lobato Formation basalts south of Chili, in addition to the silty sand of the Chamita Formation that underlies it, in the eastern monocline may create relatively higher groundwater levels to the west of this structure.

ACKNOWLEDGMENTS

We wish to thank Claudia Lewis, Scott Minor, and Jonathon Cain for their help in gathering and interpreting kinematic data along the Santa Clara fault. Kirt Kempter assisted in mapping and correlating some important volcanic dikes near the western quadrangle boundary. Chi Le and Scott Aby also provided field assistance.

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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.