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PROPOSED MEMBERS OF THE CHAMITA FORMATION, NORTH-CENTRAL NEW MEXICO

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ABSTRACT.— New geologic mapping and stratigraphic considerations lead us to favor retaining the term Chamita Formation, albeit with a geographic limitation for two of its five proposed members. West of the Rio Grande in the north-central Española basin, the predominately fluvial strata of the Chamita Formation (upper middle to upper Miocene) overlie cross-stratified, eolian Ojo Caliente Sandstone of the Tesuque Formation (middle Miocene). Here, it is straightforward to map the lower contact of the Chamita Formation. However, the Ojo Caliente Sandstone only extends about 6 km east of the Rio Grande, where it interfingers with Miocene alluvium derived from the Sangre de Cristo Mountains. The coarser, upper part of this alluvium has been subdivided into two interfingering fluvial units named the Cejita and Cuarteles (new name) Members. These two members prograded west of the modern Rio Grande in the late Miocene and comprise most of the type section of the Chamita Formation. However, progressively east of the Rio Grande, towards the Sangre de Cristo Mountains, the base of these two members becomes increasingly more difficult to recognize. Consequently, we include the Cejita and Cuarteles Members in the Chamita Formation west of the modern Rio Grande and in the Tesuque Formation east of the Rio Grande, as is allowed by the Stratigraphic Code.

We also propose the Pilar Mesa, Vallito, and Hernandez Members for the Chamita Formation, including where these units are locally present east of the Rio Grande. The Pilar Mesa Member represents distal to medial alluvial fan deposits derived from the Picuris Mountains, and generally consists of sand with various proportions of gravel dominated by quartzite and Pilar phyllite. Brownish, sandy basin floor strata deposited by a river draining the southern San Luis basin are assigned to the Vallito Member. The Vallito Member is generally composed of very fine to medium sand and silty sand, with minor pebbles whose abundance increases to the north. The Vallito Member has greater than 20% Paleozoic sandstone + granite, whereas the Pilar Mesa Member has less than 20%. The Hernandez Member is a largely volcaniclastic, fluvial deposit that coarsens up-section. We interpret that it was deposited by a river draining the Tusas Mountains and Abiquiu embayment because of its diverse volcanic clast composition (rhyolite, dacite, andesite, and basalt), the presence of subordinate quartzite, and south-southeast-directed paleoflow data. The proportion of quartzite clasts in the Hernandez Member increases upwards, which probably reflects unroofing of older Tertiary volcaniclastic deposits and volcanic flows from the Proterozoic-cored Tusas Mountains. Clast sizes in the Hernandez Member also increase up-section, as does the proportion of coarse channel deposits. As defined above, the Chamita Formation is lithologically distinct from underlying, middle Miocene strata, and serves as a useful lithostratigraphic unit in the north-central Española basin.

INTRODUCTION

The Santa Fe Group includes sedimentary and volcanic rocks related to the Rio Grande rift, excluding terrace deposits and alluvium of present valleys (Spiegel and Baldwin, 1963). The Tesuque Formation (Oligocene to upper Miocene) comprises most of the Santa Fe Group in the Española basin and consists of pinkish-tan, largely arkosic, sandstone and silty sandstone with subordinate conglomerate, siltstone, and claystone. The Chamita Formation of the Santa Fe Group, as originally defined, includes sand and gravel of predominantly fluvial strata that overlie the Ojo Caliente Sandstone Member of the Tesuque Formation (Galusha and Blick, 1971). The Chamita Formation was recognized by Galusha and Blick (1971) in the badlands north of the Rio Chama-Rio Grande confluence, beneath Black Mesa, under the Puyé Formation west of the Rio Grande and south of the Rio Chama, and in exposures immediately east of the Rio Grande between the towns of Española and Velarde (Figs. 1-2). After treating the historical usage of the formation in previous studies, including a past proposal to abandon the unit, this paper introduces five new members for the Chamita Formation and their lithologic and sedimentologic characteristics. It then concludes with a discussion of vertical sedimentologic trends in the formation and a comparison of late and middle Miocene sedimentation rates.

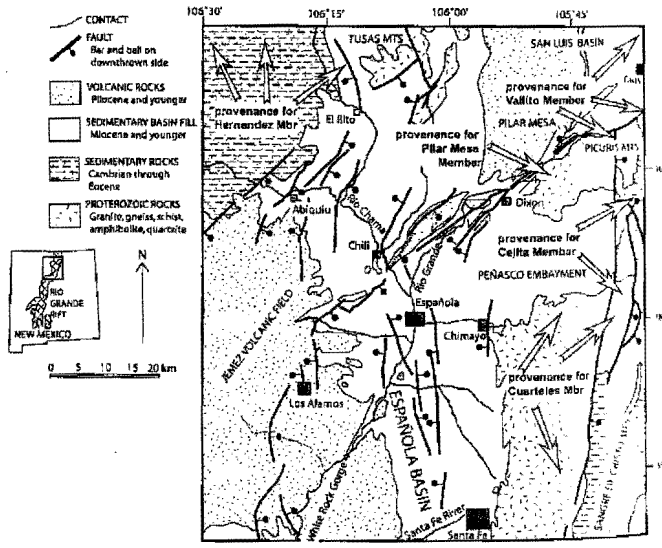

FIGURE 1. Map showing the regional geologic setting of the Española basin. Urban areas are shaded dark gray. Provenance locations for the five members of the Chamita Formation are also depicted. Map modified from Kelley (1978), Brown and Golombek (1986), and Golombek et al. (1983) according to mapping of lead author (Koning and Maldenado, 2001; Koning, 2002; Koning, 2003a; Koning and Manley, 2003; Koning and Aby, 2003; Koning, 2004; Koning et al., 2004a; Koning et al., 2005).

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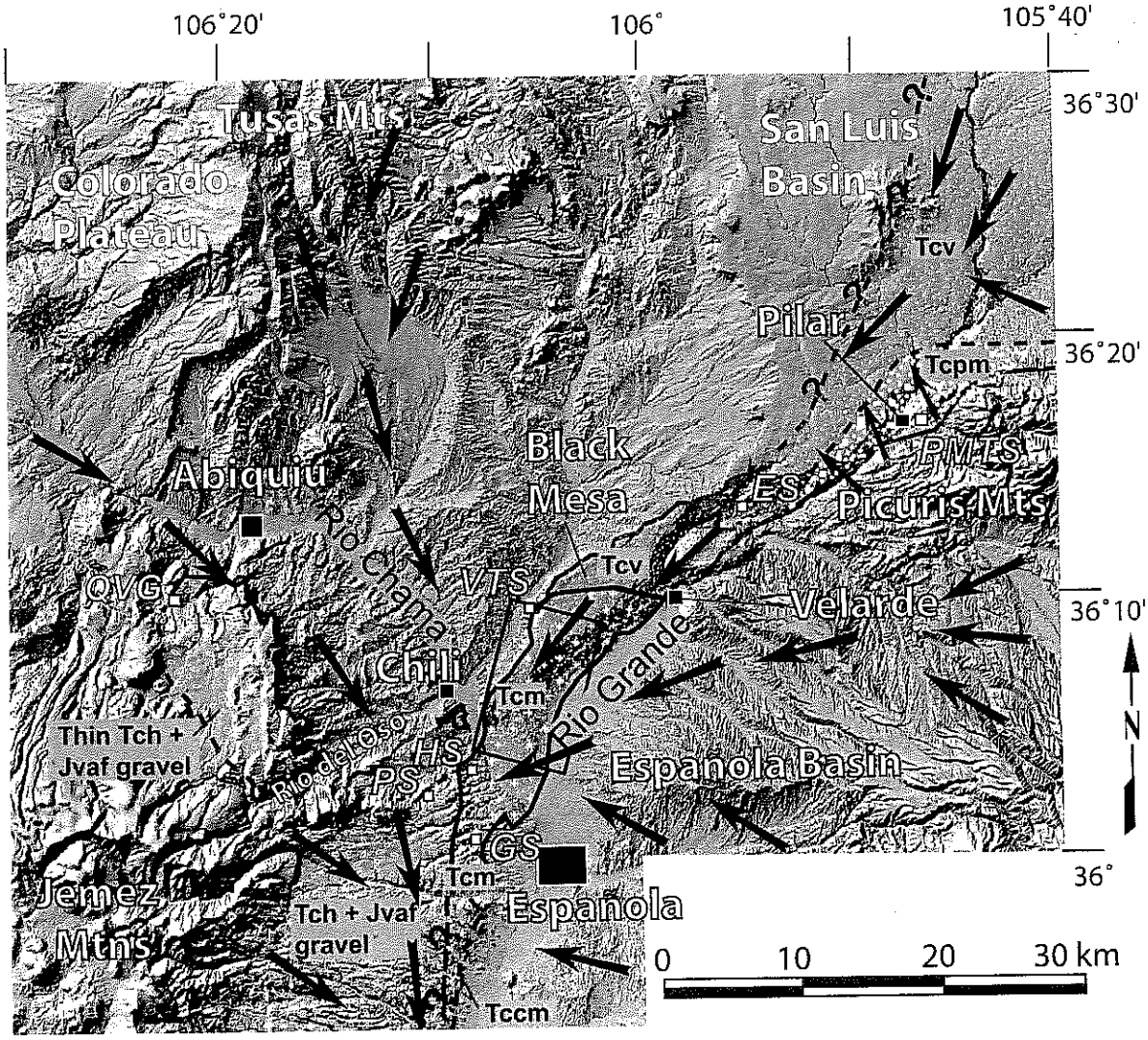


FIGURE 2. Map showing the present-day extent of the Chamita Formation in the Española and San Luis basins relative to geographic features and towns, including where its strata is located under volcanic rocks and Plio-Pleistocene sediments. We depict the Chamita Formation as four units appropriate for the scale of the map. Each of these units is represented by a different textural background and labeled as follows: Tch + Jvaf = Hernandez Member plus alluvial fan volcaniclastic sediment shed from the Jemez Mountains (older fanglomerate of Broxton and Vaniman, in press); Tcm = interbedded Hernandez, Cejita, Vallito, and Cuarteles Members; Tcv = Vallito Member; and Tcpm = Pilar Mesa Member. Black arrows show our interpreted paleoflow directions of the drainages depositing the five members. In the lower-central part of the figure, the box outlines the area of Figure 3. Labeled small, white boxes show stratigraphic sections and important localities discussed in the text: PMTS = Pilar Mesa type section, ES = Embudo reference section, VTS = Vallito type section, PS = Arroyo de la Presa stratigraphic section, HS = Hernandez stratigraphic section, GS = Gaucho stratigraphic section, QVG = quartzite-bearing volcanic gravel south of Abiquiu. Shaded relief map generated from 10 m-spaced DEM data, courtesy of Jennifer Whiteis of the New Mexico Bureau of Geology and Mineral Resources.

PREVIOUS SEDIMENTOLOGIC AND STRATIGRAPHIC STUDY

Chamita type section area

The Chamita Formation was proposed by Galusha and Blick (1971) for quartzite-rich sand and gravel that overlie the Ojo Caliente Sandstone Member of the Tesuque Formation. A type section for the Chamita Formation was established ~ 1 km north of the town of Chamita (Galusha and Blick, 1971), in the well-exposed badlands immediately north of the confluence of the Rio Grande and Rio Chama (Figs. 3-4). They interpreted that these fluvial strata were deposited in response to a major geologic event that brought to an end the eolian deposition of the Ojo Caliente Sandstone. In the Chamita Formation stratotype, distinctive lithologic features described by Galusha and Blick (1971) include the presence of abundant quartzite gravel and sand plus two tuffaceous zones: the 24-30 m-thick lower tuffaceous zone and the ~30 m-thick upper tuffaceous zone (herein referred to as the Chamita lower tuffaceous zone and Chamita upper tuffaceous zone, respectively abbreviated as CLTZ and CUTZ). The Chamita lower and upper tuffaceous zones are separated by approximately 80 m of "light brown or gray bands of fine to coarse sand in which lenses of conglomeratic sand and gravel crop out" (Galusha and Blick, 1971, p. 71). Strata in the upper portion of the Chamita upper tuffaceous zone were said to be "fine-grained and may have

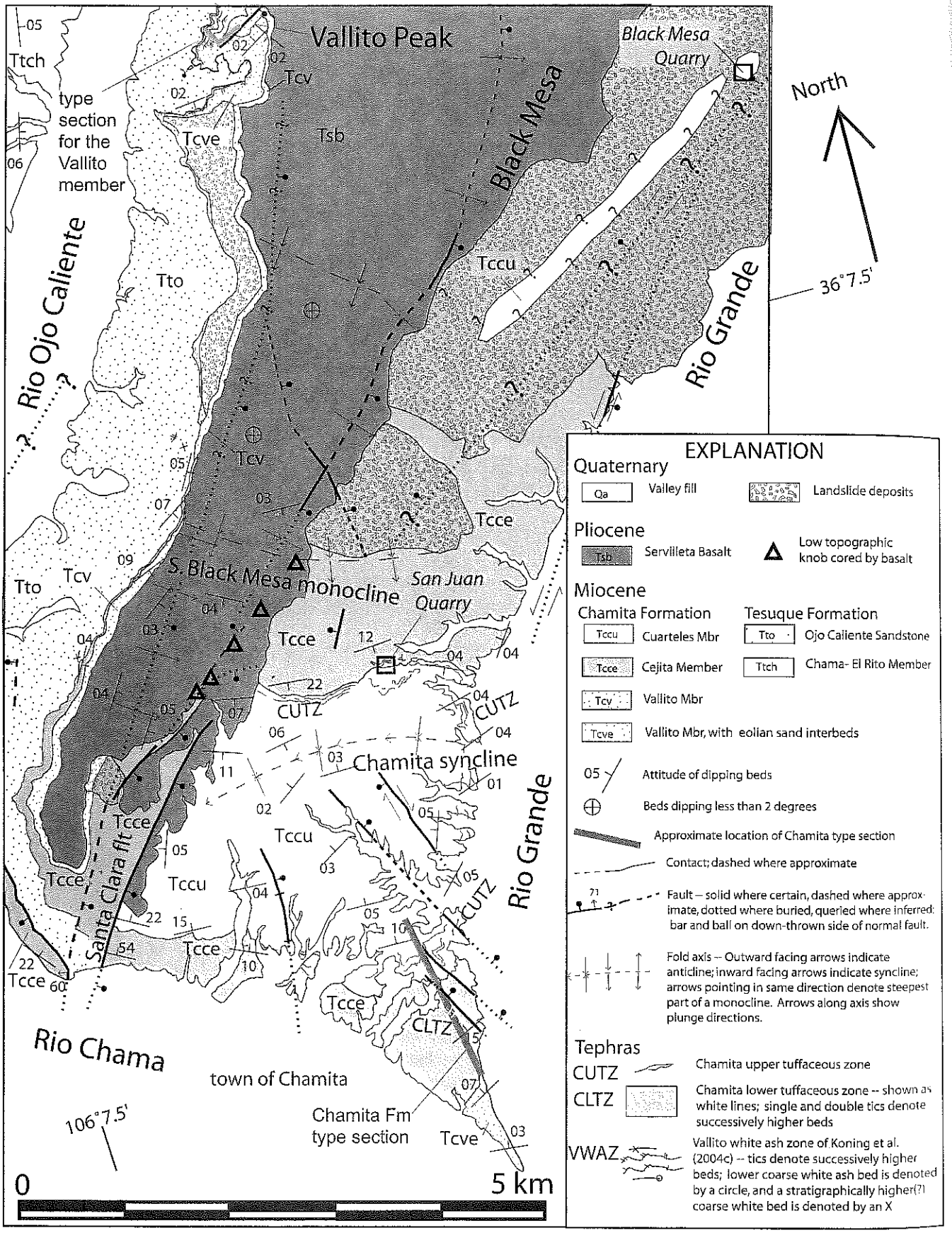


FIGURE 3. Geologic map of the area around the Chamita type section (slightly modified from Koning et al., 2004b).

many reddish, fine-sand zones and patches", with the tuffaceous zone grading upward into ~ 90 m of "pinkish, brownish, or gray sand, silt, and conglomeratic sand" that are relatively soft (Galusha and Blick, 1971, p. 71 and 74).

Fossils in the Chamita Formation stratotype belong to the early and late Hemphillian North American land mammal "age" (Galusha and Blick, 1971; MacFadden, 1977; Tedford and Barghoorn, 1993). Two zircon fission-track ages of 5.2 ± 1.0 and 5.6 ± 0.9 Ma were obtained from samples in the lower and upper Chamita tuffaceous zones, respectively (Manley, 1976). The magnetostratigraphic work of MacFadden (1977) revised by McIntosh and Quade (1995) indicate that the Chamita type section ranges in age from ~ 9 to 5.8 Ma, and the lower and upper Chamita tuffaceous zones have ages of 8.0-8.5 Ma and 6.8-6.9 Ma, respectively (McIntosh and Quade, 1995; Cande and Kent, 1995; Koning et al. this volume).

Recent mapping by Koning and Manley (2003) found that the sediment in approximately the upper half of the type section (above 175 m in Fig. 4) is arkosic and the gravel composition dominated by granite. The composition of this unit and paleoflow data indicating west-northwest stream flows (Fig. 4) support derivation from the Sangre de Cristo Mountains south of the Peñasco embayment. This unit is similar to lithosome A of the Tesuque Formation (Cavazza, 1986) in its composition and bedding characteristics.

Strata beneath this arkosic and granite-rich unit consist of floodplain fine sand and mud, with subordinate channels of sand and gravel; these deposits were correlated to the Cejita Member of Manley (1976, 1977, 1979) because of their mutual sedimentologic and lithologic similarities (Koning and Manley, 2003). The gravel is composed of clast-supported pebbles with ~10% fine cobbles; these clasts are subrounded-rounded, poorly to moderately sorted, and consist primarily of Proterozoic quartzite and Paleozoic limestone, sandstone, and siltstone (Fig 4). The Cejita Member west of the Rio Grande overlies a light yellowish brown to very pale brown unit composed of sand and silty sand, with very sparse pebbles dominated by felsic to intermediate volcanic clasts. This brown unit is correlated to the Vallito Member (new name; described and discussed below), lies just above and below the base of the original Chamita type section (Figs. 3-4), and is interbedded with subordinate, cross-stratified, eolian sand intervals.

West slope of Black Mesa

Black Mesa forms a prominent landmark in the northern Española basin. It is located between the Rio Ojo Caliente and the Rio Grande north of the confluence of the Rio Chama and Rio Grande, and lies 3 km northwest of the Chamita Formation type section (Figs. 2 and 3). Under the Pliocene-age gravel and Servilleta Basalt that cap the western side of Black Mesa, and over the Ojo Caliente Sandstone, is 15-150 m of predominantly fluvial sediment. These strata were correlated to the Chamita Formation by Galusha and Blick (1971), who noted that the unit differs somewhat from strata at the type locality although the fossils in the two areas are of equivalent age. A stratigraphic section of the Chamita Formation 2 km northeast of Vallito Peak (the latter shown in the northwest corner of Fig. 3) shows that the Chamita Formation here is 150 m-thick, with possible eolian cross-stratification present 83-105 m above its base (May, 1980, app. F). Work by Koning et al. (2004c) described the lower 65-80% of this unit as a very pale brown to light yellowish brown fluvial deposit with eolian interbeds, which is overlain by a redder silty sand. Koning et al. (2004c) provisionally extended the informal Cieneguilla member, Tesuque Formation (Leininger, 1982), to these deposits.

West of the Rio Grande and south of the Rio Chama

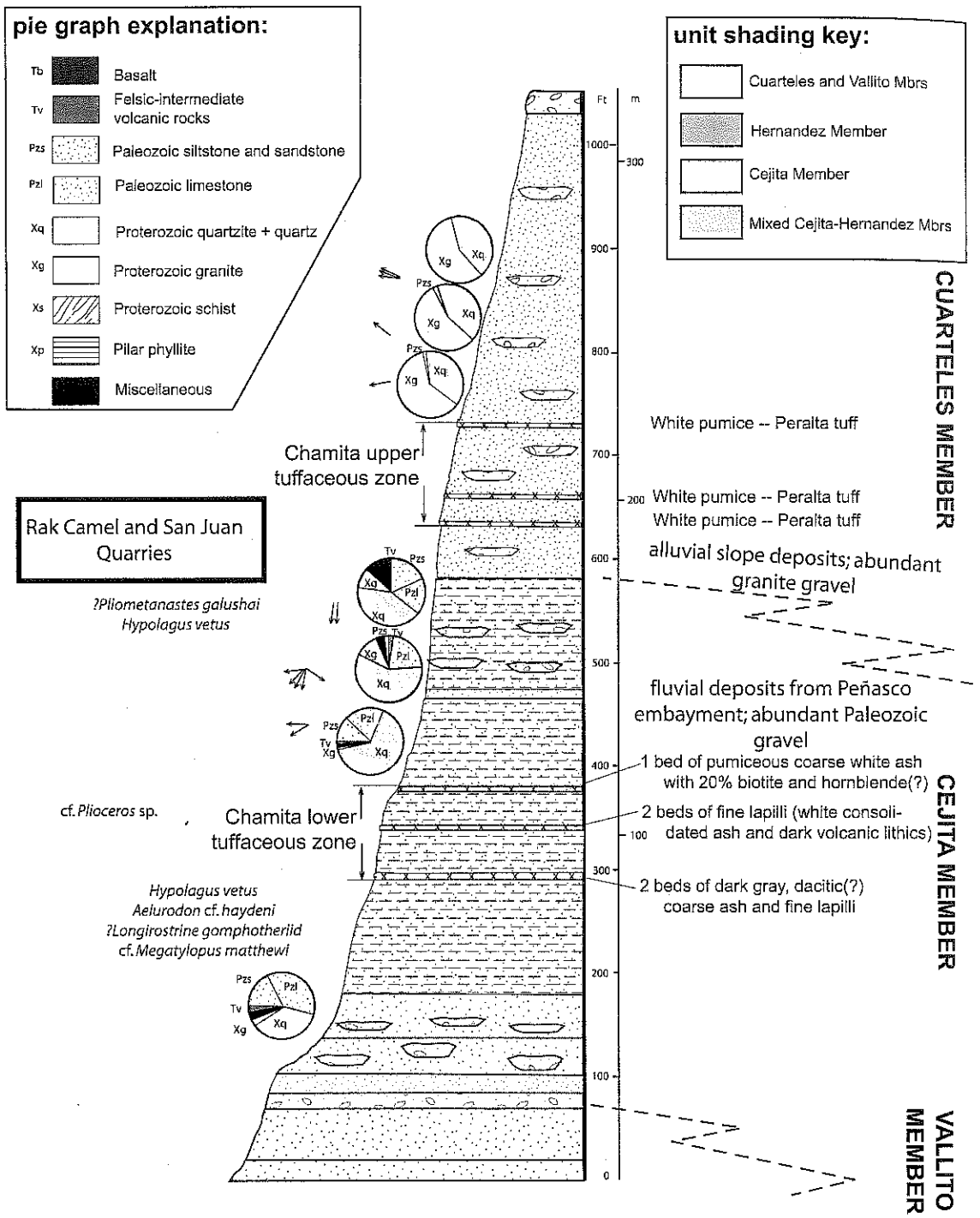
The Chamita Formation west of the Rio Grande and south of the Rio Chama commonly underlies the Puyé Formation (Plio-Pleistocene in age; Waresback and Turbeville, 1990), was thought to be relatively thin (60-150 m), and was recognized as far south as Guaje Canyon (Galusha and Blick, 1971; Dethier and Manley, 1985). Here, the sediment is described as "light brown, moderately sorted, poorly lithified quartz sandstone, reddish-brown silty sandstone and siltstone, gray pebble conglomerate, and white, gray, and pale reddish brown devitrified air-fall tephra…maximum clast size approximately 35 cm (intermediate axis); predominate clasts are of Tertiary volcanic rocks of intermediate composition and Precambrian metamorphic rocks; minor Paleozoic sandstone and fossiliferous limestone present locally" (Dethier and Manley, 1985). The gravel was inferred to be derived from the north (Tusas Mountains) and east (Sangre de Cristo Mountains), and the lower contact was observed to interfinger with the underlying Ojo Caliente Sandstone (Dethier and Manley, 1985). Recent mapping of the same quadrangle by Koning et al. (2005) differentiates the Chamita Formation into two units deposited by two fluvial systems: one from the Peñasco embayment (equivalent to the Cejita Member of Manley, 1976, 1977, 1979), which joined a river from the southern San Luis basin, and one from the Abiquiu Embayment (the Hernandez Member, described below). Locally, sediment from these two fluvial systems is interbedded at a sufficiently fine scale to justify mapping a mixed-provenance map unit at a scale of 1:24,000.

East of the Rio Grande between Española and Velarde

A band of Chamita Formation, 4-6 km wide, was mapped parallel to, and east of, the modern Rio Grande valley-fill north of Española by Galusha and Blick (1971). The discovery of Hemphillian-age(?) fossils in this band (i.e., the *Osbornoceros* quarry, location given in Galusha and Blick, 1971; Koning, plate 11 in Brister et al., 2004) was thought to establish that the strata here were temporally equivalent to strata in the Chamita Formation type area. Later mapping by Koning (2003a), Koning and Manley (2003), and Koning and Aby (2003) found that the lower Chamita Formation contact shown by Galusha and Blick (1971) could not be recognized in the field.

RETENTION OF THE TERM CHAMITA FORMATION

Recent mapping and stratigraphic work indicate that strata temporally equivalent to the Chamita Formation east of the Rio



Note: Fossil data listed in type section is from MacFadden (1977)
Type section slightly modified from Galusha and Blick (1971); clast count and paleoflow data from Koning and Manley (2003)

FIGURE 4. Chamita Formation type section and proposed member designations, slightly modified from Galusha and Blick (1971). Arrows denote paleocurrent data measured using clast imbrications and channel trends (Koning and Manley, 2003). Clast count data from Koning and Manley (2003) depicted as pie graphs. The shading and fills of the pie graphs, as well as unit shading, for all stratigraphic sections in this paper follows the explanation given in this figure. See Figure 3 for map location.

Grande and northeast of Española generally lack a mappable, formation-rank lower contact. These strata are comprised of the interfingering Cejita and Cuarteles Members (upper middle to upper Miocene; Manley, 1976, 1977, 1979; Koning and Manley, 2003; Koning and Aby, 2003; Koning, 2003a; Koning et al., this volume), which extend westward into the Chamita Formation type section, as discussed above (Figs. 4-5). East of the Rio Grande, the Cejita and Cuarteles Members are generally coarser than lower middle and lower Miocene strata of the Tesuque Formation. However, the lower part of the Cejita Member is compo

sitionally similar to the Dixon Member and lithosome B of the Pojoaque Member, although the latter may contain more volcanic clasts (Koning and Aby, 2003; Koning et al., this vol; Cavazza, 1986), and the lower part of the Cuarteles Member commonly has a similar composition to lithosome A of the underlying Pojoaque Member (Koning, 2003a). Furthermore, the basal Cuarteles Member contact is commonly gradational over 6-60 m; this gradation becomes more pronounced near the Sangre de Cristo Mountain front (Koning, 2003a; Smith et al., 2004; Koning et al., 2004c). Compounding the problem of mapping the lower contact is that the Ojo Caliente Sandstone, whose top by definition forms the base of the Chamita Formation, only extends ~ 6 km east of the Rio Grande (Fig. 5; Koning et al., this vol., fig. 2). The lack of a mappable contact near the Sangre de Cristo Mountains, and the gross similarity of strata in the Chamita type section with much of the Tesuque Formation, led Koning (2003b) and Koning et al. (2004c) to suggest grouping all Miocene strata in the north-central Española basin with the Tesuque Formation.

However, further geologic mapping and sedimentologic observations, in addition to discussion with other geologists and close inspection of the Stratigraphic Code, lead us to conclude otherwise. Recent mapping over much of the basin west of the Rio Grande (Koning, 2004; Koning et al., 2005) indicates that the lower contact of the Chamita Formation is readily distinguishable there because it lies on top of the Ojo Caliente Sandstone – an easily identifiable, eolian dune field deposit consisting of subrounded, moderately to well sorted, cross-stratified, very pale brown sand of fine-upper to coarse-lower grain size (Koning, 2004; Koning et al., 2004a). Also, upper middle to upper Miocene strata west of the Rio Grande differ from the middle Miocene strata underlying the Ojo Caliente Sandstone. Below the Ojo Caliente Sandstone lies the Chama-El Rito Member of the Tesuque Formation, which is largely composed of pink, arkosic, fine to medium sand with subordinate channel fills of coarse sand and pebbles. The pebbles consist of volcanic rocks with less than 10% combined quartzite and granite derived from the southern Tusas Mountains (Koning, 2004; Koning et al., 2004a). Most of the Chamita Formation, on the other hand, is composed of either: 1) very pale brown to light yellowish brown, very fine to medium sand with heterolithic gravel (the proposed Vallito Member), 2) very pale brown to pale brown to pale yellow sand with gravel dominated by Paleozoic sedimentary rocks or Proterozoic quartzite (proposed Cejita Member), or 3) gray to brownish gray to very pale brown, volcanic-rich sand and volcanic-dominated gravel with greater than 3% quartzite (Hernandez Member). Upper middle to upper Miocene strata of the Chamita Formation are thus distinct from the Ojo Caliente Sandstone and underlying middle Miocene fluvial sediment west of the Rio Grande.

In order to retain the Chamita Formation as a valid formation-rank term, we must allow the Cejita and Cuarteles Members to extend from the Tesuque Formation (east of the Rio Grande) to the Chamita Formation (west of the Rio Grande). East of the Rio Grande, particularly near the Sangre de Cristo Mountain front, the difference between upper middle Miocene, coarser strata versus lower middle Miocene, finer strata does not constitute a formation-rank contact. However, west of the Rio Grande the Ojo Caliente Sandstone serves to readily define the basal contact of fluvial, upper middle to upper Miocene strata. Inclusion of a member in two different formations is allowed by the Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 858).

In conclusion, the Chamita Formation does constitute a recognizable and useful stratigraphic unit, provided the following: 1) it is accepted that the Cuarteles and Cejita Members are included in both the Chamita and the Tesuque Formations; 2) the Cejita and Cuarteles Members are assigned to the Chamita Formation on the west side of the Rio Grande, where they overlie the Ojo Caliente Sandstone, and assigned to the Tesuque Formation east of the Rio Grande; 3) one recognizes three additional members (the Pilar Mesa, Vallito, and Hernandez members) not well-represented in the type section. The five new members are described below.

PROPOSED MEMBERS OF THE CHAMITA FORMATION

Recent mapping demonstrates that the Chamita Formation can readily be differentiated into five member-rank, lithostratigraphic units that formerly were assigned to the Tesuque Formation (Table 1; Koning and Manley, 2003; Koning and Aby, 2003; Koning, 2004; Koning et al., 2004c and 2005). The five units are the Pilar Mesa, Vallito, Cejita, Cuarteles, and Hernandez Members. In most places, these are not suitable formation-rank units because locally they laterally grade or extensively interfinger with one another. Each of the five members is a lithosome that can be associated with a respective fluvial system and/or depositional environment (Table 1). A schematic representation of their stratigraphic relations is shown in Figure 5, and a summary of their diagnostic characteristics is given in Table 2. Because the sediment is generally non- or weakly cemented and moderately consolidated, we do not use the ending of "stone" in textural designations (e.g., sand instead of sandstone), although locally there is sufficient cementation or consolidation to warrant it. Tephra beds or zones mentioned in the text below are described in Koning et al. (this volume) and briefly summarized in Figure 5.

Pilar Mesa Member

We apply the new name of Pilar Mesa Member for sandy and gravelly fluvial deposits that overlie, and interfinger with, the Ojo Caliente Sandstone near Pilar (Fig. 2). Leininger (1982) previously included these strata in the informal Cieneguilla member of the Tesuque Formation. However, one cannot use "Cieneguilla" in a formalized member because the name has already been applied to a Pennsylvanian formation in the northern Sangre de Cristo Mountains of New Mexico (Young, 1946) and to Tertiary mafic volcanic rocks near La Cienega in the southern Española basin (Stearns, 1953; Disbrow and Stoll, 1957). The type section for this unit is designated on the south slopes of Pilar Mesa (Figs. 2 and 6), after which it is named, and corresponds with the lower Cieneguilla member stratigraphic section of Leininger (1982, 0-400 ft of fig. 15). Located adjacent to the western and

TABLE 1. Comparison of old stratigraphic names with new members of Chamita Formation

New member name of Chamita Fm	Former member name of Tesuque Fm	Related drainage system
Pilar Mesa Member	Cieneguilla member (Leininger, 1982)	Alluvial fans(?) derived from the Picuris Mountains
Vallito Member	Cieneguilla member (Koning et al., 2004c) Fine, lower unit of Hernandez Member (i.e., south of Rio Chama; Koning et al., 2004c)	Relatively narrow(?) alluvial plain or wide braided, sandy river from San Luis Basin
Cejita Member	Cejita Member (Manley 1976, 1977, 1979). Fine, lower part of Hernandez Member (i.e., south of town of Chili; Koning et al., 2004; Plate 12, Brister et al., 2004)	River from Peñasco embayment merging with San Luis Basin drainages
Cuarteles Member	Lithosome A (Koning et al., 2004c)	Alluvial slope draining granite-dominated Sangre de Cristo Mountains east of the Picuris-Pecos fault
Hernandez Member	Hernandez Member	Ancestral Rio Chama draining Tusas Mountains

northern front of the Picuris Mountains, the Pilar Mesa Member gradationally overlies an unnamed unit (described below) and its upper contact is an unconformity. The Pilar Mesa Member is composed of very pale brown to light yellowish brown, very fine to very coarse sand interbedded with scattered, broadly lenticular channel fills of pebbly sand and sandy gravel. The sand is sub-angular to rounded, moderately to well sorted, and massive or in thin to thick, tabular beds. The gravel is mostly clast-supported, moderately to poorly sorted, angular to rounded, and consists of very fine pebbles to cobbles. Maximum clast sizes are 25-30 cm, but most clasts are less than 10 cm. The Pilar Mesa Member is at least 200 m thick near the type section; its maximum thickness is uncertain due to faulting.

Our clast count data at the type section indicate that the gravel is dominated by Proterozoic quartzite and Pilar phyllite, with a subordinate component of schist and felsic to intermediate volca-

TABLE 2. Summary of diagnostic features of the members of the Chamita Fm

	Texture	Color and *paleocurrent data*	Clast composition	Main differences with other units
Pilar Mesa Member	Sand interbedded with pebbly sand and sandy gravel.	Very pale brown to lt. yellowish brown *Northwest-west (probably north on northern flank of Picuris Mountains)*	Dominated by Proterozoic quartzite and Pilar phyllite; subordinate Tertiary volcanic rocks and Proterozoic schist. Less than 4% granite.	Contains fewer Tertiary volcanic clasts, and more locally derived Pilar phyllite, quartzite, and schist, compared to the upper Picuris Formation. Clasts of granite + Paleozoic sandstone are less than 20% of total gravel.
Vallito Member	Sand and silty sand, with minor coarse sand and pebble channel deposits that increase in abundance to the north.	Very pale brown to lt. yellowish brown; more reddish colors in upper 20-35% *South-southwest*	Dominated by Tertiary felsic to intermediate volcanic rocks, Paleozoic sandstone, and Proterozoic granite and quartzite (most to least); Pilar phyllite is 0-11%	Clasts of granite + Paleozoic sandstone are more than 20% of total gravel, which differentiates unit from the Pilar Mesa Member. Paucity of limestone and higher volcanic clast percentages differentiates unit from Cejita Member.
Cejita Member	Floodplain deposits of silt, clay, and v. fine to fine sand; various proportions of channel deposits of sandy pebble-cobble gravel.	V. pale brown to pale yellow to pale brown to lt. gray. *South-southwest-west*	Proterozoic quartzite with Paleozoic limestone, sandstone, and siltstone; minor Proterozoic granite and Tertiary volcanic rocks	Color of sand is relatively distinct, as is the presence of common limestone in its gravel fraction. At least twice as many coarse channels as underlying Pojoaque Member.
Cuarteles Member	Silty sand extra-channel sediment with various proportions of channel complexes composed of coarse sand and pebbles-cobbles	Lt. brown to reddish yellow to pink *West-northwest*	Proterozoic granite with subordinate quartzite	Has greater than 10-20% coarse channels deposits; these are noticeably more abundant than underlying Pojoaque Member of Tesuque Fm. Only granite-dominated unit of the Chamita Fm
Hernandez Member	Floodplain deposits of silt, clay, and v. fine to fine sand; channel deposits of sandy pebble-cobble gravel.	Gray, brownish gray, grayish brown, lt. yellowish brown, v. pale brown. *Southeast*	Mostly Tertiary intermediate volcanic rocks; subordinate rhyolite, basalt, and welded tuff; 3-35% quartzite	Lacks the pink to very pale brown, clean fine sand of the Chama-El Rito Member of Tesuque Fm. Lacks Paleozoic sedimentary rocks seen in the Cejita Member. Coarser than the Vallito Member.

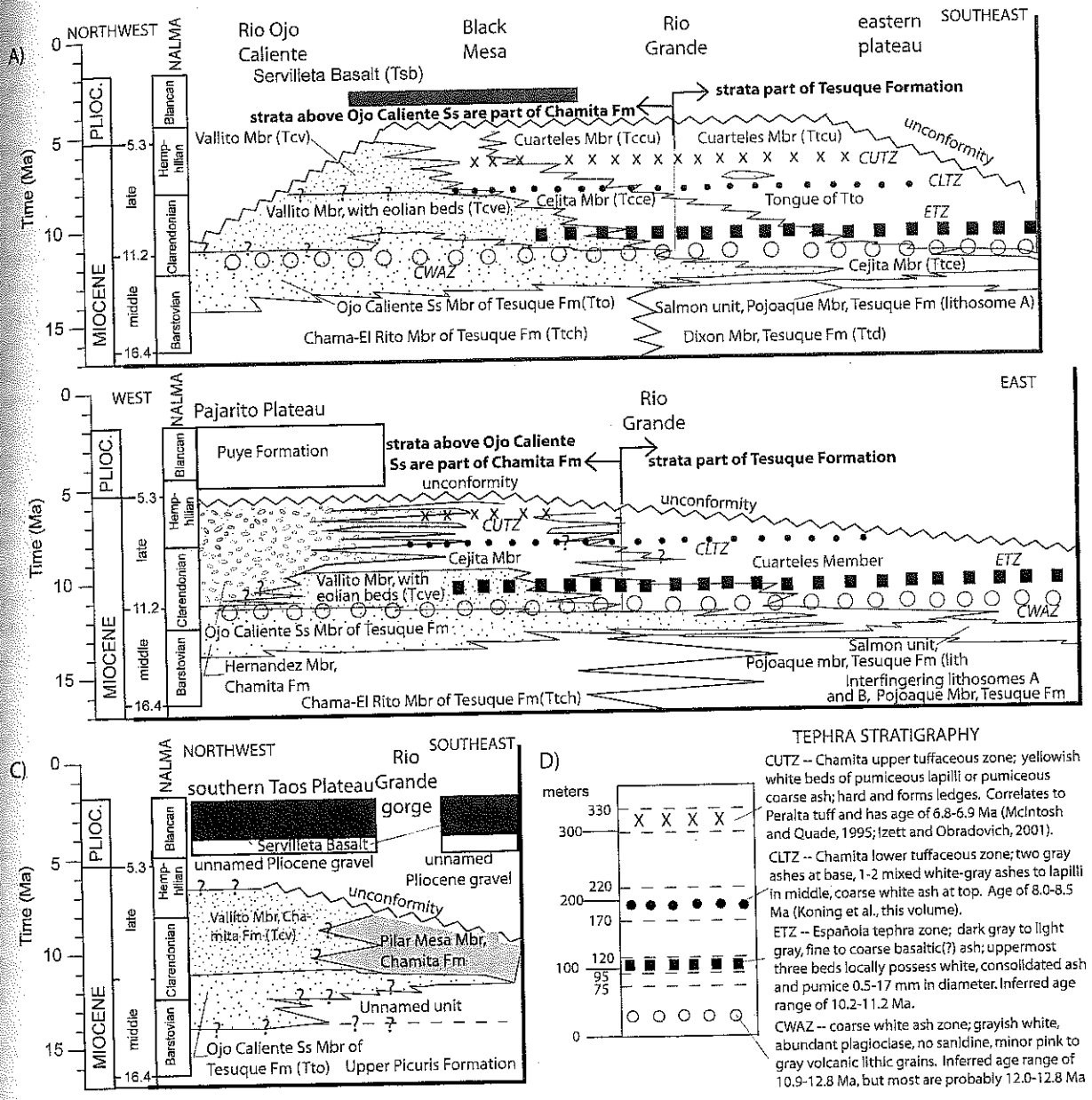


FIGURE 5. Schematic cross-sections illustrating stratigraphic relations for middle to upper Miocene members of the Chamita and Tesuque Formations for different latitudes in the Española basin: A) north of the city of Española near the northern boundary of map in Figure 3; B) through the city of Española , and C) near Pilar and the western front of the Picuris Mountains. D) shows the tephra symbols used in the above schematic cross-sections. The Pojoaque, Chama-El Rito, and Dixon Members of the Tesuque Formation are described and discussed in Koning et al. (this volume) and Koning et al. (2004c), and references therein. NALMA = North American land mammal "age."

nic rocks (Fig. 6, Table 3). Granite is less than 4% and Paleozoic sandstone-siltstone is generally absent. Combined granite and Paleozoic sandstone is less than 20% of the total gravel, and this serves as a diagnostic criterion in differentiating this unit from the Vallito Member (the latter having greater than 20%). The clast composition of the Pilar Mesa Member also differs from that of the largely volcaniclastic upper Picuris Formation (Aby et al., 2004), particularly in the abundance of locally derived Proterozoic quartzite, schist, and Pilar phyllite in the Pilar Mesa Member.

In general, we agree with the interpretation by Leininger (1982) that the Pilar Mesa Member represents distal or medial alluvial fan deposits flanking the western Picuris Mountains. Bidirectional channel trends are northwest-southeast (Figure 6), but imbrication of gravel 40-50 m below the base of the type section indicates a northwest paleoflow direction in that locality (Kelson and Bauer, 1998). This imbrication direction and the presence of Pilar phyllite is consistent with a Picuris Mountain source, as first recognized by Leininger (1982). We therefore infer a northwest flow direction throughout the section, as illustrated in Figure 6. Along the north flank of the Picuris Mountains, we do not have paleoflow data in the Pilar Mesa Member but suspect that streams there flowed north away from the Picuris Mountains.

The relative abundance of Paleozoic sandstone clasts in some beds indicates possible interfingering of the Pilar Mesa and Val-

lito Member drainage systems near Pilar. However, we infer that most of the interfingering contact is present in the subsurface west of the Rio Grande and beneath Servilleta Basalts and associated Pliocene sediments. The presence of Pilar phyllite clasts in the Vallito Member downstream (south) of Pilar indicates that alluvial fan drainages flanking the Picuris Mountain were contributing Pilar phyllite to the river depositing the Vallito Member, and thus the alluvial fans of the Pilar Mesa Member must have interfingered with the Vallito Member (Tables 3 and 4; Fig. 5). We use this interfingering relationship to interpret that the Pilar Mesa Member has a similar age as the Vallito Member (13-8? Ma).

There is an unnamed unit below intervals of the Ojo Caliente Sandstone in the Rito Cieneguilla drainage east of Pilar Mesa (below the type section of Fig. 6) and west of the topographic front of the Picuris Mountains (Kelson and Bauer, 1998). This unit consists of relatively sparse outcrops of medium to very coarse sand, pebbly sand, and sandy pebbles. Pebbly beds in this unit contain quartzite, felsic and intermediate volcanic clasts, up to 60% Pilar phyllite, up to 25% Paleozoic sandstone, and miscellaneous other Proterozoic and Paleozoic clast types. These sediments seem to grade downward into the upper Picuris Formation. Poor exposure and likely complex but cryptic faulting in this area does not allow one to determine the true thickness of these strata. This unit is undergoing further study, but it seems to represent a gradation between deposits of the upper Picuris Formation and the Pilar Mesa Member of the Chamita Formation.

We maintain that the Pilar Mesa Member is better placed in the Chamita Formation than the Tesuque Formation because it overlies the Ojo Caliente Sandstone and very likely interfingers with the Vallito Member to the west. Although many beds in the unnamed unit below the Ojo Caliente Sandstone are similar to the Pilar Mesa Member and derived from the Picuris Mountains, given sufficient exposure in the unnamed unit there are relatively common beds containing abundant clasts of Paleozoic sandstone and granite. Our study to date suggests that, in general, one should be able to differentiate the Pilar Mesa Member from this unnamed unit.

Leininger (1982) included relatively coarse gravel beds at the top of his stratigraphic section with his Cieneguilla member (our proposed Pilar Mesa Member; Fig. 6). These beds overlie the rest of the exposed section at the southern end of Pilar Mesa over a contact with 15-20 degrees of angular unconformity. We believe these sediments to be inset into the previously tilted and eroded Pilar Mesa Member deposits. These gravelly sediments therefore likely have more chronologic affinity to the sandy gravel beds interbedded in overlying Sevilleta Basalts; in addition, these gravelly units are lithologically similar. For these reasons we exclude the coarse gravels above the angular unconformity from the Pilar Mesa Member.

Vallito Member

We apply the new name of Vallito Member for generally brown, sandy strata in the lower Chamita Formation in the Española basin. It consists of very fine- to medium-grained sand and silty sand,

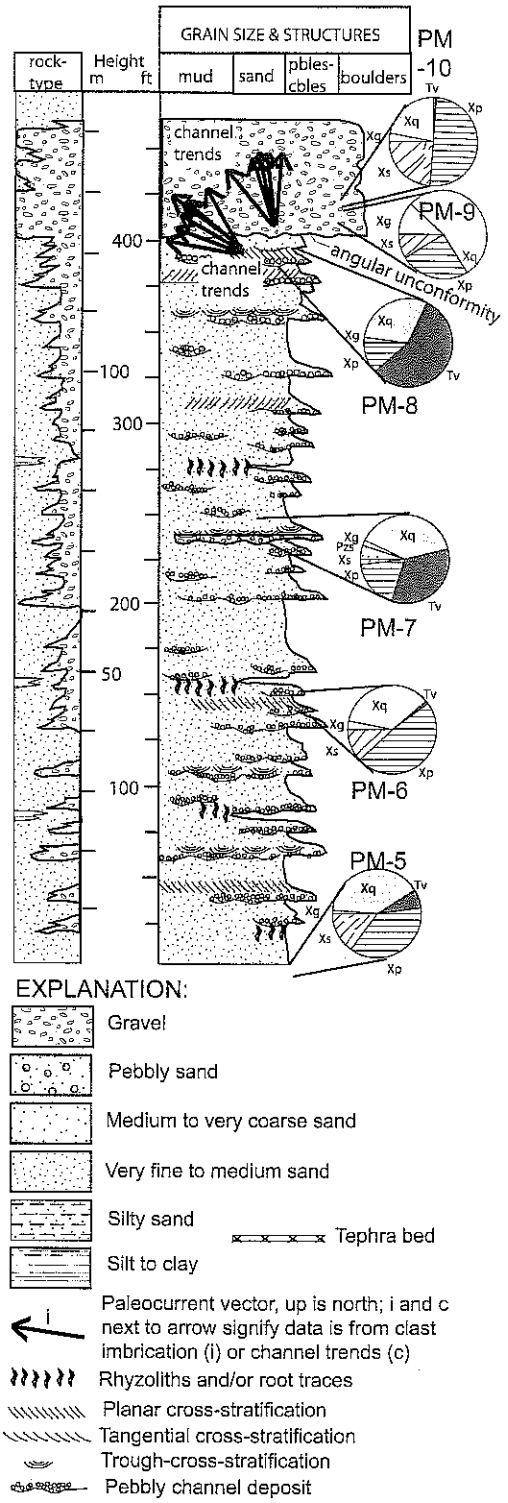


FIGURE 6. Type section of the Pilar Mesa Member of the Chamita Formation. This corresponds with the lower Cieneguilla member stratigraphic section of Leininger (1982); see Figure 2 and that work for location of section. Clast composition pie graph shading scheme follows that of Figure 4. Clast count data for sites PM-5 through PM-10 are presented in Table 3. General clast imbrication near base of section is to northwest, and this and provenance considerations were used to infer a uni-directional, northwest paleoflow direction for the channel trends near the top of the section. Explanation at base of figure explains fill textures and symbols for this and other depicted stratigraphic sections.

fluvially reworked Ojo Caliente Sandstone, cross-stratified eolian sand, minor clay and mud beds, and minor pebbly sand channel deposits, the latter increasing in abundance to the north. Eolian sand beds are minor (~10-15% in the south part of the unit) and commonly restricted to the lower 75-80% of the member, which has a very pale brown to light yellowish brown color (10YR 6/4 and 10YR 7/3-4). The upper part of the member commonly has a redder hue, a greater concentration of silt, and local pebble beds. The Vallito Member extends northeast-southwest as a relatively narrow band (~ 6 km wide) in the north-central Española basin (Fig. 2). It attains a maximum exposed thickness of 150-160 m near the type section.

The Vallito Member type section (Fig. 7) is located on the southwest side of Vallito Peak (Fig. 3), after which the member is named. Here, the sediment lacks pebbles and largely consists of very pale brown (10YR 10/3), very fine- to medium-grained sand and silty sand, with the top ~40 m being reddish yellow to yellowish red (7.5YR 7/6 to 5YR 5/6), silty very fine- to coarse-grained sand. Two other stratigraphic sections are designated as reference sections. One is the section of May (1980) that is located 2 km northeast of Vallito Peak, which is similar to the Vallito section. The other is the Embudo stratigraphic section, located 1 km north of Embudo (Figs. 2 and 8). In the Embudo section, the Vallito Member lacks eolian interbeds and pebbly sand beds are more common than in the Vallito section. The base of the Vallito Member ranges from sharp to gradational (within 2 vertical meters) at and near these three sections. At a location 0.5 to 1.0 km north of the Embodo section, the base of the Vallito Member is noticeably scoured into the Ojo Caliente Sandstone. The top contact of the Vallito Member corresponds to an unconformity, over which generally lies Pliocene-age gravel.

The Vallito Member was extensively described at other exposures as well, and these descriptions were combined with the stratigraphic section data for the following lithologic and sedimentologic summary. The very fine- to medium-grained sand and silty sand are commonly massive or in medium to thick, tabular to broadly lenticular beds. These beds are generally internally massive, although locally there is planar lamination. The pebbly sand deposits are in very thin to thick, broadly lenticular beds with common planar-lamination and low-angle cross-lamination generally less than 20 cm thick. Pebbles are subrounded, moderately to poorly sorted, and generally very fine to medium in size (with minor coarse and very coare pebbles). The pebbles are composed of felsic to intermediate volcanic clasts (7-55%), greenish to brownish Paleozoic sandstone (15-36%), pink to brown granite (5-35%), quartzite (6-28%), and minor amounts of vein quartz (commonly ~5%), Pilar phyllite (0-11%), greenish to yellowish gray siliceous porphyry with quartz phenocrysts (0-5%), and up to 1% gray-white granite to granodiorite (Table 4). No cobbles have been observed in the northern Española basin, but these are likely present to the north. Although there is no significant clast imbrication, channel trends in and near the Embudo reference section trend SSW-NNE (Fig. 8; Koning and Aby, 2003).

The Vallito Member is readily observed under basalt-capped mesas north of Española, where formerly (Table 1) it was provisionally assigned to the Cieneguilla member of Leininger (1982).

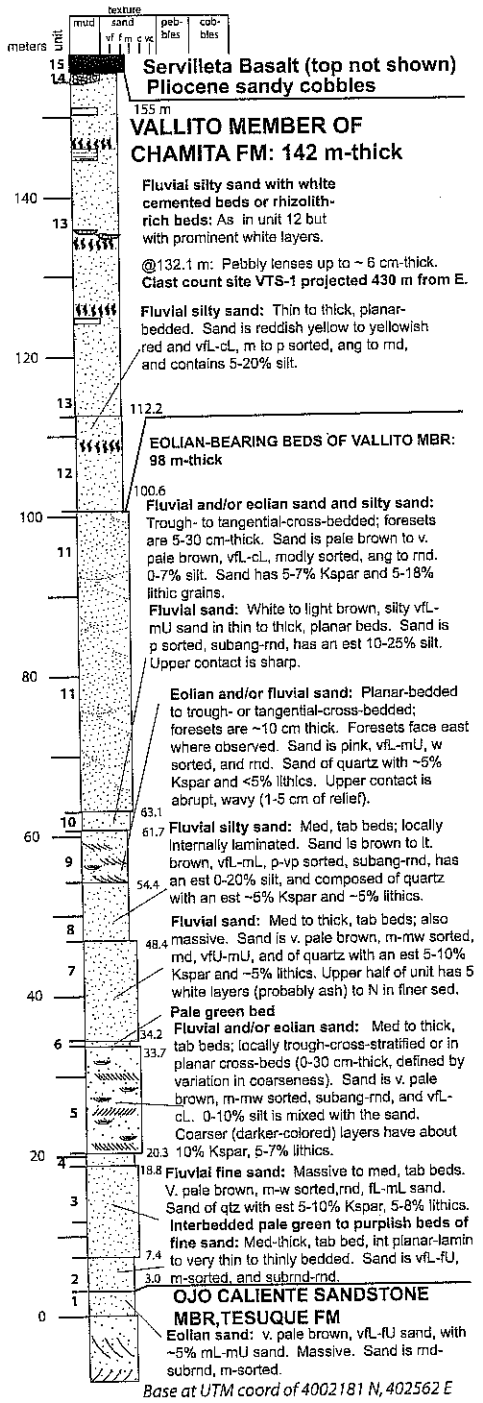


FIGURE 7. Type section for the Vallito Member. See Figure 3 for map location, and Figure 6 for explanation of shading and symbols. Abbreviations used in descriptions are: w = well, modly = moderately, mw= moderately well, p= poorly, vp= very poorly, lt = light, v= very, rnd = rounded, subrnd= subrounded, 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.

TABLE 3. Clast count data for type section of Pilar Mesa Member, Chamita Formation

Pilar Mesa Member of Chamita Formation

Stratigraphic height of Pilar Mesa Mbr (m)	Clast count site*	Paleozoic sandstone & siltstone (%)	Granite (%)	Proterozoic Quartzite (%)	Felsic to intermediate volcanic rocks (%)	Pilar phyllite (%)	Schist (%)
0	PM-5	0	1	40	7	37	15
44.5	PM-6	0	3	36	1	48	12
76.0	PM-7	5	2	39	34	18	2
119.0	PM-8	0	2	30	57	11	0
Avg:		**0.6**	**2**	**34**	**16**	**36**	**12**

Unnamed Pliocene gravel overlying the Pilar Mesa Member

Stratigraphic height (m)**	Clast count site*	Paleozoic sandstone & siltstone (%)	Granite (%)	Proterozoic quartzite (%)	Felsic to intermediate volcanic rocks (%)	Pilar phyllite (%)	Schist (%)
124**	PM-9	0	12	54	0	25	9
125**	PM-10	0	3	22	1	50	24
Avg:		**0**	**7.5**	**38**	**1**	**38**	**17**

Notes:

* Clast count site labeled on Figure 6.

** These clast count sites are from Pliocene gravel that overlie the Pilar Mesa Member; height measured from the base of the section (see Figure 6).

TABLE 4. Clast count data for Vallito Member, Chamita Formation

Clast count site	UTM coordinates (zone 13, NAD 27)	Paleozoic sandstone and siltstone (%)	Granite (%)	Vein quartz (%)	Proterozoic quartzite (%)	Felsic to intermediate volcanic rocks (%)	Pilar phyllite (%)	Other
SAV-25	4010075 421300	26	14	0	18	35	7	
SAV-26	4009075 417550	15	11	0	28	35	11	
SAV-27	4009000 417225	33	35	0	23	9	0	
SCV-1618	4006860 415170	36	8	3	25	28	0	1% felsic hypabyssal intrusive clast
SCV-1502	4004550 412020	34	24	2	28	7	3	4% Paleozoic limestone
SCV-1608	4006550 412110	27	22	7	12	31	1	
SCV-1704	4007695 410755	34	13	9	12	24	2	2% Paleozoic limestone, 2% gneiss, 1% muscovite schist
SCV-1640	4006440 413300	15	18	3	6	55	3	4% gneiss
SCV-1702	4003000 410645	29	27	4	11	17	5	1% seritized granite, 2% felsic hypabyssal intrusive, and 5% siliceous porphyry with quartz phenocrysts
VPS-1	4007695 410755	25	5	23	18	26	1	1% unidentified, 1% cherty quartz
ES-1	4008880 417500	17	21	3	11	40	0	1% white quartz monzonite, 2% mylonite, 5% siliceous porphyry with quartz (minor biotite) phenocrysts
Avg:		***26%***	***18%***	***5%***	***17%***	***28%***	***3%***	***3%***

However, recent work demonstrates that the alluvial fan deposits of the Pilar Mesa Member (Cieneguilla member of Leininger, 1982) are lithologically distinct from sediment of the proposed Vallito Member (Tables 2-4). In particular, the Vallito Member contains significantly more Paleozoic sandstone (15-36%) and granite (8-35%). A gravel composition of 20% combined granite and Paleozoic sandstone serves as a lithologic distinction between the Vallito and Pilar Mesa Members. In addition, locally in the Vallito Member there is a distinctive greenish to yellowish gray porphyry with quartz phenocrysts. This type of clast has not been noted in the Pilar Mesa alluvial fan deposits or in deposits derived from the Peñasco embayment. However, the clast type has been observed in the San Luis basin in Pliocene-age deposits derived from the Taos Mountains, and also in late Quaternary Rio Grande terrace deposits (Koning and Aby, 2003, table 1).

Strata of the Vallito Member are interpreted as primarily basin floor deposits deposited by a river that drained the southern San Luis basin. The river was probably wide and braided, and its bed load dominated by sand. As discussed in Koning et al. (2004c – where the unit is called the Cieneguilla member), the clast composition is consistent with the interpretation that the river was sourced in the San Luis basin, with some contribution from the Picuris Mountains and possibly the southeastern Tusas Mountains. This interpretation is supported by the local presence of the quartz phenocryst-bearing porphyry clasts derived from the Taos Range, the general absence of limestone clasts (2 and 4% at two localities) which are more common in sediment derived from the Peñasco embayment (2-20% and generally subequal to sandstone, Table 5), and the presence of this unit north of Embudo, where channel trends are to the SSW-NNE.

The Vallito Member probably spans the entire length of the central Española basin in outcrop and in the subsurface, and extends into the southern San Luis Basin (Fig. 2). This unit is not exposed in the San Luis basin, but likely correlates with upper middle(?) to upper Miocene fluvial strata overlying the Ojo Caliente Sandstone of the Tesuque Formation, as is observed in boreholes (Drakos et al., 2004). West of Española, the Vallito Member contains more pebbles than under southern Black Mesa. These pebbles consist of intermediate to felsic volcanic rocks, and likely reflect input of detritus from one or more streams draining the Abiquiu embayment prior to the establishment of the more powerful river represented by the Hernandez Member (described below). Beneath the Puyé Formation near Los Alamos, we suspect that the Vallito Member correlates to much of the fine-grained sediment that underlies coarser volcaniclastic fanglomerate (Broxton and Vaniman, in press). The nature of the basal contact of the Vallito Member near Los Alamos is not known because the Ojo Caliente Sandstone probably does not extend that far south (see Galusha and Blick, 1971). There, it is possible that a slightly coarser Vallito Member directly overlies a slightly finer Chama-El Rito Member of the Tesuque Formation.

The Vallito Member has an interpreted age range of 13-8 Ma in the northern Española basin. On the western slopes of Black Mesa, this unit contains fossils that are reportedly Hemphillian in age, particularly because of the appearance of sloths (Galusha and Blick, 1971; Richard Tedford, personal commun., 2005). In this area, the Vallito Member overlies Ojo Caliente Sandstone. Southwest of Black Mesa, in a location approximately 1-2 km south of Chili (Fig. 2), the Vallito Member interfingers with the Cejita Member. Approximately 40 m of these interfingering strata underlie a Lobato Formation basalt flow dated at 9.6 ± 0.2 Ma Ma (Baldridge et al., 1980), and locally the Vallito Member occupies the same stratigraphic position as this flow. Immediately northwest of Española (Stop 1 in the First Day Road log; fig.

TABLE 5. Clast count data for Cejita Member, Chamita Formation, in Gaucho and Hernandez Sections

Stratigraphic section Unit	Granite (%)	Paleozoic limestone (%)	Paleozoic sandstone and siltstone (%)	Proterozoic quartzite (%)	Felsic to intermediate volcanic rocks (%)	Vein quartz (%)	Other (%)
H-9d*	7	0	21	46	5	5	16**
H-6 (est)	0		undivided	50	5-10	15	
H-9b (est)	4	19		56	0	5	2***
H-3	1	14	30	55	0	0	
G-12	14	17	10	44	3	13	1****
G-10a[µ]	13	2	13	55[µ]	7	4	6^
G-5a	3	12	11	35	38	2	

Notes:

Est = estimated using percentage charts

Pie graphs for units G-5a and H-6 (est) are not shown on Figure 9 due to space limitations.

*Unit represents bed(s) of an ancestral Rio Grande derived from the San Luis Basin.

** Other clasts include 1% muscovite schist, 1% biotite-rich, reddish, mafic rock, 2% gneiss with quartz, plagioclase, and biotite, 1% biotite-granodiorite, 1% gabbro, 4% white granite to white quartz monzonite, 1% unidentified, and 5% slightly greenish, white siliceous porphyry with quartz phenocrysts.

*** Other clast includes a possible hyperbyssal rock and an unidentified mafic rock.

**** Other clast is grayish quartz- and biotite- bearing, siliceous porphyry.

[µ] Counted pebbles are only very fine to medium in size and may be skewed toward having more abundant quartzite.

^Other clasts include 1% un-identified mafic rock, 1% muscovite schist, 1% mylonite, 1% foliated biotite, 1% white granite, and 1% siliceous porphyry or hypabyssal intrusive.

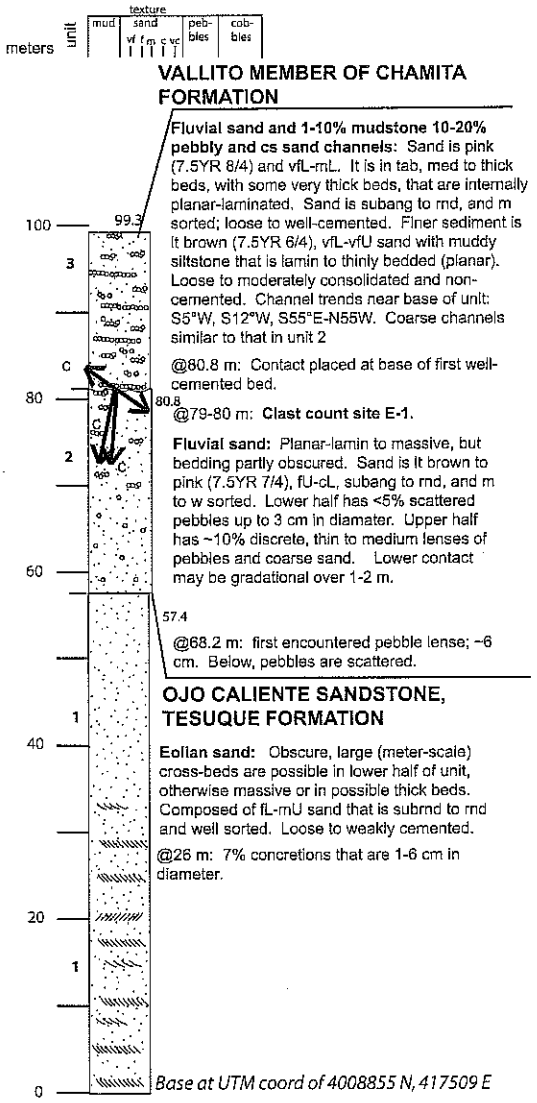


FIGURE 8. Embudo stratigraphic reference section for the Vallito Member. See Figure 2 for map location. Key for symbols and fill textures given in Figure 6. Abbreviations in descriptive text explained in Figure 7 caption. UTM coordinates are in NAD 27 and zone 13.

2 of Koning et al., this volume), at least 40-50 m of the Vallito Member underlie the coarse white ash zone described in Koning et al. (2004c), which has an interpreted age range of 10.9-12.8 Ma (Koning et al., this volume). Since Hemphillian fossils have been found in the Vallito Member, its minimum age is 9-5 Ma (very likely closer to 9 Ma).

Cejita Member

The Cejita Member of the Chamita Formation is characterized by 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. In the Tesuque Formation, east of the Rio Grande, a type section for the Cejita Member type section has already been established (Manley, 1976). However, we designate the 20-177 m interval (70-580 ft) in the Chamita Formation type section (Fig. 4) as a reference section for the Cejita in the Chamita Formation. This member is also observed in the Gaucho and Hernandez stratigraphic sections (Fig. 9; full text descriptions in Koning et al., 2005).

The stratigraphic relations of the Cejita Member with other units are as follows. East of the Rio Grande, the Cejita Member interfingers to the southeast with the piedmont facies of Manley (1976, 1977, 1979), renamed the Cuarteles Member by Koning et al. (this volume). The interfingering of these two units is also observed in the Chamita Formation beneath the eastern slopes of southern to central Black Mesa (Fig. 5). To the northwest, the Cejita Member interfingers with the Vallito Member (Fig. 5; Koning and Aby, 2003; Koning et al., 2004c). The base of the Cejita Member gradationally overlies the Vallito Member west of the Rio Grande, and its top lies beneath Pliocene gravel across an angular unconformity; this Pliocene gravel is found near the top of Black Mesa beneath the Servilleta Basalt.

The lithologic and sedimentologic characteristics of the Cejita Member in the Chamita Formation are generally similar to that member in the Tesuque Formation. 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 (Fig. 10). 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; Table 5; Figs. 4 and 9). The proportion of quartzite in the Cejita Member near and above the Chamita lower tuffaceous zone (40-60%), represented in the clast counts of Table 5 and pie graphs of Figures 4 and 9, is greater than that observed near the base of the Cejita Member east of the Rio Grande (12-26%; Koning et al., this volume). The gravel is clast-supported, locally imbricated, subrounded to rounded, poorly to moderately sorted, and consists of pebbles and fine cobbles. Maximum clast sizes average about 9 cm (intermediate axis) near the Chamita stratotype (Koning et al., 2004c) but are typically 3-6 cm south of the Rio Chama. 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). The Chamita Formation type section (Fig. 4) and cross-sections in Koning et al. (2004c) indicate an approximate thickness of 150-200 m for the unit where it is exposed.

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 9 and Table 5, 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

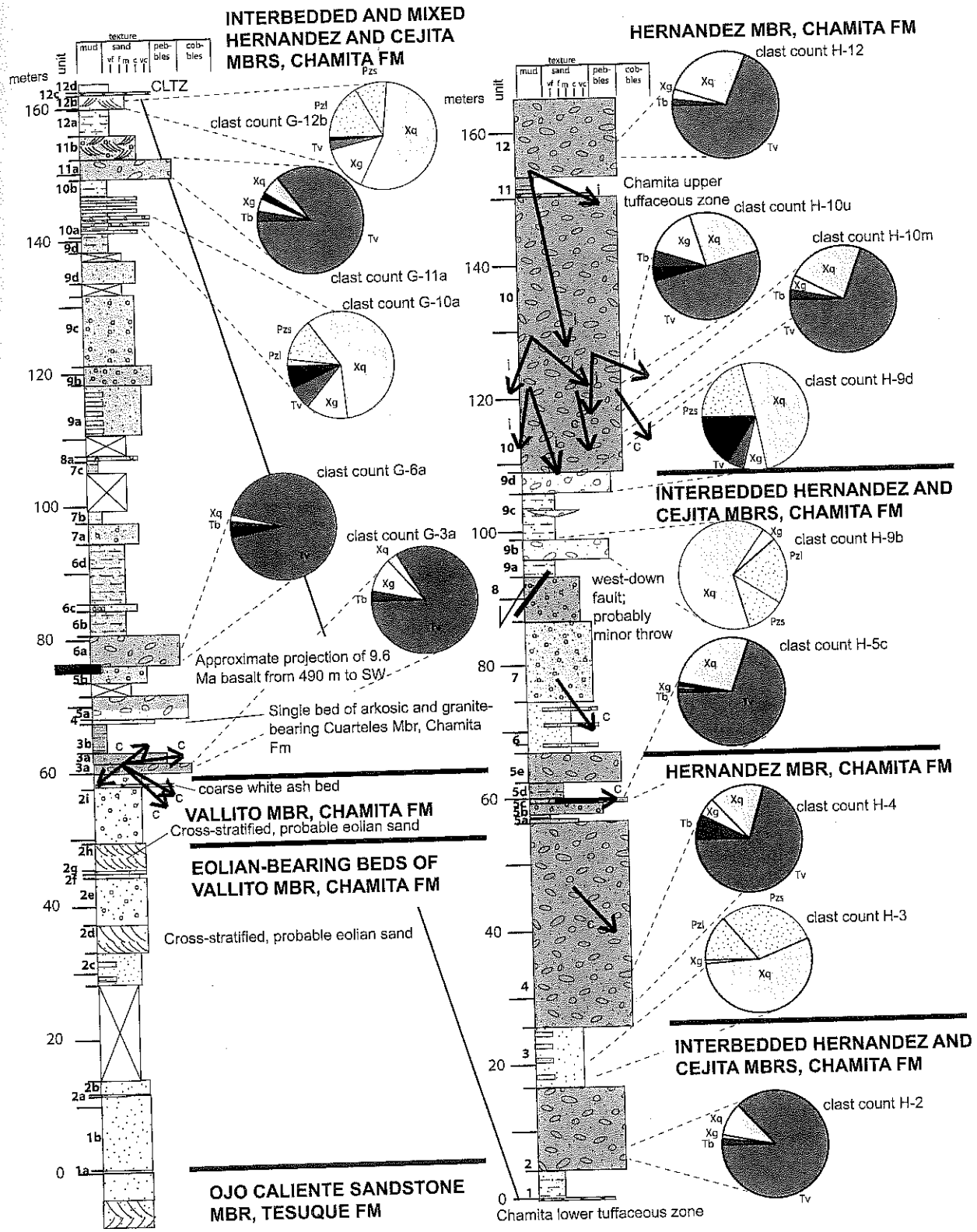


FIGURE 9. Graphic columns illustrating the Gaucho and Hernandez stratigraphic sections. Full descriptions provided in Koning et al. (2005). Paleocurrent directions are shown by heavy black arrows (scaled in proportion to number of measurements, 10 per bin), and relative clast composition is shown by 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 and unit shading are in Figure 4; key for symbols and fill textures is given in Figure 6. Clast count data presented in Tables 5-7. See Figure 2 and fig. 2 of Koning et al. (this volume) for map location. UTM coordinates of base: 3,985,332 N, 398,325 E (Zone 13, NAD 27).

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.

We interpret the age range of the Cejita Member in the Chamita Formation to be ~12.8 to 5.8 Ma. The coarse white ash zone (CWAZ) is found in the Cejita Member immediately northwest of Española (see fig. 2 of Koning et al., this volume). Considering the interpreted age range for the main part of this tephra zone (10.9-12.8 Ma; Koning et al., this volume), the base of the Cejita Member in the Chamita Formation is probably as old as 12.8 Ma. The Chamita lower tuffaceous zone (8.0-8.5 Ma; McIntosh and Quade, 1995) is present in the Cejita Member as well (Figs. 4 and 9). The Cejita Member likely is as young as ~5.8 Ma, since that is the minimum age of the Cuarteles Member and the two interfinger with one another.

Cuarteles Member

Koning et al. (this volume) assign the Cuarteles Member (new name) of the Tesuque Formation to arkosic, granite- and quartzite-bearing sediment that is well-exposed in Arroyo de Cuarteles, located 4.5-5.0 km east of Española (the name is Quarteles on the San Juan Pueblo 7.5-minute topographic map, but the local population spells it as Cuarteles and that convention is followed here). The part of the Chamita Formation type section above 177 m (580 ft) is designated as a reference section for the Cuarteles Member in the Chamita Formation west of the Rio Grande (Fig. 4). However, the bedding style, composition, and color of the Cuarteles Member in the Chamita Formation type section are similar to Cuarteles Member strata exposed in Arroyo de Cuarteles. The Cuarteles Member in the Chamita Formation attains a maximum thickness of 200-250 m. It is best observed near the Chamita Formation stratotype, but is also locally exposed along the eastern slopes of southern to central Black Mesa and immediately northwest of Española (see fig. 2 of Koning et al., this volume; Koning, plate 11 in Brister et al., 2004 – where unit is called lithosome A).

This member was formerly referred to as the coarse upper unit of lithosome A (Koning and Manley, 2003; Koning and Maldonado, 2001; Koning, 2002; Koning, 2003a). It is compositionally similar to lithosome A of Cavazza (1986) in the underlying Pojoaque, Skull Ridge, and Nambe members of the Tesuque Formation. However, the Cuarteles Member differs from these underlying members in that it has larger clasts and more abundant coarse channel complexes (the latter generally exceed 10-20% of the total sediment volume). Immediately east of Black Mesa near the Chamita Formation stratotype, the Cuarteles Member is locally dominated by silty fine sand and silty sand, with only 3-20% coarse channels.

The Cuarteles Member of the Chamita Formation consists of light brown to reddish yellow (7.5YR 6/4-6) to pink (7.5YR 7/3-4), silty sand and sandy silt in tabular, thin to thick beds; in these beds are minor coarse- to very coarse-grained sand and locally scattered pebbles. There are subordinate channel complexes of pebbly sand and clast-supported sandy gravel. These channel complexes are tabular to broadly lenticular, but internal

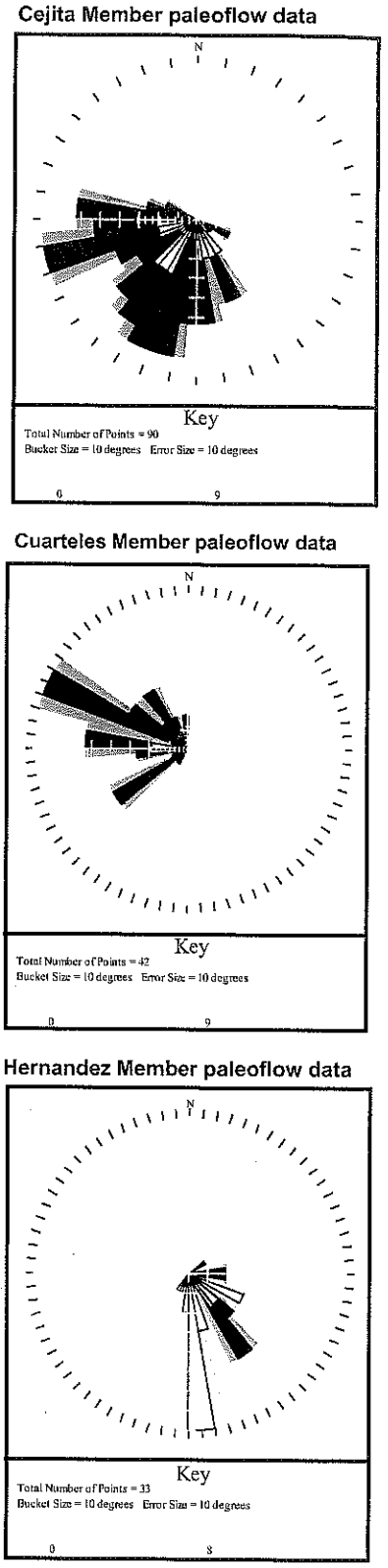


FIGURE 10. Rose diagrams illustrating paleoflow directions for the Cejita, Cuarteles, and Hernandez Members of the Chamita Formation. White shade outlined in black represents mono-directional data from clast imbrication and trough cross-stratification. Black shades represent all measurements (both bi- and mono-directional, the direction of the former constrained by the latter and by provenance considerations). Gray shading shows the ± 10 degree estimated error in the measurements.

bedding is laminated to very thin-medium, planar to lenticular. Gravel generally consists of poorly to moderately sorted, subrounded to subangular pebbles, but minor cobbles are locally present. The maximum intermediate clast diameters near the Chamita Formation stratotype average about 8 cm (Koning et al., 2004c). Clast composition is granite with about 15-40% quartzite. Sand is mostly very fine- to medium-grained outside of the coarser channel complexes and subangular to subrounded, moderately to poorly sorted, and arkosic. Paleocurrent data indicate a west-northwest flow direction (Fig. 10); these data together with the granite-dominated composition of the gravel support a provenance from the Sangre de Cristo Mountains south of the Peñasco embayment (Fig. 1).

The stratigraphic and age relations of the Cuarteles Member are as follows. This member interfingers with the Cejita Member to the northwest under the southern and central parts of Black Mesa (Fig. 5). The Cuarteles Member west of the Rio Grande generally underlies Pliocene gravel across an angular unconformity (this Pliocene gravel is overlain by the Servilleta Basalt that caps Black Mesa), and the base of the Cuarteles Member is gradational with the underlying the Cejita Member. At the Chamita Formation type section, the minimum age of the Cuarteles Member is ~5.8 Ma based on $^{40}Ar/^{39}Ar$ dating of tephra beds and consequent magnetostratigraphic revisions (McIntosh and Quade, 1995; we used the geomagnetic polarity time scale of Cande and Kent, 1995). West of the Rio Grande, the lowest beds of the Cuarteles Member are found ~60-80 m stratigraphicly above the CWAZ, the bulk of which was probably deposited 10.9-12.8 Ma (Koning et al., this volume). These stratigraphic relations and age control indicate that the Cuarteles Member in the Chamita Formation has an age range of 11-5.8 Ma.

Near the Chamita Formation stratotype, careful mapping of the base of the Cuarteles Member indicates that it is time-transgressive (i.e., it progrades and becomes younger to the west; Figs. 3-5; Koning and Manley, 2003). The Chamita lower tuffaceous zone (CLTZ) is located within the Cejita Member, but the basal Cuarteles Member contact is only 65-70 m above it in the southeastern part of the Chamita badlands (i.e., where the Chamita Formation type section was measured; Figs. 3-4). The age of the Chamita lower tuffaceous zone is 8.0-8.5 Ma (McIntosh and Quade, 1995; MacFadden, 1977; Cande and Kent, 1995; Koning et al., this volume). Thus, at 8.0-8.5 Ma the boundary between the Cuarteles and Cejita depositional systems was located to the east of the Chamita Formation stratotype, probably a few km east of the present Rio Grande (consistent with map data of Koning and Manley, 2003). The Chamita upper tuffaceous zone (CUTZ) is all within the Cuarteles Member in the easternmost part of the Chamita badlands (Fig. 4), but at a longitude coinciding with the San Juan fossil quarry (Fig. 3) the lower portions of this tephra zone are in the Cejita Member. Thus, at 6.8-6.9 Ma, the age of the CUTZ (McIntosh and Quade, 1995; Izett and Obradovich, 2001), the western margin of the Cuarteles Member was within a kilometer of the present eastern margin of Black Mesa. After 6.8 Ma, the Cuarteles Member extended westward under the present eastern margin of southern Black Mesa (Fig. 3).

Hernandez Member

The Hernandez Member consists of interbedded gravelly, volcaniclastic channel fill and fine-grained deposits; it was introduced and briefly described by Koning et al. (2004c). The type section for the Hernandez Member is herein designated from 109 to 165 m in the upper Hernandez stratigraphic section, which is in an unnamed arroyo 1.4 km west of the Capilla de San Jose in the town of Hernandez (Fig. 9; fig. 2 of Koning et al., this volume). The Arroyo de la Presa stratigraphic section shows the lower part of the Hernandez Member and its basal contact (Fig. 11). Here, very fine- to medium-grained sand, with minor silty sand, are interbedded with subordinate pebbly channel fill deposits. The sand is light yellowish brown to very pale brown (10YR 6/4 and 10YR 7/3), and locally may contain fluvially reworked Ojo Caliente Sandstone. Grains are subangular to rounded and poorly to well sorted. Clasts in the channel deposits are subangular to rounded, poorly sorted, and composed of 2-7% Proterozoic quartzite, 8-13% basalt to basaltic andesite, and 80-90% felsic to intermediate volcanic rocks (Table 6). The lower part of the Hernandez Member is also illustrated in the Gaucho section (Fig. 9), where it interfingers with the Cejita Member (see also Fig. 5). The Hernandez stratigraphic section, 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 (Fig. 9).

Both the upper and lower contacts of the Hernandez Member can be observed west of Española. The upper contact of the Hernandez Member is an angular unconformity beneath the Puyé Formation. Nine to ten kilometers up Rio del Oso (Fig. 2; Koning et al., 2005), on the immediate footwall and hanging wall of the Cañada del Amalgre fault, the Hernandez Member lies below, and also is interbedded with, Lobato Formation basalt flows (Koning et al., 2005). Beneath one Lobato Formation basalt flow, 70 cm of pebbly sand of the Hernandez Member overlies the Ojo Caliente Sandstone.

The three aforementioned stratigraphic sections (Figs. 9 and 11) collectively show that the Hernandez Member consists of 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%) (Tables 6-7). Maximum gravel sizes range from 5 to18 cm (intermediate clast axis; Fig. 12). Sand in the coarse channels is gray to brownish gray to grayish brown (2.5Y-10YR 5-6/1-2;

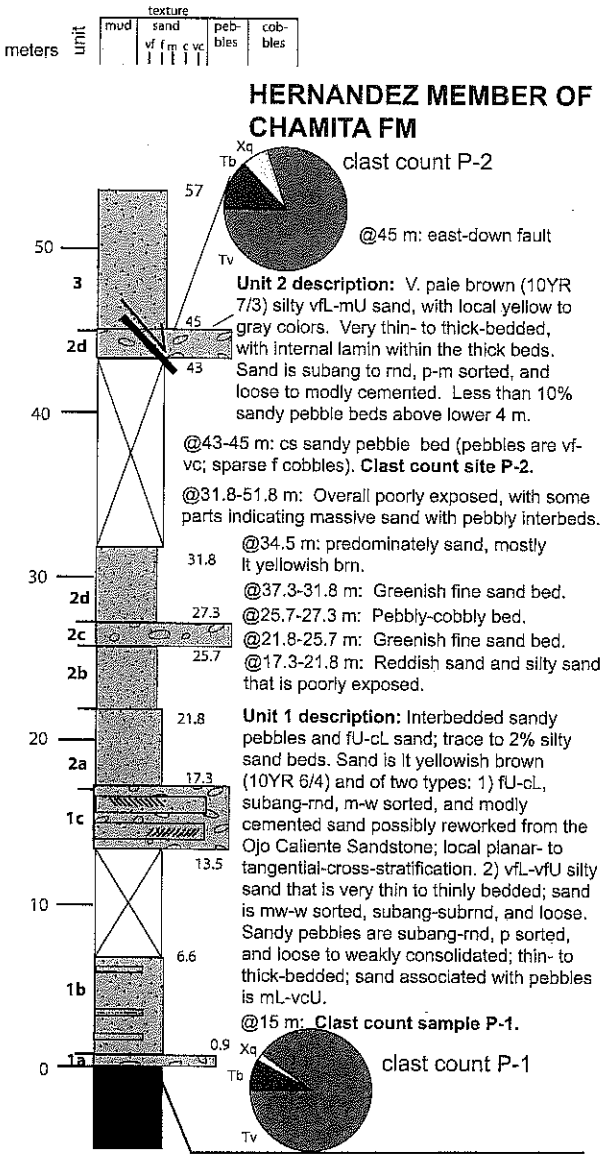


FIGURE 11. Arroyo de la Presa stratigraphic section, showing the lower, finer part of the Hernandez Member overlying a Lobato Formation basalt flow dated at 11.9 ± 0.3 Ma (Dethier et al., 1986). This flow provides a lower age limit for the Hernandez Member. See Figure 2 and fig. 2 of of Koning et al. (this volume) for map location. Explanations for clast composition pie graphs and unit shading are in Figure 4, and key for symbols and fill textures is given in Figure 6. Abbreviations in descriptive text explained in Figure 7 caption. Clast count data presented in Tables 6 and 7. See Figure 2 and fig. 2 of Koning et al. (this volume) for map location. UTM coordinates are in NAD 27 and zone 13.

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 (Fig. 10; Koning et al., 2005).

From data presented in these three stratigraphic sections, it is evident that quartzite increases up-section from 2-7% to 22-27% (Table 6). There is also an upward increase in clast size along with the relative proportion of coarse channel deposits (Figs. 9 and 12). For example, in the upper 50 m of the Hernandez section, gravelly channel deposits comprise greater than 90% of the member, whereas these coarse channels are less common near the base of the member in the Gaucho and Arroyo de la Presa sections.

Clast composition and paleocurrent data of the Hernandez Member can be used to interpret the provenance of the fluvial system which deposited it. Given the south-southeast paleocurrent data, it is reasonable to interpret that the sediment was derived from the north-northwest. The volcanic and quartzite gravel of the Hernandez Member is similar to rock types seen in the Tusas Mountains and Abiquiu embayment, but is dissimilar to the typical clasts found in the Cuarteles, Cejita, and Pilar Mesa Members. The Tusas Mountains have abundant Proterozoic quartzite in addition to other Proterozoic metasedimentary rocks that underlie remnants of mid-Tertiary volcaniclastic units (New Mexico Bureau of Geology and Mineral Resources, 2003). However, there are no known quartzite outcrops in the Jemez Mountains nor has quartzite bedrock been encountered in drill holes (D. Broxton, written commun., 2005). The largely intermediate composition of the volcanic clasts in the Hernandez Member is consistent with those of the Conejos and Los Pinos Formations in the Tusas Mountains. Some of the quartzite and volcanic rocks in the Hernandez Member may also be derived from reworking of basin fill from the Abiquiu embayment (in particular, the Chama-El Rito Member of the Tesuque Formation and the middle-upper Abiquiu Formation), which are generally dominated by felsic-intermediate volcanic rocks and have less than 5-10% quartzite. Locally, very sparse clasts of welded tuff that contain chatoyant

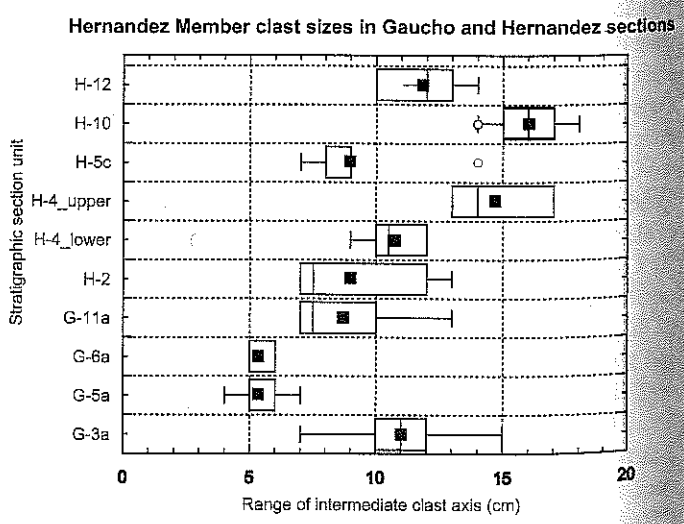


FIGURE 12. Box and whisker plot illustrating clast sizes of the Hernandez Member in the Gaucho and Hernandez sections. Small, filled square represents the mean, the vertical line in the larger rectangle is the median, the length of the larger rectangle represents the upper and lower quartile (25% above and 25% below the median), the bracket(s) represent the 95% range, and circles are outliers.

TABLE 6. Clast count data for Hernandez Member of Chamita Formation in Gaucho, Hernandez, and Arroyo de la Presa stratigraphic sections

T Strat section unit*	Basalt and basaltic andesite (%)	Granite (%)	Hypabyssal intrusive rock (%)	Proterozoic quartzite (%)	Felsic to intermediate volcanic rocks (%)	Other (%)
H-12	2	3	0	26	69	0
H-10u	5	15	0	25	50	4% blue qtz
H-10m	3	4	0	22	66	0
H-5c	1	1	1*	27	69	1 un-i.d.
H-4	7	5	0	15	65	1 quartz
H-2	2	1	0	10	87	0
G-11a	3	4	2	6	87	0
G-6a	2	0	1	2	93	2 volcaniclastic sandstone
G-3a	3	10	0	3	81	3% Paleozoic sandstone
P-2	13	0	0	7	80	0
P-1	8	0	0	2	90	0

sanidine are present; these are likely the Amalia Tuff and possibly derived from the Los Pinos Formation (Cordito Member; Manley, 1981) or the Abiquiu Formation. Basalt clasts may be partially derived from the Lobato Formation basalt or possibly from the Hinsdale Basalt. We cannot rule out a partial Jemez Mountains source for the volcanic rocks.

The Hernandez Member extends south to White Rock Canyon, where it appears to be interbedded with locally derived volcaniclastic fanglomerate shed from the Jemez Mountains (Broxton and Vaniman, in press); we do not include this fanglomerate with the Hernandez Member because it likely warrants a separate member-rank status. The Hernandez Member possibly is present as far west as Abiquiu. Rounded fluvial gravel, consisting largely of volcanic rocks, locally underlies the Lobato Formation south of Abiquiu. At one locality, minor quartzite appears to be mixed with the volcanic gravel (QVG in Fig. 2), although exposure is poor here (Kirt Kempter, personal commun., 2005). We infer that these gravel deposits south of Abiquiu can be correlated with the Hernandez Member where quartzite clasts are present.

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 (Fig. 12), particularly in its upper part where there is common clast imbrication, indicates relatively high stream power. Given our interpretation of the origin of the quartzite clasts, this fluvial system had its headwaters in the Tusas Mountains. The presence of quartzite-bearing volcaniclastic gravel south of Abiquiu implies that at least one stream of the Rio Chama drainage may have drained the southwest part of these mountains. Drainages in the vicinity of El Rito and the Rio Ojo Caliente, tributaries to the modern Rio Chama, were also likely present and contributed detritus to the Hernandez Member from the southeastern Tusas Mountains.

The Hernandez Member ranges in age from 10-12 Ma to less than 6.5-7 Ma. In the Arroyo de la Presa section, the base of the Hernandez Member lies immediately above a basalt flow dated by K-Ar methods at 11.9 ± 0.3 Ma (Fig. 11; 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 Canada del Amalgre 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 (Fig. 9). 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. The tephra of the Chamita upper tuffaceous zone is noteworthy because such coarse pumice is absent in lower tephra beds near Española, except locally in the dark gray beds of the Española tephra zone that are ~200 m below this pumiceous tephra. This pumiceous tephra bed is approximately 100 m below the inferred top of the Hernandez Member at the Santa Clara fault zone.

VERTICAL SEDIMENTOLOGIC AND LITHOLOGIC CHANGES IN THE CHAMITA FORMATION

Two vertical changes occur in the Chamita Formation that are worthy of discussion. One is an upward decrease in the relative proportion of eolian interbeds. Minor eolian interbeds are present in the lower 65-80% of the Vallito Member in its southern extent, but are not usually present in its uppermost part. The simplest explanation for this is that eolian activity diminished after the deposition of the lower-middle part of the Vallito Member. South of the Rio Chama, where age control is better than to the north, eolian interbeds are restricted to 15-45 m below a Lobato Formation basalt flow dated at 9.6 Ma ± 0.2 (Baldridge et al., 1980); this is seen 1-2 km south of Chili and in the Gaucho section (Fig. 9; Koning et al., 2005). Thus, eolian activity seems to have greatly diminished by 9.6-10 Ma south of the Rio Chama, although local eolian dune fields may have persisted a little longer north of the Rio Chama (see discussion of this unit in Koning et al., 2004c, where it is called the Cieneguilla member).

Another important sedimentologic trend is the upward increase in the proportion of quartzite clasts in the gravel of the Cejita and Hernandez Members. In the lower Cejita Member east of the Rio Grande, where it is in the Tesuque Formation and underlies the coarse white ash zone (CWAZ), quartzite clasts comprise 12-26% of the gravel assemblage (Koning et al., this volume). West of the Rio Grande, the Cejita Member is stratigraphically higher because it lies within or above the CWAZ (Fig. 5). A clast count of Cejita Member strata within the CWAZ returned 27%

quartzite. However, the amount of quartzite in the Cejita Member above the CWAZ, as reflected in clast counts in the Gaucho and Hernandez sections (Table 5), is 35-56%. We interpet that the upward increase of quartzite observed in the Cejita Member may reflect progressive unroofing of Paleozoic strata from the quartzite-cored Truchas Peaks or increased erosion in the Picuris Mountains. This unroofing or erosion likely involved deeper incision or elaboration of drainages at these localities.

In the Hernandez Member, clast count data indicate that quartzite comprises 2-10% of the gravel assemblage below the Chamita lower tuffaceous zone (CLTZ). Stratigraphically higher than 50 m above the CLTZ, quartzite abundance increases to 22-27% (Table 7 and Fig. 9). The upward increase of quartzite clasts in the Hernandez Member gravel is likely due to progressive removal of volcaniclastic sediment, volcanic flows, and ignimbrites from the Tusas Mountains to the northwest. These volcanic rocks are primarily intermediate in composition and have been included in the Conejos Formation (29.5-33 Ma, Lipman and Mehnert, 1975; Lipman, 1989; Lipman et al., 1996), Treasure Mountain Group (31.0-28.4 Ma; Lipman and Mehnert, 1975; Lipman, 1975, 1989; Lipman et al., 1996) and the Los Pinos Formation; the latter is interbedded with basalts of the Hindsdale Formation (28-5 Ma; Manley, 1981; Lipman and Mehnert, 1975; Baldridge et al., 1980). Under these volcanic units lie primarily Proterozoic rocks consisting of quartzite together with various metasedimentary and metavolcanic rocks (New Mexico Bureau of Geology and Mineral Resources, 2003), which we interpret became increasingly exposed and eroded with the progressive removal of the overlying volcaniclastic and volcanic rocks. The proposed removal of volcaniclastic sediment from the Tusas Mountains during the late Miocene would indicate that paleoclimatic conditions and relief were such that sufficient discharge and slope were available to streams for erosion and transportation of coarse gravel. Increases in discharge due to stream elaboration and drainage capture are also possible. Furthermore, changes in underlying bedrock type of these streams as they progressively incised may have led to increased stream power (see Kelson and Wells, 1989, for examples of how different lithologic substrates influence stream power). The erosion of Proterozoic quartzite from the Tusas Mountains continued into the late Neogene, as indicated by abundant quartzite clasts in Quaternary gravel deposits of the Rio Chama in the Abiquiu embayment (see Koning et al., 2004a, for clast count data of the Rio Chama terrace deposits).

THICKNESS CHANGES IN THE CHAMITA FORMATION

Thickness comparisons of the Chamita Formation allow for speculative inferences regarding middle to late Miocene tectonic activity. Cross-section data in Koning et al. (2004c) indicate that the cumulative thickness of the Cejita, Vallito, and Cuarteles Members (the latter two are named Cieneguilla and lithosome A units in Koning et al., 2004c) west of the Rio Grande is 410-520 m. Chamita Formation thickness measured in the Gaucho and Hernandez stratigraphic sections total 329 m, or ~ 430 m if one includes estimation of stratal thickness above the top of the Hernandez section. Given these values, the Chamita Formation in the Española basin is of comparable thickness to the underlying Ojo Caliente Sandstone, the latter which is 200-550 m (Koning et al., this volume; Koning et al., 2004c, fig. 3). In the San Luis basin, upper Miocene fluvial strata probably correlative to the Chamita Formation is 200-300 m thick and thinner than the underlying Ojo Caliente Sandstone (>430 m; Drakos et al., 2004). The basal Chamita Formation contact is 11-13 Ma (see discussion of the Vallito, Cejita, and Hernandez Members above; Koning et al., this volume); revised magnetostratigraphic interpretations of the Chamita Formation indicate a minimum age of ~5.8 Ma (McIntosh and Quade, 1995; Cande and Kent, 1995).

The above data give a sedimentation rate of 0.05-0.09 mm/yr for the preserved Chamita Formation in the Española basin, and 0.03-0.05 mm/yr in the San Luis basin, assuming they are of the same age. This rate is slightly less than the sedimentation rate of underlying middle Miocene strata: 0.06-0.16 mm/yr associated with what has been preserved of the Ojo Caliente Sandstone (assuming a maximum age of 13.5 Ma per Koning et al., this volume, and a minimum age of 10 Ma), 0.06-0.7 mm/yr for fluvial strata that interfinger with the Ojo Caliente Sandstone (Koning et al., this volume, table 3), and 0.04-0.7 mm/yr calculated for 14-16 Ma fluvial strata in the Tesuque Formation (Koning et al., this volume). Lower values of stratal accumulation rates for the Chamita Formation compared to earlier strata are consistent with interpretations by Koning et al. (this volume) that asymmetric basin subsidence of the north-central Española basin half-graben was comparably higher before 13-14 Ma than later. This may have created more accommodation for strata predating the Chamita Formation. However, other factors need to be considered in assessing these rates. One factor is the compli-

TABLE 7. Detailed clast count data for Hernandez Member, Chamita Formation

Sample #	Location on stratigraphic sections	Basalt-basaltic andesite	Andesite	Dacite	Welded tuff	Rhyolite	Granite	Pink porphyry	Proterozoic quartzite	Paleozoic sedimentary rocks
P-1	15 m on Arroyo de la Presa section	8%	72%	13%	3%	2%	0	0	2%	0
G-3A	61 m on Gaucho section	3%	43%	29%	2%	7%	10%	0	3%	3%
H-10u	122 m on Hernandez section	5%	38%	8%	0	4%	15%	4%	25%	0

cation posed by local faulting -- both in creating local subsidence next to fault structures for sediment to accumulate, and also in preserving strata after deposition. Other factors include the degree of integration of the axial fluvial system in the middle to late Miocene, changes in local base level in the Rio Grande rift and whether basins were in an overfilled or underfilled condition, and possible climatic changes around 13-14 Ma (Koning et al., this volume).

CONCLUSIONS

A basal contact for Chamita Formation strata west of the Rio Grande is readily identifiable because it overlies the Ojo Caliente Sandstone; however, there are significant problems in mapping a formation-rank contact for chronologically equivalent, coarse fluvial strata east-northeast of Española. Furthermore, lithologic and sedimentologic characteristics of upper middle to upper Miocene, fluvial strata west of the Rio Grande differ from those of the underlying Ojo Caliente and Chama-El Rito Members of the Tesuque Formation. West of the Rio Grande, we thus favor retaining the name Chamita Formation for the predominantly sand and gravel fluvial strata that overlie the Ojo Caliente Sandstone with the following revisions: 1) the formation should be subdivided into the Pilar Mesa, Vallito, Cejita, Cuarteles, and Hernandez Members, and 2) the Cejita and Cuarteles Members should be defined as extending from the Chamita Formation (west of the Rio Grande) into the Tesuque Formation (east of the Rio Grande).

The Chamita Formation generally represents basin floor alluvium that differs lithologically from underlying middle Miocene strata. Distal alluvial slope or alluvial fan deposits are present only near its eastern extent (i.e., Pilar Mesa and Cuarteles Members). The dominant rivers during this time included one extending south from the San Luis basin, one draining the Peñasco embayment and converging with the one draining the San Luis basin, and one draining the Abiquiu Embayment. During the time represented by the Chamita Formation, eolian deposition became less significant and surrounding mountain ranges were increasingly eroded. Our calculation of sedimentation rates indicate lower values in the late middle to late Miocene compared to the early part of the middle Miocene.

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