Miocene stratigraphic relations and problems between the Abiquiu, Los Pinos, and Tesuque Formations near Ojo Caliente, northern Espanola Basin

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MIOCENE STRATIGRAPHIC RELATIONS AND PROBLEMS BETWEEN THE ABIQUIU, LOS PINOS, AND TESUQUE FORMATIONS NEAR OJO CALIENTE, NORTHERN ESPANOLA BASIN

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INTRODUCTION

The complex stratigraphic relations of the Abiquiu Formation, the mid-Miocene part of the Los Pinos Formation, and the Tesuque Formation are locally well exposed in the northern Espanola Basin near Ojo Caliente (Fig. 1). Exposures in this area show that much of the Los Pinos in the Ojo Caliente—Petaca area is equivalent in stratigraphic level and age to the Chama—El Rito Member of the Tesuque Formation (Fig. 2) and most or all of the Abiquiu Formation in the Espanola Basin. In the Ojo Caliente area the Abiquiu and Los Pinos represent a large southwest-sloping fan complex of volcaniclastic conglomerate and sandstone derived from rhyolitic and andesitic terranes to the north and northeast (Manley, 1981). The Tesuque Formation records a large arkosic accumulation of sand carried mainly west and south from Precambrian rocks of the Sangre de Cristo uplift. In the Ojo Caliente area these two alluvial systems merged and intertongued in a complex manner, producing the Chama—El Rito Member of the Tesuque Formation which contains interbedded volcaniclastic gravels and arkosic sandstones of the two systems.

ABIQUIU FORMATION

The Abiquiu Formation (Abiquiu Tuff of Smith, 1938) consists of light-gray, tuffaceous sandstone and minor volcaniclastic conglomerate exposed near the town of Abiquiu and distributed widely throughout the Abiquiu 30-min quadrangle. Only the uppermost part of the Abiquiu is exposed at Ojo Caliente and is composed of andesite- and rhyolite-pebble conglomerate containing sparse pebbles of Precambrian quartzite, metarhyolite, gneiss, and schist. The Abiquiu of this report is restricted to the lower 0-80 m of the roughly 420 m mapped as Abiquiu by Smith (1938) in the Ojo Caliente area. The remaining upper 360 m of volcaniclastic conglomerate and tuffaceous sandstone is considered to be the Los Pinos Formation (Cordito Member?) based on its stratigraphic position and approximate lithologic similarity with the Cordito to the north.

Lithology

Near Ojo Caliente, the Abiquiu contains mainly white, very light-gray, light-brown, and minor red and green layers of tuffaceous sandstone. In the upper 20 m are a few layers of andesite- and rhyolite-pebble conglomerate, sparse fluvial crossbeds, laminar beds and channel-fill structures. Sparse, discontinuous seams of mudstone occur locally. In the lower 40 m, several dark lenses of conglomerate and breccia contain subangular cobbles and fragments of locally derived Precambrian metarhyolite. These lenses are lithologically similar to the Ritito Conglomerate north of La Madera. The best local exposure is 3 km west—southwest of Ojo Caliente in a 70 m section along the north wall of Arroyo El Rito (Fig. 1).

The sandstone is variable in composition, consisting of medium to coarse-grained, subangular to subrounded quartz, K-feldspar and plagioclase, with a few granular fragments of Tertiary sedimentary and volcanic rocks and Precambrian metamorphic rock. Traces of opaque minerals and altered biotite flakes also occur. Larger angular fragments and granules of metarhyolite and pink feldspar occur in minor amounts throughout the sandstone, but generally decrease upward in size and number. The fine-grained interstitial debris in most layers has a tuffaceous appearance.

The Abiquiu appears to thicken greatly from a maximum of 90 m near Ojo Caliente to over 300 m to the west and southwest in the Abiquiu area. The basal contact with the pre-Miocene rocks may drop as much as 200 m because of pre-Abiquiu topography, allowing for the greater thickness to the west.

Contacts

Throughout most of the western Espanola Basin the Abiquiu unconformably overlies pre-Miocene rocks. In the hills west of Ojo Caliente the Abiquiu overlies a mature, early Miocene topography eroded on Precambrian crystalline rock (see third-day road log, this guidebook). This surface locally exhibits up to 300 m of relief. The Abiquiu probably represents the initial major influx of elastic debris that filled the Espanola Basin.

Smith (1938) and Smith and others (1961) recognized a gradational upper contact of the Abiquiu with the overlying Santa Fe Formation. However, in the Ojo Caliente area, the contact they recognized is considered here to be the upper contact of the Los Pinos Formation. Under the more restricted definition of the Abiquiu used here, the Abiquiu grades upward into the Los Pinos in the Ojo Caliente area. To the south and southwest it probably grades upward into the Chama—El Rito Member of the Tesuque Formation of the Santa Fe Group (Fig. 2), although this relationship can be seen only west of El Rito Creek. Galusha and Blick (1971) also reported a slight angular unconformity between the Abiquiu and Chama—El Rito near the "Ojo Caliente intrusive" southwest of the town, but the beds under the unconformity at this location are the tuff-ring facies of the much younger Ojo Caliente tuff ring (May, 1980) and are located in the middle part of the ChamaEl Rito (Figs. 1, 2).

In the Ojo Caliente area the only exposure of the upper contact is 3 km west of town. Here the formation grades up into the Los Pinos through a 40-m section. The very light-gray tuffaceous sandstones gradually turn darker gray and the rhyolite- and andesite-pebble conglomerates gradually increase to the point where they make up a major part of the section. The contact is chosen at approximately 15 m above the lowest volcanic-pebble conglomerate or where the conglomerates make up more than 25% of the section. Although a few of the conglomerates are locally erosional at their bases, the contact exhibits neither significant erosion nor angularity between the underlying and overlying beds.

Age

The Abiquiu ranges from 22 to 17-18 m.y. in age (early Miocene) near Ojo Caliente. Basalt flows of the Hinsdale Formation lie between the Abiquiu and the underlying Precambrian rocks along the north wall of Arroyo El Rito and have been K—Ar dated by Baldridge and others (1980) at 22.1 ± 0.6 m.y. These flows intertongue with thin discontinuous seams of light-gray tuffaceous sandstone, indicating Abiquiu deposition during eruption of the flows. However, the lower part of the Abiquiu in its type area is probably lower stratigraphically and older than the Abiquiu in the Ojo Caliente hills, implying that it is also partly upper Oligocene. Vazzana (1980) inferred a 27-26 m.y. age for the base of the formation to the west.

Age of the upper contact is well constrained locally. Four km west of Ojo Caliente, a small olivine-nephelinite flow on the south slope of Cerro Negro yielded a K—Ar date of 18.9 0.7 m.y. (Baldridge and

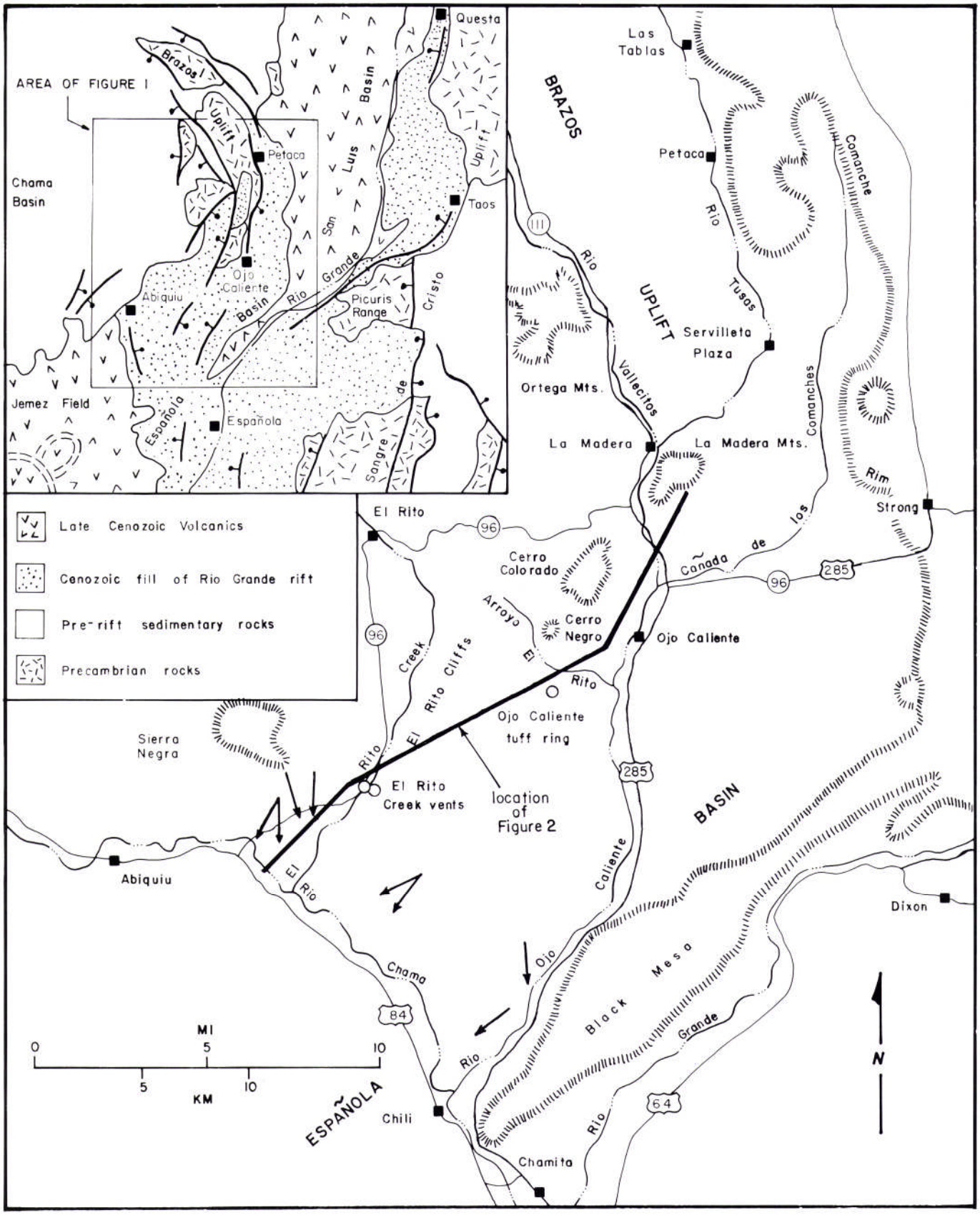

FIGURE 1. Index map of northern Española Basin and southern Brazos uplift showing areas discussed in text. Arrows in southern part of map show paleochannel directions in the Chama–El Rito Member of the Tesuque Formation.

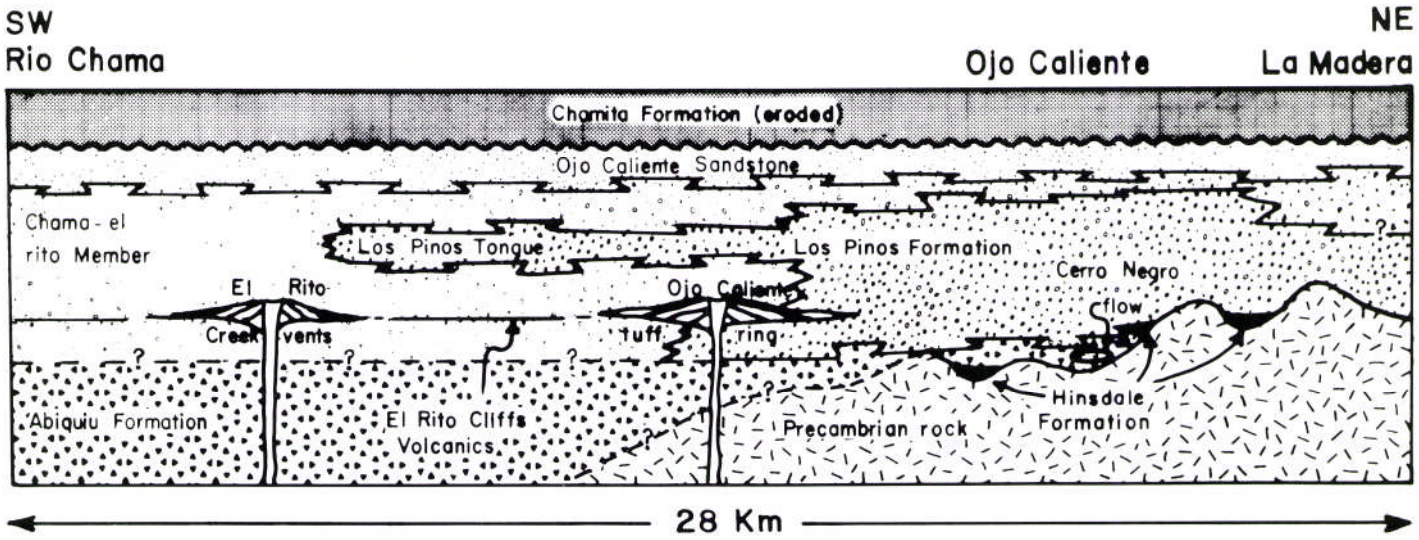

FIGURE 2. Generalized northeast–southwest stratigraphic section of Miocene rocks from La Madera to Rio Chama. Thicknesses not to scale.

others, 1980); this flow occurs approximately 40 m below the top of the Abiquiu, implying an approximate 18 m.y. age for the top. Manley and Mehnert (1981) reported a 17.3 ± 0.8 m.y. K—Ar age on a dacitic clast approximately 10 m below the top of the Abiquiu Formation 7 km northeast of Abiquiu. They also reported a 15.9 ± 0.9 m.y. K—Ar age on a dike that cuts the Abiquiu 6 km north of Sierra Negra, thereby bracketing the age of the upper contact between 17.3 and 15.9 m.y. Since the dike is probably of the same age as the mid-Chama—EI Rito volcanic field of May (this guidebook), the 17.3 m.y. date may approximate the age of the upper contact most closely in this area.

LOS PINOS FORMATION

The Los Pinos Formation, first named Los Pinos Gravel by Atwood and Mather (1932), is composed of conglomerate, sandstone and ash-flow tuff. Interbedded basalt flows are part of the Hinsdale Formation (Lipman and Mehnert, 1975). On the east side of the Tusas Mountains, the formation forms an eastward-thickening wedge of volcaniclastic debris carried south by Miocene and Pliocene streams flowing out of the late Tertiary San Juan volcanic field (Lipman and Mehnert, 1975).

The Los Pinos (Cordito Member?) at Ojo Caliente was first mapped and correlated with the Conejos Formation by Atwood and Mather (1932). These deposits were also assigned to the Abiquiu Tuff by Smith (1938). Three to five km south of Ojo Caliente, the Los Pinos grades laterally into the Chama—El Rito Member of the Tesuque Formation, which overlies the Abiquiu Formation in the Abiquiu area.

Bingler (1968) first mapped the Los Pinos at Ojo Caliente, but included the upper 80 m of Abiquiu in his basal Los Pinos. In this report the Los Pinos is restricted to those volcaniclastic conglomerates and sandstones (approximately 360 m thick) that overlie the light-gray tuffaceous sandstones of the Abiquiu Formation west of Ojo Caliente and underlie a thin tongue of light-brown to pale-orange siltstones, sandstones, and gray volcanic conglomerates of the Chama—El Rito 1 km east of town. The Los Pinos is also recognized as a northward-thickening tongue, 130-200 m thick, in the upper half of the Chama—El Rito along the north-trending cliffs east of El Rito Creek (Figs. 1, 2).

Lithology

In the Ojo Caliente area, the Los Pinos Formation is primarily purplish-gray volcanic-pebble conglomerate with numerous interbeds of slightly tuffaceous pink, light-brown, and pale-orange siltstone and sandstone that are similar to the Chama—El Rito. The basal 30 m of the formation contain numerous locally derived angular fragments of metarhyolite, granite, amphibolite gneiss, and muscovite schist where it overlies hills of Precambrian rock.

The conglomerates consist of granules, pebbles, and cobbles of maroon and bluish-gray rhyolite and rhyolitic welded tuff, containing eutaxitic structure and phenocrysts of quartz. Clasts of light-gray quartz latite(?) and andesite porphyry are also abundant; both contain phenocrysts of hornblende, light-gray feldspar, and sparse biotite and quartz. Minor granules and pebbles of soft, light-pink to light-gray andesite and rhyolitic tuff breccia and a few zones with rounded boulders of porphyritic andesite(?) and rhyolite (0.3-1.0 m in diameter) imply one or more nearby volcanic sources for some of the debris. Minor angular fragments of Precambrian metarhyolite, amphibolite, schist, and pink feldspar throughout the Los Pinos are slightly larger in average size than the more rounded volcanic clasts and are most common in the lower third of the section.

Conglomerates are 0.1-3.0 m thick and generally have erosional bases exhibiting 0.1-0.3 m of relief. Fluvial crossbeds, slightly imbricated cobbles, and granular to pebbly volcaniclastic and arkosic sandstone fill numerous paleochannels. Some conglomerates grade laterally into granular sandstone, and in many areas the sandstones and conglomerates are finely interbedded.

A tongue of Los Pinos conglomerate in the Chama—E1 Rito Member along the cliffs east of El Rito Creek (Fig. 1) is similar to the Los Pinos conglomerate at Ojo Caliente but contains more clasts of Precambrian rock. In the southern part of the tongue, the conglomerate contains about 75% rounded pebbles and cobbles of andesite, rhyolite, quartz latite, and dacite(?), and 25% subangular pebbles of quartzite, metarhyolite, and gneiss. As the tongue is traced northward along the cliffs, the pebbles of Precambrian rock gradually become larger (locally 0.3-1.0 m in diameter) and eventually comprise up to 90% of the debris in some layers near the latitude of Ojo Caliente. No northward increase in grain size or angularity of the volcanic clasts is noticeable.

Light-brown, pink, and pale-orange siltstones and sandstones that are interbedded with the Los Pinos conglomerates generally consist of quartz, feldspar, and minor, small lithic grains in a slightly tuffaceous matrix. The layers are loosely cemented, evenly bedded, and are approximately similar in appearance to those of the Chama—El Rito although the amount of tuffaceous debris decreases slightly to the south.

Contacts

The Los Pinos unconformably overlies the Precambrian rocks near Ojo Caliente along a surface of high relief, with stratigraphically higher levels of the Los Pinos overlying what were the higher elevations on the hills before Neogene east-tilting of the region. In areas where the elevation on the surface of Precambrian rocks was low enough, the Abiquiu Formation underlies the Los Pinos along a gradational contact.

The upper contact of the Los Pinos grades up into a thin tongue of upper Chama—El Rito 1 km east of Ojo Caliente and is located at the uppermost major gravel layer in the pale-orange siltstones and sandstones of the Chama—El Rito. Because most gravel layers are not continuous for more than 1 km, the uppermost major gravel occurs at slightly different levels in the section from one place to another, and the contact rises and falls as it is traced laterally.

North of Ojo Caliente, the upper contact with the Chama—El Rito is more complex. At Ojo Caliente, the Los Pinos conglomerates (360 m thick) appear to be at approximately the same stratigraphic level as the middle to upper(?) Cordito Member north of La Madera, but are separated from it, at least in their upper part, by a laterally intervening zone of the Chama—El Rito exposed on the north side of Canada de los Comanches (Figs. 1, 2). Northward of Ojo Caliente, the volcaniclastic conglomerates in the upper Los Pinos diminish abruptly and the upper contact drops in the section near the confluence of Canada de los Comanches and Rio Ojo Caliente. Exposures along N.M. 96 for the first 3 km north of Canada de los Comanches contain more volcaniclastic conglomerates than the overlying Chama—El Rito to the east, suggesting that this gradational contact continues north at a lower stratigraphic level (parallel to the highway) for at least a few kilometers. However, poor exposures between this area and La Madera make it difficult to demonstrate that the Los Pinos at Ojo Caliente is physically continuous with the Cordito to the north. The relationship is better exposed 8-10 km west—northwest of Ojo Caliente in the hills east of El Rito, where a complex intertonguing relationship occurs between the Los Pinos, Chama—E1 Rito and Abiquiu.

The Los Pinos exposed at Ojo Caliente grades south and upward into the Chama—El Rito Member of the Tesuque Formation. Three to five km south of Ojo Caliente the number of conglomerate layers diminishes and the more arkosic pale-orange siltstones and sandstones of the Chama-El Rito dominate the section from here south into the Espanola Basin. A few volcaniclastic conglomerates extend many kilometers to the south, and tongues of pink and brown sandstone, up to 25 m thick (typical of the Chama—El Rito), extend north beyond La Madera, thereby making this laterally gradational contact difficult to locate precisely. Of all contacts in the Tertiary section, the contact between the Los Pinos and Chama—El Rito is the most subject to reinterpretation or relocation by other workers, depending on where the most significant lithologic change is thought to occur.

The tongue of Los Pinos in the cliffs east of El Rito Creek grades south into the upper half of the Chama—El Rito and is thought to be a west—southwest extension of the thick gravels at Ojo Caliente. The lower contact of the tongue, although gradational, occurs as a relatively sharp upward increase in the abundance of conglomerate near the base of the cliffs. The contact appears to drop in the section northward near the latitude of Ojo Caliente.

The upper contact of the tongue is exposed very poorly a short distance east of the cliffs, but with difficulty can be traced to the north along a large easterly dip-slope in the upper Chama—El Rito. At the latitude of Ojo Caliente this contact rises stratigraphically at the expense of the overlying Chama—El Rito and is only about 35 m below the base of the Ojo Caliente Sandstone, similarly to the situation east of Ojo Caliente.

Age

Age of the Cordito(?) at Ojo Caliente ranges from 18 to approximately 12 m.y. (mid-Miocene). The base of the member is approximately 40 m stratigraphically above an olivine-nephelinite flow dated at 18.9 ± 0.7 m.y. by Baldridge and others (1980), and is probably 17-18 m.y. old.

The approximate 12 m.y. age for the upper contact is not well constrained near Ojo Caliente. Southeast of town the upper contact is about 110 m higher stratigraphically than the 15.3 m.y. old Ojo Caliente tuff ring (May, this guidebook) and very approximately 250 m lower than basalt flows in the lower Chamita Formation near Chili (24 km south) dated at 9.6 ± 0.2 m.y. by Baldridge and others (1980). The middle of the Los Pinos tongue exposed along the cliffs east of El Rito Creek is about 170 m above a 15.3 m.y. old volcanic vent (date by Ekas and others, this guidebook) exposed along the creek, and is probably 1314 m.y. old.

In southern Colorado, the Los Pinos underlies, and is interbedded with, basalts of the Hinsdale Formation, from which Lipman and Mehnert (1975) reported radiometric ages of 25-5 m.y. Bingler (1968) also reported a 25.9 m.y. date from a welded rhyolite tuff in the lower part of the Cordito Member west of Petaca. The Los Pinos is therefore upper Oligocene to uppermost Miocene in the eastern Tusas Mountains and is age-equivalent to the Abiquiu, Tesuque, and Chamita Formations to the south.

HINSDALE FORMATION

Two exposures of basalt flows occur between the Precambrian and Tertiary rocks in the hills west of Ojo Caliente; one at Arroyo El Rito, the second near Cerro Colorado. The basalts (formerly Jarita Basalt of Butler, 1946; Barker, 1958; May, 1980; Baldridge and others, 1980) are now included in the Hinsdale Formation in accordance with Lipman and Mehnert (1975), who assigned all interlayered basalts of the Los Pinos Formation to the Hinsdale. The flows are at slightly different levels in the Tertiary section and appear to be small, isolated flows that were extruded into Miocene valleys from several local vents now buried by the Los Pinos and Abiquiu Formations.

The Arroyo El Rito exposure, the lower of the two, is 4 km S7OW of Ojo Caliente. There a series of four(?) superimposed flows overlies the Precambrian rocks and underlies the Abiquiu Formation (Figs. 1, 2). The greatest thickness of the flows is 30 m where they have filled a valley eroded on the Precambrian rocks. Elsewhere, the thickness is generally 15-20 m. Lateral extent of the flows is uncertain, but probably is greater than that seen in the exposures. To the north, stratigraphically higher parts of the Abiquiu directly overlie the Precambrian. Some flows are separated from each other by thin, discontinuous zones of light-gray, tuffaceous sandstone (0-1.2 m thick) similar to the Abiquiu Formation.

Chemical analyses and norm calculations for the flows indicate a quartz-tholeiite composition with 53% SiO_2 and 3.8% normative quartz (Baldridge and others, 1980). Most major-element oxides are within 1% of those reported by Barker (1958) for his Jarita Basalt at Tusas Creek in the Las Tablas quadrangle. Similar SiO_2 values at 51 and 52% were reported by Lipman and Mehnert (1975) and Lipman and others (1978) for basalts in the Hinsdale Formation.

Several flows of the basalt also occur on the southeast flank of Cerro Colorado between the Precambrian rock and the overlying Los Pinos Formation. The basalt is 0-35 m thick and is exposed intermittently for a distance of 3 km (Fig. 2). The dark-gray flows are deeply weathered olive green and purple in most outcrops and locally exhibit spheroidal weathering. Petrographically, the flows are approximately similar to the flows along Arroyo El Rito, but are approximately 65 m higher in the section. They could be slightly younger than the flows at Arroyo El Rito or could have erupted at the same time, but at an elevation 65 m higher on the Precambrian rocks, thereby not being buried until the basal Los Pinos was deposited.

TESUQUE FORMATION (CHAMA—EL RITO MEMBER)

The Chama—El Rito Member of the Tesuque Formation was named by Galusha and Blick (1971) for buff to pink sandstone, siltstone, and interbedded purplish-gray, lenticular layers of volcaniclastic conglomerate exposed in the badlands north of Rio Chama, 5 km east of its confluence with El Rito Creek. These beds are confined to the western and northern parts of the Espanola Basin and grade north into the Cordito(?) Member of the Los Pinos near Ojo Caliente.

Lithology

The Chama—El Rito is primarily a sequence of arkosic siltstone, sandstone, and lesser volcaniclastic conglomerate. Minor beds of white and pale yellowish-green airfall tuff and tuffaceous sandstone, thin beds of reddish-brown silty clay, and very sparse layers of white limestone occur mainly in the upper 200 m in the badlands north of Rio Chama, implying lower paleoslopes to the southwest.

South of Ojo Caliente the Chama—El Rito is 460-550(?) m thick and typically occurs in widely spaced, fault-controlled exposures in the structurally higher areas. It also forms a tongue (35-60 m thick) between the Los Pinos Formation and Ojo Caliente Sandstone 1 km east of Ojo Caliente. Two km north of Ojo Caliente the member thickens abruptly to more than 150 m along a laterally gradational contact with the underlying Los Pinos conglomerates and is well exposed in the badlands on the north side of Canada de los Comanches.

The bulk of the Chama—El Rito is a sequence of silty to medium-grained, moderately to well-sorted, arkosic to lithic sandstone beds colored light-orange brown, orange-pink, and salmon. Layers are medium-bedded to massive, with even, parallel bedding. Mineral composition is variable, but typical amounts are 50-70% quartz, 20-30% plagioclase and K-feldspar, 5-15% volcanic and lesser plutonic rock fragments, 1-3% opaque minerals, and 1-2% other miscellaneous grains including secondary(?) clay. In some beds, the sand-sized fraction contains glassy and tuffaceous grains (20-35%). The sandstones are typically friable to crumbly, slightly tuffaceous, and weakly cemented with minor clay, hematite, and calcite. Interbeds of loosely cemented, reddish-brown, sandy siltstone (0.1-3.0 m thick) occur in the south near Rio Chama along with very minor beds of dune-like sandstone.

Volcaniclastic conglomerates occur throughout the Chama—El Rito section, but a few systematic variations are noticeable. Conglomerates comprise up to 60% of the Los Pinos at Ojo Caliente, but become thinner, fewer, and slightly finer-grained as they are traced south and southwest into the Chama—El Rito. They make up less than 10% of the section in the south near Rio Chama. In most areas, the conglomerate are sparse or absent in the upper 25-35 m. Five to six km southwest of Ojo Caliente, an ill-defined gravelly zone (90-120 m thick) in the Chama—El Rito is about 70 m stratigraphically above the Ojo Caliente tuff ring of May (this guidebook) and is probably equivalent to the tongue of Los Pinos along the El Rito cliffs.

The conglomerates contain subangular to rounded granules, pebbles, and small cobbles of rhyolite ash-flow tuff, light-gray porphyritic andesite, dacite, quartz latite(?), and Precambrian blue and gray quartzite, brown metarhyolite, granite, quartz, and green to black gneiss and amphibolite. Rock types are given above in very approximate order of decreasing abundance, although relative amounts are variable throughout the region and no systematic study of the variations was attempted. Clasts of the Tertiary volcanics are by far the most abundant except near hills of Precambrian rock and are generally more rounded than those of the Precambrian. The gravels are poorly sorted and generally have a light-gray or light-brown sandy matrix rich in quartz and lesser feldspar, rock fragments, and minor tuffaceous debris. A detailed petrographic study of the conglomerates, as also suggested by Galusha and Blick (1971), will provide needed additional insight on the source of these deposits (Ekas and others, and Dethier and Martin, this guidebook).

Geometry of the conglomerates is variable. Most layers grade laterally and upward into beds of nonvolcanic sandstone. Many have sharp erosional bases and, in some areas, a subtle upward-fining grain size. Some form continuous sheet-like layers (3-6 m thick) that are traceable for up to 1 km (especially in the south near Rio Chama) and that have only 0.1-1.0 m of erosional relief at their bases. Within these larger tabular layers are numerous small stringers (0.1-1.0 m thick) of slightly imbricated pebbles and cobbles that extend laterally 5-30 m, but do not scour the underlying beds.

Numerous paleochannels (generally 2-8 m wide) exhibit 0.1-0.6 m of erosional relief at their bases, although a few cut down as much as 1.0-1.2 m. These channels generally form at the base of the larger tubular layers. A few also occur as small, lenticular channels (3-15 m across) that are isolated in the sandstone. The bottom of a few of the more deeply entrenched channels is lined with lag zones of imbricated cobbles. In some channels, trough-shaped crossbeds in the sandstone dip 5-20° into the channel axes, approximately conforming to the floor of the channels. Foreset beds are sparse. Few, if any, slump structures occur on the channel walls, and flute casts and ripple marks in the finer-grained layers are very sparse.

Paleotrend measurements on eight channels show a high directional variability and an average S2OW direction (Fig. 1). Directions are determined by:

(1) pebble imbrication in paleochannels,
(2) dip direction of foreset crossbeds, and
(3) correlation of channels between outcrops.

Channels west of El Rito Creek trend almost due south, whereas those to the east near lower Rio Ojo Caliente trend more to the southwest. This convergence may indicate that the axis of the basin trended north—south during the mid-Miocene and was near the longitude of lower El Rito Creek. Possible minor east-tilting of the west side of the basin may have caused this southerly diversion of the southwest-flowing streams near Ojo Caliente.

Several thin, widely spaced layers of white, very light-gray and pale yellowish-green airfall tuff and tuffaceous sandstone occur in the upper 90 m of the Chama—El Rito and lower 60 m of the overlying Ojo Caliente Sandstone. The tuffs first appear about 6-8 km south of Ojo Caliente and increase slightly in abundance southward toward Rio Chama and beyond.

In the badlands west of lowermost Rio Ojo Caliente, several white and very light-gray limestones (0-1.5 m thick) occur 45-125 m below the top of the Chama—El Rito, implying low paleoslopes and proximity to the basin center. Most layers are traceable for 90-1000 m, and, in some areas, several discontinuous beds occur at various levels in the section. Although no fossils were identified, the beds appear to be intensely bioturbated by worm(?) tubes and contain mudcracks(?). In thin section, the tubes are filled with mosaic, sparry calcite and fibrous chert. The matrix is calcareous mud (micrite). Scattered throughout the mud are sparse rounded quartz grains (eolian?) and possible fragments of fossil algae and $CaCO_3$. The sparse limestones may be deposits of small playas or shallow depressions of standing saline water on the interfluvial plains and are absent to the north near Ojo Caliente.

Contacts

The Chama—El Rito grades down into the Abiquiu Formation throughout most of the area; grades north into the Cordito(?) Member of the Los Pinos Formation; and grades up into the overlying Ojo Caliente Sandstone as a series of tongues of orange-brown siltstone of the Chama—El Rito and light-brown eolian sand of the Ojo Caliente Sandstone.

Age

In the Ojo Caliente—Rio Chama area, the Chama—El Rito is laterally equivalent to the Cordito(?) Member of the Los Pinos. Here the Cordito(?) has an age range of 18-12 my. and establishes an approximately similar age range for the Chama—El Rito in this area. A 15.3 m.y. old volcanic horizon occurs in lower middle part of the Chama—E1 Rito between Ojo Caliente and lower El Rito Creek (Ekas and others, and May, this guidebook).

CORRELATION OF UNITS

Correlation of the Miocene units is complicated by contacts that intertongue, grade laterally and are time-transgressive as a result of evolving uplifts, and by basin geometry and source areas. Figure 2 summarizes the stratigraphic relationships between La Madera and the Rio Chama.

The lower 0-80 m of section west of Ojo Caliente consist of white tuffaceous sandstone (here considered to be upper Abiquiu) which is probably similar in stratigraphic level and age to part of the upper Abiquiu in its type area. The lower few meters of metarhyolite conglomerate and breccia in the section at Ojo Caliente may be physically continuous with, but younger than, the 90 m thick basal granitic gravel of the Abiquiu in the type area. This unit is also tentatively correlated with the Ritito Conglomerate to the north, which Vazzana (1980) considered to be basal Abiquiu. The Abiquiu in the type area probably thinned to the north, as it was deposited on the hilly topography of the former Laramide Brazos uplift in the Ojo Caliente area during the early Miocene.

The Abiquiu as defined here is age-equivalent with, and appears to grade northeast into, the lower Cordito in the El Rito—Ortega Mountain area, based on limited reconnaissance work (May, 1980). However,

careful study of Abiquiu — Los Pinos — Chama—El Rito relationships is still needed in this critical area of intertonguing. The Upper Member of the Abiquiu Formation (of Vazzana, 1980; Vazzana and Ingersoll, 1981) contains clasts of ash-flow tuff similar to those of the Cordito, implying that the conglomerates of the upper Abiquiu are southwestern tongues of the Cordito (Manley, 1981). However, 3 km west of Ojo Caliente the Abiquiu clearly grades upward into the Los Pinos along a contact that is about 18 m.y old. South of Ojo Caliente the Abiquiu underlies, and in most places grades up into, the Chama—El Rito.

Reconnaissance work north of Ojo Caliente suggests that the 360 m of volcaniclastic conglomerate at Ojo Caliente I mapped as upper Abiquiu Tuff by Smith (1938), but considered here to be Cordito(?)] is approximately equivalent in stratigraphic level and probably in age to the middle part of the Cordito Member as defined by Barker (1958) in the Las Tablas quadrangle and Butler (1946, 1971) in the eastern Tusas Mountains. These conglomerates are thought to be coarser-grained, stratigraphically higher and younger than the Abiquiu in its type area near Abiquiu, and grade laterally to the south into the Chama—El Rito Member of the Tesuque Formation.

SOURCE AREAS AND DEPOSITIONAL ENVIRONMENTS

During the Miocene, the Ojo Caliente area was near the southern end of a large alluvial apron derived from volcanic terranes in the San Juan Mountains and the Questa—Taos area (Lipman and Mehnert, 1975; Manley, 1981). The Brazos uplift, which was still a low northwest-trending highland of Precambrian rock, was gradually being buried by Abiquiu and Los Pinos alluvium at this time. In broadest terms, this volcanic system merged and intertongued with a dominantly arkosic alluvial system (Tesuque Formation) brought west and southwest from the Sangre de Cristo Mountains.

The Abiquiu Formation formed a broad alluvial deposit derived from streams originating in a rhyolitic to andesitic volcanic region to the north and northeast (Vazzana and Ingersoll, 1981). The tuffaceous alluvium buried a widespread erosion surface formed on hills of Precambrian rock in the western Brazos uplift and on lower Tertiary and Mesozoic sedimentary rocks to the southwest where relief was more subdued. The debris entered a mildly sagging basin (early Espanola Basin) whose boundaries were wider than its present fault boundaries, as indicated by the presence of Abiquiu on the eastern flanks of the Nacimiento uplift and at Cerro Pedernal, both of which are west of the fault margin of the basin. Paleochannel measurements of the lower Abiquiu indicate southwesterly stream flow, and measurements in the upper Abiquiu indicate southeasterly flow away from the San Juan volcanic field along the western side of the Brazos highland, perhaps as a result of early east-tilting of the western Espanola Basin (Vazzana, 1980; Vazzana and Ingersoll, 1981). Clasts of ash-flow tuff are similar to those of the Los Pinos, possibly implying a common source area and that the Abiquiu may have simply been a more distal, finer-grained part of the early Los Pinos depositional complex (Manley, 1981).

The Los Pinos formed a widespread alluvial deposit derived from areas consisting of rhyolitic and andesitic ash-flow tuffs and flows. Several distant and local volcanic sources are indicated. In the southeastern San Juan Mountains, the Los Pinos forms a debris apron around late-stage volcanic cones and domes along the northern rim of the Platoro caldera (Lipman and Steven, 1970) and "accumulated as great coalescing alluvial fans along the east front of the San Juan Mountains; accumulation was a response to eastward tilting of the Oligocene volcanic sequence concurrent with structural development of the San Luis Valley graben" (Lipman, 1975). According to Manley (1981), P. W. Lipman identified clasts of rhyolitic ash-flow tuff in the Los Pinos that are similar to volcanic units in the Questa area to the northeast. In the eastern Tusas Mountains, Manley also noted clasts derived from local outcrops of ash-flow tuff that erupted from the Questa area. A few large cobbles and boulders of light-gray, rhyolitic ash-flow tuff and porphyritic andesite in the Ojo Caliente area also indicate local erosional sources for a small amount of the debris.

Manley (1981) noted a greater amount of porphyritic, intermediate-composition volcanic clasts in the Chama—El Rito than in the Cordito, which contains abundant clasts of rhyolitic ash-flow tuff, and suggested different sources for the volcanic debris in the two units. Although the Los Pinos conglomerates at Ojo Caliente are similar in appearance to the Cordito and contain clasts of rhyolitic ash-flow tuff, more petrographic study of the clasts is needed to positively identify them as the Cordito Member.

Near Ojo Caliente, the Los Pinos streams maintained southwesterly courses as they flowed around the southern end of the former Laramide Brazos uplift. This is indicated by several lines of evidence:

(1) thickness, abundance, and grain size of conglomerate layers in the Los Pinos (and laterally equivalent Chama—El Rito) decrease to the south and southwest;
(2) imbricated pebbles in the Los Pinos fluvial channels have a slight tendency to dip northeast in many exposures (no systematic study was made, however);
(3) on the southeastern flank of Cerro Colorado, erosional debris of Hinsdale basalt flows in the basal Los Pinos occurs southwest of Hinsdale exposures;
(4) abundance, grain size, and angularity of quartzite, metarhyolite, and gneissic rubble in the Los Pinos tongue at El Rito cliffs increase northward, culminating southwest of Cerro Colorado and La Madera Mountain, which formed major topographic highs of Precambrian rock during Los Pinos deposition.

By 18 m.y. ago, shortly after eruption of the olivine-nephelinite flow at Cerro Negro, the Abiquiu alluvial system was buried by the Los Pinos (Cordito Member?) in the Ojo Caliente area. Shortly thereafter, light-brown and pale-orange beds of arkosic sandstone occurred in Los Pinos gravels of the Ojo Caliente area and were abundant in the Chama—El Rito to the south. This change at about 18 my. might be a slightly delayed effect of uplift of the Sangre de Cristo Range 1-2 my. earlier, which according to Manley (1981) was already the site of a volcanic edifice in the Questa area supplying debris to the lower Los Pinos Formation. Local advance of the Los Pinos gravels over the finer-grained Abiquiu system at Ojo Caliente occurred simultaneously with introduction of the arkosic Chama—El Rito above the tuffaceous Abiquiu farther south at this time. This implies uplift of an already present volcanic terrane in the Sangre de Cristos to the northeast near Questa and simultaneous uplift of a granitic and sedimentary terrane farther south along the range.

The Chama—El Rito south of Ojo Caliente accumulated in the more central part of the Espanola Basin as it was simultaneously receiving arkosic sand and andesitic to rhyolitic gravel from the two source areas. The south- and southwest-flowing streams were probably shallow and wide, forming a braided distributary(?) system, as indicated by the lateral extent of many gravel layers and the scarcity of cut-and-fill structures more than 0.6 m deep. Sparse lenticular sandstone layers at various levels in the conglomerates may represent small sandbars between the migrating channels. Ripple marks and fluvial dunes are sparse and upper flow-regime bedforms absent. A slight southwesterly decrease in average grain size and in the number of cut-and-fill channels also indicate a slight southwesterly decrease in stream turbulence and competence.

The numerous fine-grained sandstones of the Chama—El Rito probably were deposited on broad, flat areas between the distributary channels (interfluvial plains), but depositional mechanisms are uncertain. The sandstone layers may have been deposited by short-lived surges of sand-laden water overflowing the channels, forming sheet floods across the interfluvial plains. In support of this interpretation, the sandstones are finer-grained and more evenly bedded than the conglomerate layers and have a laterally gradational relationship with some of the conglomerates. An eolian origin for some of the fine-grained sandstones and siltstones is supported by good sorting, a lack of upward-fining texture, and a massive appearance similar to loess. Therefore, paleoslopes south of Ojo Caliente gradually flattened into the Espanola Basin during the mid-Miocene, as indicated by lacustrine limestones in the south, convergent paleostream trends, and finer grain size.

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Barranca was the station at the top of Barranca Hill. Stages for Taos and Ojo Caliente connected with the trains. Now only a stock pen and the abandoned grade (visible in the foreground) remain.