



Exhumed mid-Miocene volcanic field in the Tesuque Formation, northern Espanola Basin, New Mexico

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EXHUMED MID-MIOCENE VOLCANIC FIELD IN THE TESUQUE FORMATION, NORTHERN ESPANOLA BASIN, NEW MEXICO

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INTRODUCTION

A small field of basaltic tuff rings, cones, minor flows, and dikes is locally exposed for a distance of 20 km between the town of Ojo Caliente and the lower El Rito Creek area in the northern Espanola Basin (Fig. 1). The field is one of the few interruptions in a mid-Miocene volcanic lull identified throughout much of the Rio Grande rift (Chapin, 1979). These tephra eruptions occurred during deposition of the middle Chama—El Rito Member of the Tesuque Formation and are closely associated in terms of mineral and textural composition, stratigraphic position, age, and possibly eruptive mechanism. North—northeast-trending dikes and minor growth faults contemporaneous with volcanism imply a local N70W-oriented axis of least principal stress during mid-Miocene time. A possible genetic relationship with the Hinsdale Basalt (of Lipman and Mehrt, 1975) is suggested on the basis of approximately similar mineralogy, stratigraphic position, and age.

OJO CALIENTE TUFF RING

The Ojo Caliente tuff ring (May, 1980) is the best exposed of the middle Chama—El Rito volcanic centers and is located 3 km southwest of Ojo Caliente in the area where the mid-Miocene part of the Los Pinos Formation grades south into the Chama—El Rito (Fig. 1). Other vents elsewhere in the Chama—El Rito occur within 40 m of the same stratigraphic level (May, Miocene Stratigraphic Relations etc., fig. 2, this guidebook). A circular vent, 1 km across, containing bombs, inward-dipping basaltic tephra, and concentric dikes, is surrounded by a tuff-ring facies of outward-dipping basaltic tuff (Fig. 2). The tuff ring tapers radially outward into the Los Pinos and Chama—El Rito beds and is bounded by angular unconformities at the top and base. The tuff ring is separated from the vent facies by a funnel-shaped angular unconformity that dips 24–50° into the vent (Fig. 3). Deeper stratigraphic levels of the tuff ring are exposed in the north and northwest because of post-volcanic tilting to the southeast and deep erosion of Arroyo El Rito. As a result, higher beds of the Chama—El Rito in the south still overlie the higher slopes on the tuff ring. A N20W-trending fault cutting the southern part of the vent is down-dropped to the west, allowing preservation of Chama—El Rito beds that were stratigraphically high enough to overlie the vent. Here, the vent margin (Fig. 2) is inferred beneath the Chama—El Rito. Exposures of the vent facies 50–75 m north of the dotted line indicate proximity to the vent margin and contain steep northerly dips and a concentric dike similar to dikes near the vent margin elsewhere.

Vent Facies

The vent facies is a mottled maroon to gray, basaltic lapilli tuff and is confined completely to the vent. Ill-defined bedding results from numerous flattened basaltic bombs and indistinct layering in the tuffaceous matrix. Inward dips as steep as 36° near the vent margin flatten to less than 10° in the middle of the vent.

The tuff is a poorly sorted mixture of angular, scoriaceous lapilli in an ashy matrix. In some areas, the tuff grades into zones of extremely scoriaceous and amygdaloidal, cryptocrystalline basalt and basaltic glass. The basaltic lapilli are composed of fine-grained augite and traces of olivine(?) in dark-brown tachylite, which also contains traces of finely divided magnetite and hematite, and many calcite-filled amygdules. Plagioclase is scarce to absent. The more crystalline basaltic lapilli contain numerous flow-banded microlites of plagioclase with lesser augite grains in dark-brown tachylite. A few angular cognate blocks of

fine-grained basalt are scattered throughout the tuff and may be fragments of basalt explosively torn from the walls of the underlying conduit. Sparse exotic debris includes angular fragments of polycrystalline quartz with feathery biotite grains (Ortega Quartzite?) brought up from the Precambrian basement, and pulverized fragments of Tertiary latite and rhyolite from the underlying Chama—El Rito beds. In some areas, light-colored tuffaceous debris similar to the tuff-ring facies forms inward-dipping layers, 0–20 m thick, immediately inside the vent unconformity, and may represent large masses of debris on the vent rim which slumped back into the vent during eruption.

Numerous oval, spindle-shaped, and ropey basaltic bombs are scattered throughout the tuffaceous matrix and have a maximum size of 12 m (Fig. 4). Many appear to have been tapered by flight through the air and have light-gray, vesicular rims.

Numerous dark-gray, inward-dipping basalt dikes, concentric to the vent margin, are most abundant within the outer 60 m of the vent. The concentric dikes, 1–10 m thick, dip inward at angles equal to, or greater than, the obscurely bedded vent facies. Grain size is slightly larger than that of the basalt bombs in the vent. Most dikes are only slightly vesicular and exhibit flow flotation and amygdules aligned parallel to both contacts. On a small scale, the contacts have irregular shapes and a few apophyses, but no scoriaceous zones. Some dikes are severely contorted, implying slumping or internal movement of the vent material during cooling. Although some of these "dikes" could have been shallow lava lakes ponded inside the vent, the evidence indicates that most of them are intrusive into the vent facies. One radial dike north of the vent may have fed the small flow at the base of the tuff-ring facies on the north side of Arroyo El Rito (Fig. 2). The flow, 0–1 m thick, wedges out eastward in the tuff-ring facies, into a horizon containing coarse lapilli erupted contemporaneously with the flow.

Petrographically, the flow, dikes, and vent bombs are identical in thin section and are probably chemically similar to the glassy and frothy basalt of the vent facies, but faster cooling of the vent facies seems to have caused less complete crystallization. The most crystalline samples contain scattered, glomerophytic aggregates of augite (0.25–1.0 mm) and smaller isolated grains of augite. The groundmass consists mainly of tiny, randomly oriented laths of plagioclase (0.2 mm) and sparse olivine (0.1 mm) suspended in dark-brown to black basaltic glass. Some plagioclase laths and augite grains are zoned. The nonflow-banded plagioclase may have crystallized after emplacement. Calcite- and natrolite(?) -filled vesicles occur in most samples.

Tuff-ring Facies

The surrounding tuff-ring facies outside the vent is a circular, fan-shaped pile of bedded basaltic tuff that tapers radially from a thickness of 75 m at the vent margin to about 25 m in its westernmost exposure and approximately 10 m at its eastern end. Original thicknesses may have been slightly greater, especially near the vent where erosion probably continued until the Chama—El Rito buried the higher flanks of the volcano. The height-to-width ratio of the structure was approximately 1:25 prior to erosion (lower than most cinder cones).

Although Galusha and Blick (1971) described these beds as the Abiquiu Tuff, a local and genetic relationship with the vent is clear. The relatively non-systematic pattern of dip directions in the vent and tuff-ring facies (Fig. 2) partly results from later, Pliocene warping and 9° of southeastward tilting into the Espanola Basin. When these dips are

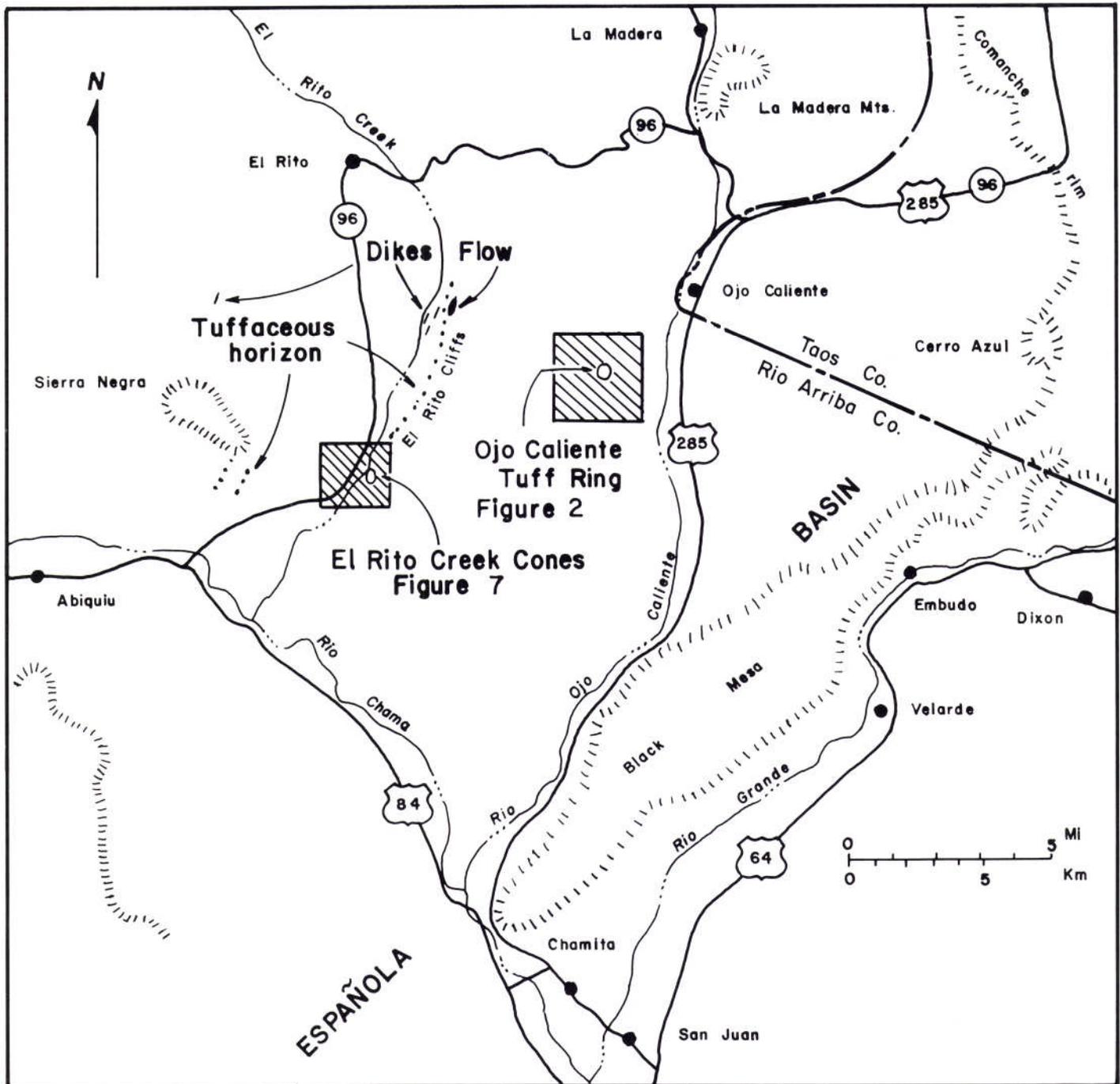


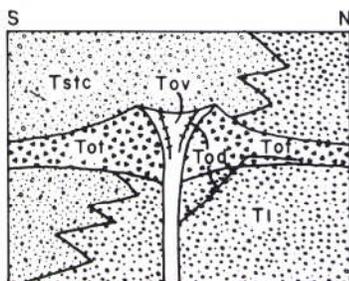
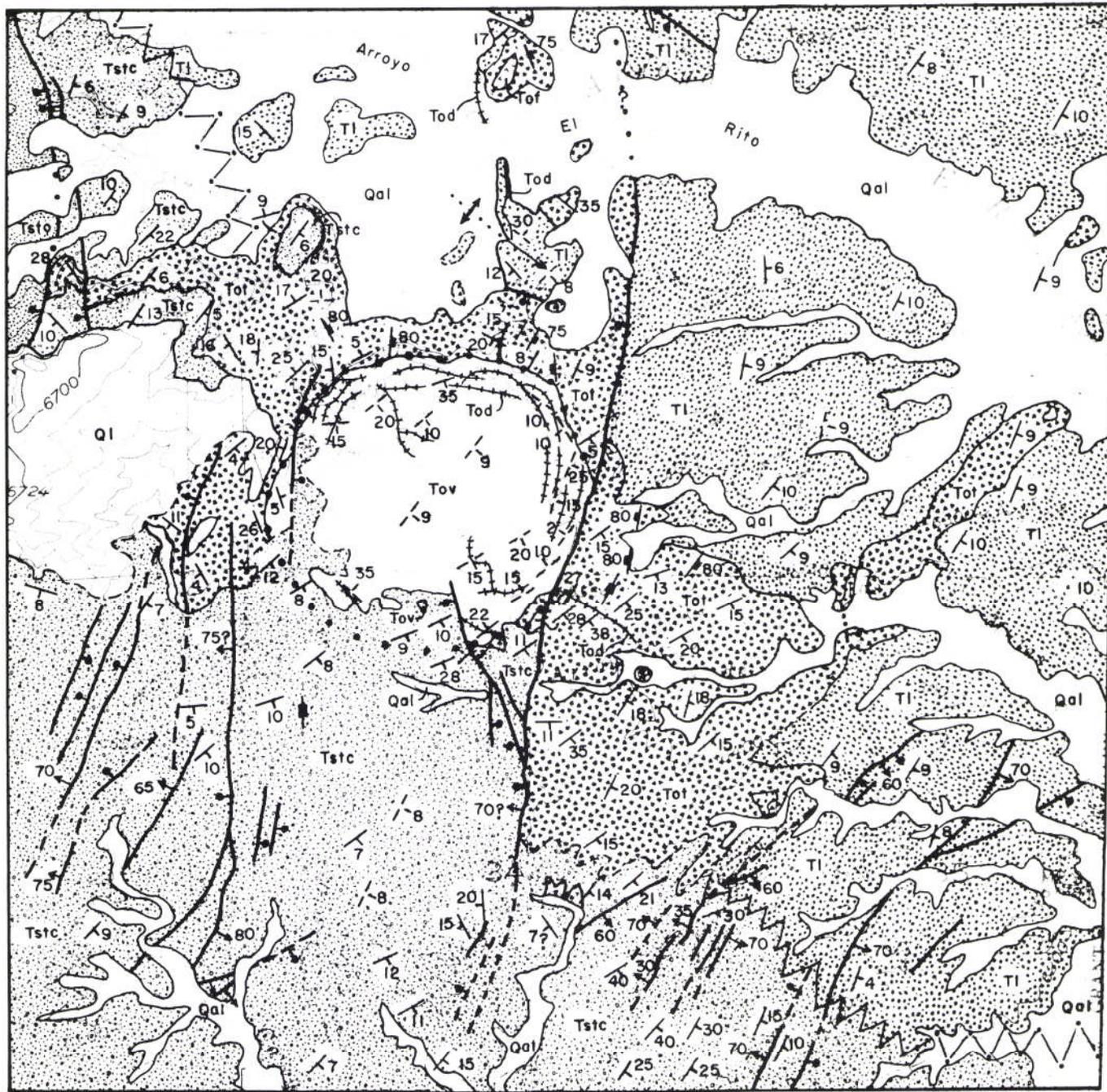
FIGURE 1. Map showing location of mid-Chama—El Rito volcanic centers in northern Española Basin.

rotated out using a stereonet, a more systematic pattern develops in which the tuff ring dips radially outward and the vent facies dips concentrically inward. This systematic pattern is most evident on the northwest side of the vent (Fig. 5). A general steepening of dips near the vent margin is seen in both the vent and tuff-ring facies, as is typical of tuff rings and maare (Heiken, 1971; Lorenz, 1973). Few dips exceeded 25° prior to regional tilting.

The unconformity between the top of the tuff ring and the overlying Chama—El Rito is more angular than the one at the base and gradually becomes more discordant ($3\text{--}25^\circ$) as it is traced toward the vent because of the tuff ring's steeper dips in the vent area. The unconformity itself also slopes away from the vent, with higher beds of the Chama—El Rito lying at successively higher levels on the tuff ring, indicating that the volcano formed a low hill during deposition of the Tertiary beds. The

unconformity at the base of the tuff ring is less angular, but where traced away from the vent, the tuff ring appears to lie on successively higher beds in the Los Pinos Formation.

The tuff-ring facies is mainly pale greenish-brown, basaltic air-fall tuff. Bedding is even and parallel. Subtle graded bedding occurs in some layers. Very sparse, discontinuous layers of foreset crossbeds dip away from the vent, possibly indicating rare base surges during the eruption or minor streams flowing down the flanks of the volcano. Sparse layers of fine-grained lapilli occur locally in the section. Average grain size decreases slightly away from the vent. Sparse bomb sags containing fragments of the Precambrian basement and Tertiary volcanic cobbles of the Chama—El Rito occur within 200 m of the vent margin



Schematic Cross Section of Ojo Caliente Tuff Ring

- | | | | | | |
|---------|------|----------------------|------|---------------------------------------|--------------------------------------|
| Quat. | Qal | alluvium | — | contact | |
| | Qi | eolian silt | | 75 | normal fault showing dip & downthrow |
| Miocene | Tod | dike + + + + | / 10 | strike and dip of beds (<10 inferred) | |
| | Tov | vent facies | | ~ ~ ~ | laterally gradational contact |
| | Tof | flow | | ↑ | anticline |
| | Tot | tuff ring facies | | ⌒ | vent margin (dotted where concealed) |
| | Tstc | Chama-el rito Member | | | |
| | Tl | Los Pinos Formation | | | |

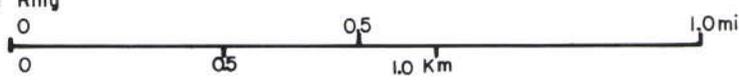


FIGURE 2. Geologic map of Ojo Caliente tuff ring. Modified from May (1980).

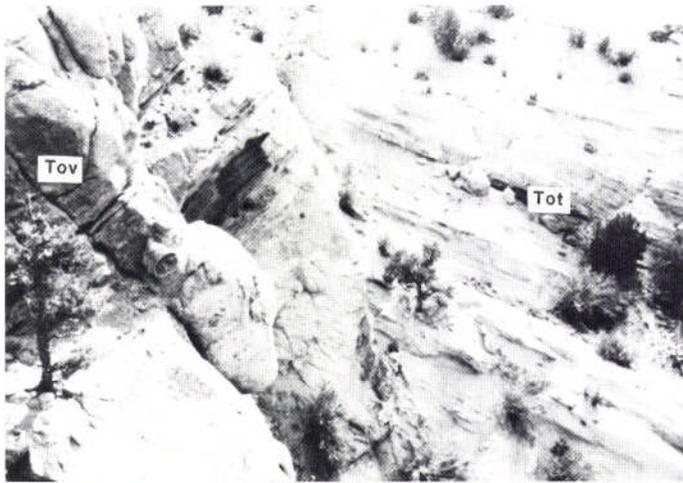


FIGURE 3. Angular unconformity along northwestern vent margin of Ojo Caliente tuff ring. Inward-dipping vent facies (Tov) truncates outward-dipping tuff-ring facies (Tot) (SW $\frac{1}{4}$ sec. 27, T24N, R8E).



FIGURE 4. Ropey basalt bomb in tuffaceous matrix of Ojo Caliente tuff-ring vent (SE $\frac{1}{4}$ sec. 27, T24N, R8E).

(Fig. 6). Ropey bombs and angular blocks of basalt similar to those in the vent facies are very sparse.

The finer-grained fraction of the tuff consists of a heterogeneous mixture of poorly sorted scoriaceous lapilli, devitrified glassy shards, fragmented crystals of clinopyroxene (augite?), sparse angular chips of Precambrian quartzite and metarhyolite, and rounded granules of Tertiary rhyolite, andesite, latite, and sandstone. Secondary epidote and minor chlorite are common alteration products of the basaltic debris and are probably responsible for the tuff's pale greenish-brown color.

Relationships to Tertiary Section

Near the top, base, and distal ends, the debris is mixed with fluvial volcanoclastic debris of the Los Pinos and Chama—El Rito. Poorly sorted, rounded pebbles of rhyolite and latite, and angular, vesicular clasts of basalt are scattered through a locally crossbedded sandy matrix of quartz, orthoclase, microcline, clinopyroxenes of mixed origin, and tuffaceous debris. The basal 15-20 m of overlying Chama—El Rito have a light-brown, tuffaceous appearance from reworking of the tephra. Layers of basaltic tephra are interbedded with typical Chama—El Rito beds overlying the tuff ring, especially in the distal areas. The tuff-ring facies is approximately 275 m higher in the section than basalt flows of the

Hinsdale Formation (formerly Jarita Basalt) 3 km southwest of Ojo Caliente that were K—Ar dated at 22.1 ± 0.6 m.y. by Baldridge and others (1980).

Large veins of milky opalite and white calcite occupy northeast-trending joints in the tuff-ring facies 100-200 m east of the vent. The opalite may have formed from silica released by devitrification of the glassy debris as hydrous fluids migrated through the tuff.

Local Deformation

Minor structural deformation on a local scale accompanied the eruption. A small growth fault, 1 km east of the vent, is located at the base of the tuff ring and several minor ones in the tuff-ring facies are exposed beneath the vent unconformity on the northwestern side of the vent. An angular unconformity is exposed in the lower tuff ring along the west-trending cliffs 1 km northwest of the vent. More subtle unconformities elsewhere can be traced for short distances through the tuff-ring facies.

Eruptive Mechanisms

Eruptions of the tuff ring were probably explosive despite the relative scarcity of dune-like structures and the apparent lack of palagonite

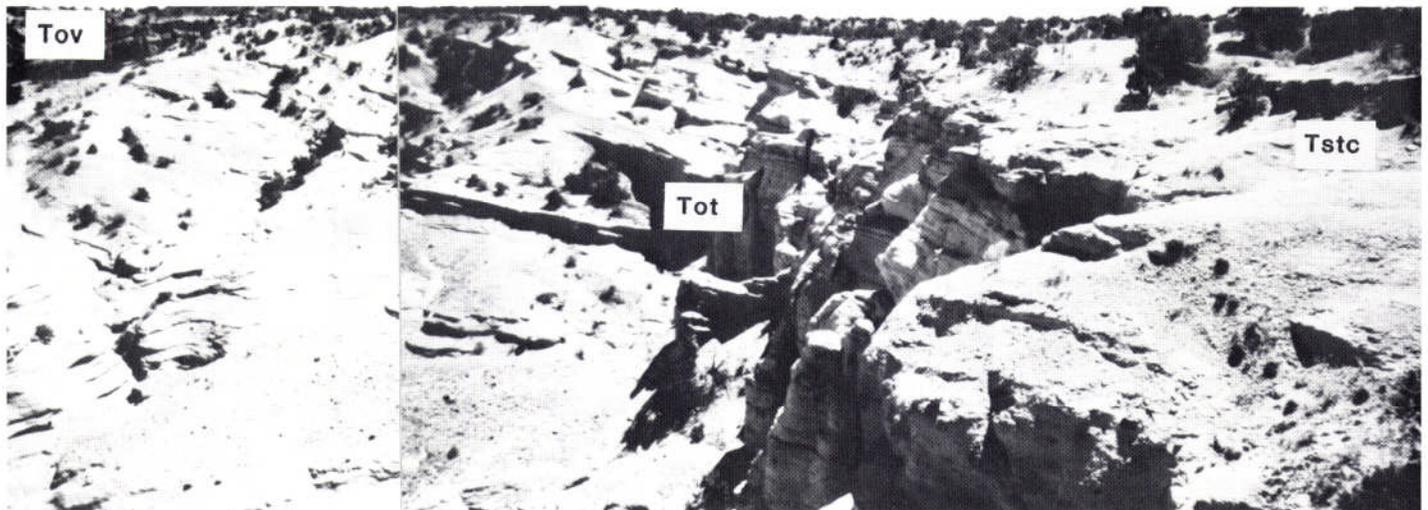


FIGURE 5. View south toward northwestern part of the Ojo Caliente tuff ring, showing dark vent facies (Tov) at upper left and light-colored tuff-ring facies (Tot) which dips to the right (away from vent). At far right, flat-lying Chama—El Rito (Tstc) overlies the tuff ring in angular unconformity (SE $\frac{1}{4}$ sec. 27, T24N, R8E).



FIGURE 6. Bomb sags in tuff-ring facies of Ojo Caliente tuff ring, 180 m northeast of vent. Cavity was once occupied by a block, since weathered out. Another block of andesite (above) occupies sagged bedding. Two other bomb sags are at left (SE¹/₄ sec. 27, T24N, R8E).

which otherwise might indicate the presence of water necessary for phreatomagmatic eruptions. Considerable fragmentation and horizontal dispersal of the ejecta distinguish this vent from cinder cones as indicated by:

- (1) A fairly low topographic profile and low outward dips of the tuff-ring facies;
- (2) very minor presence of possible base-surge crossbeds;
- (3) sparse bomb sags;
- (4) the abundance of glassy, juvenile debris;
- (5) widely scattered fragments of the underlying Chama—El Rito and Precambrian basement.

The fact that the tuff ring probably erupted in the central part of a large Miocene basin in which numerous streams were depositing a thick pile of porous sand and gravel may imply the presence of abundant interstitial ground water necessary for a phreatomagmatic eruption. Aubele and others (1976) noted the presence of many similar volcanic structures along the Rio Grande rift.

EL RITO CREEK TUFFACEOUS SPATTER CONES

Two tuffaceous spatter cones of basaltic composition are exposed 12 km southwest of Ojo Caliente along El Rito Creek (Figs. 1, 7). These vents occur in the lower part of the middle Chama—El Rito and are probably 0-40 m stratigraphically lower than the Ojo Caliente vent. A tuffaceous spatter facies and a surrounding fluvial volcaniclastic facies are recognized. The two vents are partly covered by the Chama—El Rito beds and Quaternary alluvium of El Rito Creek. Mineral composition, texture, general appearance, and age of the tuffaceous spatter facies are nearly identical to those of the vent facies of the Ojo Caliente tuff ring, implying a similar magmatic source. The El Rito Creek vents are smaller than that of the Ojo Caliente tuff ring and the surrounding fan of air-fall is less well exposed at the current level of erosion.

Ekas and others (this guidebook) report a 15.3 ± 0.4 m.y. K—Ar date on a basaltic bomb derived from the vent on the east side of the creek. This age determination is significant because it probably dates the entire volcanic field, thereby providing age-control through the mid-Miocene part of the section for a distance of 20 km between Ojo Caliente and the lower El Rito Creek area.

Tuffaceous Spatter Facies

The western part of a tuffaceous spatter cone is exposed along the west side of N.M. 96 in a northeast-trending elliptical outcrop (Fig. 7). The eastern side of the exposure is in contact with downfaulted beds of the Chama—El Rito that are stratigraphically 30-60 m higher than the cone. The debris is an obscurely bedded accumulation of maroon, basaltic tuff mixed with abundant, dark-gray basaltic spatter and egg-

shaped bombs slightly flattened parallel to layering in the tuff. The obscure layers appear to dip radially away from a point near the highway, and probably represent material aerially deposited on the outer flanks of a volcano whose vent is now beneath El Rito Creek alluvium. The debris occurs as ill-defined, layered units that probably resulted from either eruptive surges causing variations in the amount of basaltic spatter that accumulated on the upper flanks of the volcano, or possibly from minor lahars of volcanic debris that moved down the side of the volcano. The debris appears to dip to the west beneath the green, red, and light-brown tuff and tuffaceous sandstone in the volcaniclastic facies surrounding the vent, indicating burial of the cone by the tuff. The presence of very sparse bomb sags in the tuff and obscure layering that dips radially away from the cone imply a local source for the tuff in the vicinity of the vent.

The eastern tuffaceous spatter cone, east of the creek, appears to overlie the center of a bowl-shaped structural depression in the underlying volcaniclastic facies (Fig. 7). Dips in the surrounding volcaniclastic facies range from 9 to 45° inward. Only the northern halves of the cone and depression are exposed. Because of later southwestward tilting of the area, the Chama—El Rito still unconformably overlies the southwestern half of the volcano and depression. A small outlier of Chama—El Rito also unconformably overlies the western side of the vent margin. To the southeast, the lower Ojo Caliente Sandstone is downfaulted against the depression by a later fault.

The northern half of a circular vent, 240 m across, is identified in the cone by steep inward dips in the obscurely bedded tuffaceous spatter facies and by slightly greater amounts of ropey bombs and red, scoriaceous basalt. Obscure eastward dips a few meters to the east of the vent margin are thought to be tuffaceous spatter and flows erupted from the vent and deposited on the outer slopes of the cone. Because the outer flanks of the cone appear to stratigraphically overlie the volcaniclastic facies, this cone may be slightly higher in the section and younger than the western cone. The scoriaceous basalt of the vent has a dark, glassy, extremely vesicular groundmass containing red to opaque hematite and finely divided magnetite. Suspended in the groundmass are tiny laths of plagioclase and grains of augite. Amygdules are mainly filled with calcite and a few are lined with tridymite(?).

Volcaniclastic Facies

The spatter cones are surrounded by volcaniclastic facies of dark-green, red, and light-brown tuffaceous sandstone and lesser air-fall tuff derived from the volcanoes. The debris grades laterally outward and intertongues with beds of the Chama—El Rito. The relationship is seen best on the east side of Arroyo del Perro 2.5-3 km north of Highway 96, where a thick section of green tuffaceous sandstone grades north into light-brown, arkosic sandstone.

Most tuffaceous layers consist of variegated, poorly sorted fluvial sandstone with minor amounts of locally derived basaltic debris. Typical constituents are grains of quartz (45-65%), feldspar (25-30%), granules and pebbles of andesite and latite (5-10%), basaltic ash and lapilli (0-20%), fragments of Tertiary sandstone and Precambrian metamorphic rock (0-3%), opaque minerals (0-2%), and variable secondary calcite. Chips and blocks of locally derived basalt are most common near the vents. Fluvial crossbeds and channel fills are widespread.

Several other isolated outcrops of the volcaniclastic facies are in fault contact with the Chama—El Rito 6 km to the west (Fig. 1). The beds are mainly red and green tuffaceous sandstone with minor rhyolite pebbles and much secondary calcite, and are overlain by a slight angular unconformity. Correlation with the volcaniclastic facies of El Rito Creek is likely, but is difficult to demonstrate because of poor intervening exposures. Interbedded layers of andesite- and rhyolite-pebble conglomerate and arkosic sandstone of the Chama—El Rito occur at various levels in the volcaniclastic facies and indicate continued deposition of the Chama—El Rito during volcanism and erosion of the tuffaceous debris.

The abundance of arkosic sandstone and sparse andesite pebbles in the volcaniclastic facies indicate that the Chama—El Rito streams were



Quat.	Qal	alluvium		contact
	Qt	terrace deposits		normal fault showing dip and downthrow
Miocene	Tsto	Ojo Caliente Sandstone		strike and dip of beds
	Tet	volcaniclastic facies		inferred strike and dip of beds
	Tev	tuff-spatter facies		vent margin (dotted where concealed)
	Tstc	Chama-el rito beds		

FIGURE 7. Geologic map of El Rito Creek tuffaceous spatter cones, 5 km northeast of Rio Chama on N.M. Highway 96. Modified from May (1980).

able to maintain their southwesterly course through the basaltic field in spite of the accumulating tuffaceous debris. Some layers of greenish tuff may have formed small fans that rerouted the streams around the lower flanks of the volcanoes, for a short time, but otherwise contributed only moderate amounts of debris to what was mainly Chama—El Rito alluvium. Minor north—northeast-trending growth faults 1 km N20W of the western El Rito Creek vent and a slight angular unconformity at the top of the volcanoclastic facies in some outcrops (Fig. 8) indicate local deformation and erosion during this volcanic episode.

EL RITO CLIFFS VOLCANIC ROCKS

Northeast of the El Rito Creek vent, a greenish-gray volcanoclastic horizon in the lower—middle Chama—El Rito can be traced northeastward for several kilometers between El Rito Creek and an area of high cliffs to the east (Fig. 1). Although the zone is laterally continuous, its thickness and abundance of volcanic debris varies greatly, implying the presence of several widely spaced volcanic sources buried locally in the Chama—El Rito. Overall appearance, composition, and stratigraphic level of the debris are similar to the Ojo Caliente tuff-ring facies and the volcanoclastic facies of the El Rito Creek vents. A small flow and several northeast-trending dikes are petrographically similar to the basaltic debris in the tuffaceous horizon and are probably of similar age and genesis.

The volcanoclastic facies, 10-30 m thick in most areas, is mainly light greenish-gray and greenish-brown fluvial sandstone containing variable amounts of reworked basaltic tuff and debris. Numerous sandy layers contain fluvial crossbeds and sparse channel-fill structures. Locally contorted layers indicate soft-sediment deformation by slumping or possible minor tectonic deformation associated with the eruptions. A persistent angular unconformity seems to characterize the upper contact of the volcanoclastic facies, but is much more subtle than the ones at the Ojo Caliente tuff ring and El Rito Creek vents.

Composition of the clasts is variable, but the sand-sized fraction is mainly poorly sorted, subrounded quartz and feldspar. Less abundant clasts include broken crystals of plagioclase, magnetite, sparse augite(?), devitrified glass shards and secondary epidote, sericite, and calcite. The coarser debris includes scattered angular clasts of slightly amygdaloidal basalt, Precambrian metarhyolite, and sparse pebbles of Tertiary rhyolite, dacite, and andesite.

A small, dark-gray amygdaloidal basalt flow, 1 m thick, overlies the volcanoclastic facies (Fig. 1) and appears to have been fed by a small dike nearby (SW¹/₄ sec. 24, T24N, R7E). Proximity to an explosive



FIGURE 8. Angular unconformity between volcanoclastic facies (Tet) of the El Rito Creek tuffaceous spatter cones and overlying tan Chama—El Rito (Tstc). Two meters high ledge above the unconformity is a well-cemented Chama—El Rito conglomerate layer (also in background at extreme left) along east wall of Arroyo del Perro; 1.5 km northwest of El Rito Creek vents.

vent is indicated by numerous amygdaloidal basaltic bombs and angular blocks of Precambrian metarhyolite. A metarhyolite block, 0.3 m in diameter, occupies 0.5 m deep bomb sag in the underlying sandstone.

Several N20E-trending dikes 0.5 km southwest of the flow (Fig. 1) occur in the underlying Chama—El Rito and are petrographically similar to the flow. The basalt contains nonflow-banded, partly zoned, fine-grained laths of plagioclase (15%), and tiny magnetite specks (1%) in a slightly vesicular tachylite groundmass. The dikes and flow were probably contemporaneous.

MID-MIOCENE STRESS FIELD

Dike trends within the volcanic field indicate that the tensional stress field responsible for the pervasive north—northeast-trending latest Miocene—Pliocene faults in the northwestern part of the Espanola Basin may have been in operation by at least mid-Miocene time. The N20E-trending dikes associated with the El Rito cliffs volcanoclastic horizon are exposed in the lower Chama—El Rito beds, but were probably contemporaneous with mid-Chama—El Rito deposition. Petrographic similarity of the dikes with the small nearby flow in the Chama—El Rito implies a similar age. A north—northeast-trending basaltic dike north of Sierra Negra (Fig. 1) yielded a K—Ar age of 15.9 ± 0.9 m.y. (Manley and Mehnert, 1981) and is probably related to the volcanic field. Three km west of Ojo Caliente, several vertical dikes trend N30E away from the slightly older Cerro Negro plug (see geologic map of Stop 4, third-day road log, this guidebook) and are approximately 18 m.y. old (May, 1980). Several north—northeast-trending growth faults in an area 1 km northwest of the El Rito Creek vents also parallel the north—northeast-trending mid-Miocene dikes of the region. These faults and dikes are consistent with a nearly horizontal, approximately N70W-oriented axis of least principal stress in the mid-Miocene. However, the lack of major faults of this age in the area and throughout the basin indicates that the magnitude of extension was probably very slight at this time. In the latest Miocene and Pliocene, following deposition of most or all of the Tesuque Formation, this stress field must have intensified, producing the pervasive N25E-trending post-Tesuque faults of the region and tilting the rocks southeast into the basin. The three dikes that radiate outward from the Ojo Caliente tuff ring (Fig. 2) may indicate a locally dilational stress environment centered around that vent during eruption.

This local west—northwest direction of extension in the mid-Miocene is suggested for the northwestern part of the Espanola Basin and differs somewhat from more regional interpretations by Zoback and Zoback (1980) and Golombek and others (1983), who have proposed a regional west—southwest direction of extension during mid-Miocene time and a change to west—northwest extension about 10 m.y. ago. Their work is based on a broader range of information throughout the Basin and Range province and the Rio Grande rift.

This local west—northwest-extending domain within the larger west-southwest-extending Basin and Range province may have been mechanically influenced by north—northeast-trending Precambrian tectonic trends or Laramide structural grain parallel to the southern end of the Brazos uplift. Possibly the north—northeast-trending dikes and faults of the mid-Miocene volcanic field signify the presence of north—northeast-trending pre-Miocene fractures that were simply close enough to being perpendicular to a west—southwest axis of extension to allow access to the rising basaltic magma.

CONCLUSION

About 15 m.y. ago, a small field of basaltic tuff rings and tuffaceous spatter cones erupted in the Ojo Caliente—El Rito Creek area during deposition of the middle part of the Chama—El Rito and may be related to basalts of the Hinsdale Formation in the San Luis Basin and Tusas Mountains. The abundance of tephra in the volcanics probably resulted from explosive magma interaction with near-surface ground water in the Chama—El Rito. Subtle angular unconformities, dikes, and a few growth faults near the volcanic centers indicate local structural deformation and possible minor local west—northwest crustal extension accompanying the eruptions. This volcanic horizon dips gently southeast into the subsurface toward the axis of the Espanola Basin and its lateral

extent is not known. A detailed magnetic survey in the northern part of the basin might further delineate the limits of this field.

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