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NEOGENE STRATIGRAPHY AND STRUCTURE OF THE OJO CALIENTE-RIO CHAMA AREA, ESPANOLA BASIN, NEW MEXICO

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INTRODUCTION

The Ojo Caliente-Rio Chama area is located in the northern Espafiola basin of the Rio Grande rift, west of the basin axis, and lies between the town of Ojo Caliente in the north and the Rio Chama in the southwest. The area is characterized mainly by gently southeast-dipping Neogene sandstone, conglomerate and intercalated volcanics that fill the basin and are cut by northeast-trending Pliocene and Quaternary(?) faults. The basin is one of several north-trending, en-echelon structural depressions of late Cenozoic age that form the Rio Grande rift (fig. 1). Downfaulted "basin-fill" sediments of the Santa Fe Group and related beds are exposed throughout most of the basin. Along the western margin of the basin, these beds overlie an unconformity of locally high relief developed on Precambrian crystalline rocks in the Ojo Caliente area and on Mesozoic sedimentary rocks farther south and west.

The basic structure of the Espanola basin is a broad, gentle, northeast-trending syncline with a mainly downfaulted western margin. Within the basin, numerous north- and northeast-trending normal faults are downthrown toward the axis of the syncline. The axis extends southwest under Black Mesa and can be traced farther south where it is overlapped by the Jemez volcanic field. Typical dips on the basin limbs are 3-12° inward. Outliers of Tertiary "basin fill" rocks west of the present fault margin indicate that the original width of the depositional basin was greater than it is today.

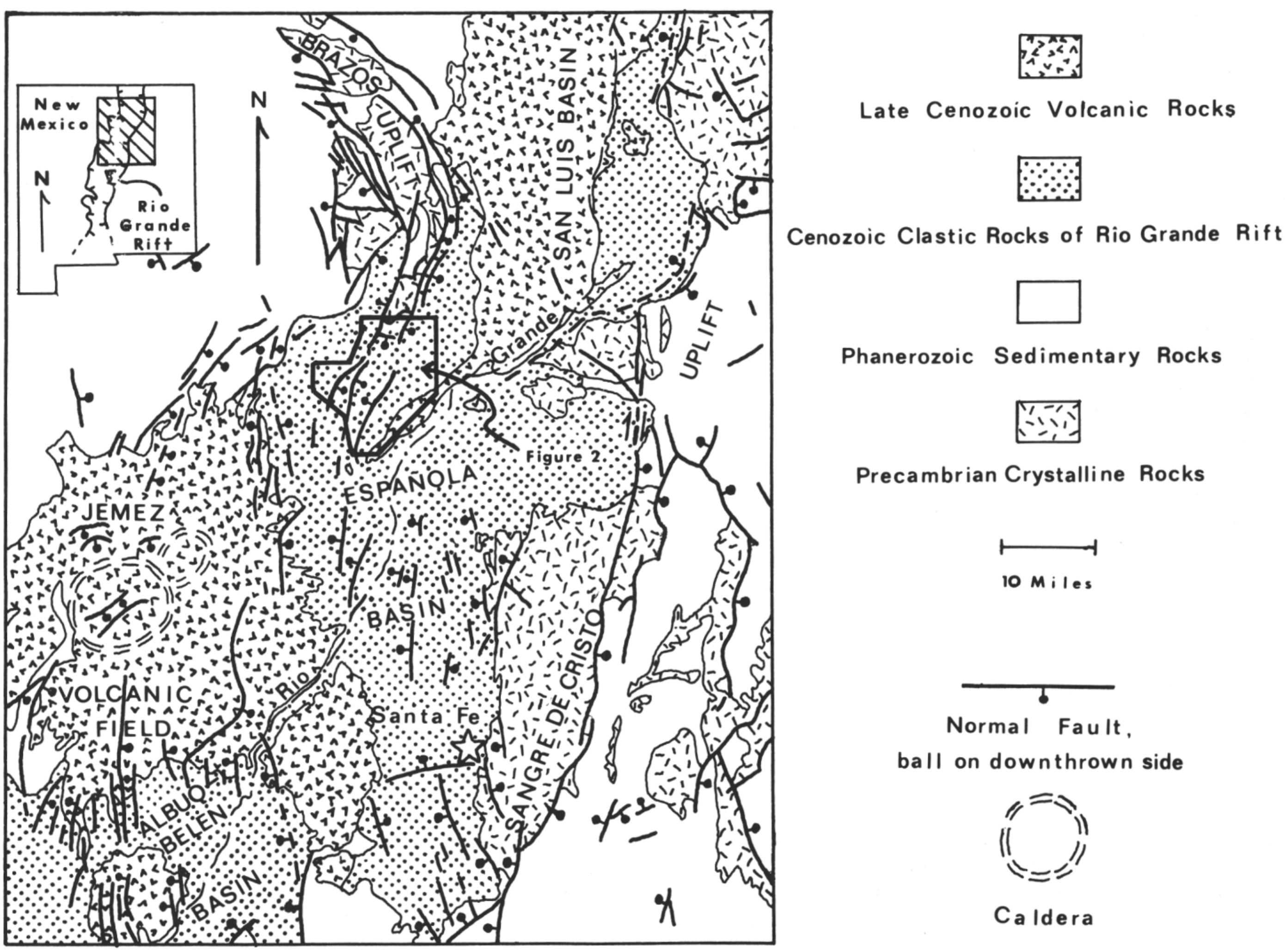

Figure 1. Generalized geologic map of Española basin and vicinity showing location of Ojo Caliente-Rio Chama area (modified from Woodward and others, 1978).

To the north of the Espanola basin, the Tertiary Brazos uplift forms an arcuate horst exposing Precambrian igneous and metamorphic rocks raised vertically along northeast- and northwest-trending faults. The Precambrian rocks are covered locally by mid- to upper Tertiary volcaniclastic rocks including the Oligocene to Pliocene Los Pihos Formation. The southern end of the range plunges gently southward beneath upper Tertiary sedimentary rocks of the basin. The Ojo Caliente-Rio Chama area is part of a gently southeast-dipping homocline forming the western limb of the basin where the uplift and the basin merge.

STRATIGRAPHY

Except for an exposure of Precambrian rocks near Ojo Caliente, the area is underlain by lower Miocene to Recent sand, sandstone and conglomerate with minor volcanic flows, dikes and tuff (fig. 2). All units except the Miocene Ojo Caliente Sandstone locally contain appreciable amounts of tuffaceous debris. Stratigraphy in the area is summarized in Figure 3. The Oligocene to Miocene Abiquiu Tuff is the lowest exposed stratigraphic unit and unconformably overlies the Precambrian igneous and metamorphic rocks of the Ojo Caliente area in the north. The formation consists of light-gray to variegated tuffaceous sandstone with minor volcanic-pebble conglomerate near the top. Its thickness (0-60 m) is controlled largely by erosional relief developed on the underlying Precambrian rocks. Three kilometers west-southwest of Ojo Caliente, a quartz-tholeiite flow, possibly correlative with the Jarita Basalt Member of the Los Pinos Formation of Butler (1946) and an olivine-nephelinite flow(?), both within 50 m of the top of the Abiquiu, have been dated radiometrically at 22.1 m.y. and 18.9 m.y., respectively (Scott Baldridge, 1979, personal commun.). The Abiquiu grades upward and possibly northward into the lower Los Piños in the north part of the area. Farther south, it appears to grade upward into the Chama-el rito Member of the Tesuque Formation of Galusha and Blick (1971). Its uppermost part may be laterally equivalent to the basal Chama-el rito, though the evidence for this is tenuous.

The Los Pinos Formation in the Ojo Caliente area (Cordito Member? of Barker, 1958) consists of roughly 410 m of gray volcanic- and metamorphic-pebble conglomerate and tuffaceous sandstone with a few light-brown, tuffaceous sandstone beds similar to the Chama-el rito Member of the Tesuque Formation. The Los Pihos grades southward into and intertongues with the Chama-el rito, and possibly, the upper Abiquiu. In the Ojo Caliente area, the formation also grades upward into a thin tongue of Chama-el rito (fig. 3). Local sedimentologic evidence (i.e., crossbeds, paleochannel axes and pebble imbrications) indicates that the Los Pinos formed a broad, south-sloping alluvial fan derived from the erosion of an Oligocene to Miocene volcanic source area of intermediate composition to the north (probably the southern San Juan Mountains).

The Chama-el rito (lower member of the Tesuque Formation of Galusha and Blick, 1971) consists of 30-550 m of pink and tan, slightly tuffaceous sandstone and siltstone with interbedded lenses of gray volcanic-pebble conglomerate similar to the Los Piiios. The conglomerate lenses gradually become thinner, fewer and finer grained to the south, and probably represent the distal ends of the Los Pihos alluvial channels that extended into that part of the basin where the Tesuque was accumulating. The Chama-el rito grades upward as a series of tongues into the overlying Ojo Caliente Sandstone through an interval of 25-75 m, and probably grades downward into the Abiquiu Tuff throughout much of the area, though this relationship can be seen only west of El Rito Creek. A small, partly buried field of basaltic tuff rings occurs in the middle part of the Chama-el rito between Ojo Caliente and the Rio Chama (fig. 3). A vent exposed along El Rito Creek has yielded a tentative 13 m.y. radiometric date (Kim Manley, 1978, personal commun.). A more well exposed vent occurs at the same stratigraphic level 3 km southwest of the town of Ojo Caliente. These tuff rings are higher stratigraphically than the Jarita Basalt but are petrographically similar.

The Miocene Ojo Caliente Sandstone (upper member of the Tesuque Formation of Galusha and Blick, 1971) is a 160-m thick, tan, crossbedded, eolian sandstone with a few beds of light-gray, airfall tuff and tuffaceous sandstone near the base. Quartz and feldspar predominate. The predominance of east-dipping eolian crossbeds implies deposition by prevailing westerly winds in the Miocene, and therefore, a westerly source. The sandstone is overlain unconformably (?) by the Chamita Formation along the sides of Black Mesa. Regionally, the lower contact of the Ojo Caliente with the Chama-el rito is probably more closely parallel to bedding and inferred time-lines than are other mapped lithologic contacts in the area. Yet, it too appears to rise and fall stratigraphically and may fall regionally 30-50 m relative to bedding when traced westward from Black Mesa to El Rito Creek.

The upper Miocene Chamita Formation consists of a series of brown, fluvial sandstone beds with numerous tuffs and tuffaceous sandstones throughout. Two zircon fission-track dates of 5.2 and 5.6 m.y. from tuffs in the formation were reported by Manley and Naeser (1977). An abbreviated section 160-m thick along Black Mesa overlies the Ojo Caliente and is overlain unconformably by Servilleta Basalt from which Manley (1976) reported a 2.8-m.y. K-Ar date.

In summary, the stratigraphy in the Ojo Caliente-Rio Chama area is moderately complex. Vertical and lateral facies changes complicate defining and mapping of lithologic units. Contacts of many mapped units are gradational, and in some areas, contacts cut across bedding in a regional sense. Few, if any, lithologic contacts are isochronous, and fossils and marker beds are rare. Precise correlation of units between the east and west sides of the Espanola basin is still uncertain because of the lack of stratigraphically deep exposures along the basin axis. Total exposed stratigraphic thickness is approximately 900 m plus an unknown thickness of unexposed Abiquiu Tuff and older(?) rocks in the central part of the area.

STRUCTURE

The basic structure of the Ojo Caliente-Rio Chama area consists of a faulted homocline dipping gently southeast and forming part of the western limb of the Espanola structural basin (figs. 1, 2). Although there is a wide scatter in the strikes of bedding attitudes, dips in the west are approximately 10-12° southeast and decrease to less than 3° near the basin axis under Black Mesa. Tertiary rock units exposed at the surface range from the upfaulted Abiquiu Tuff at the west edge of the area to the Chamita Formation and Servilleta Basalt at Black Mesa in the southeast.

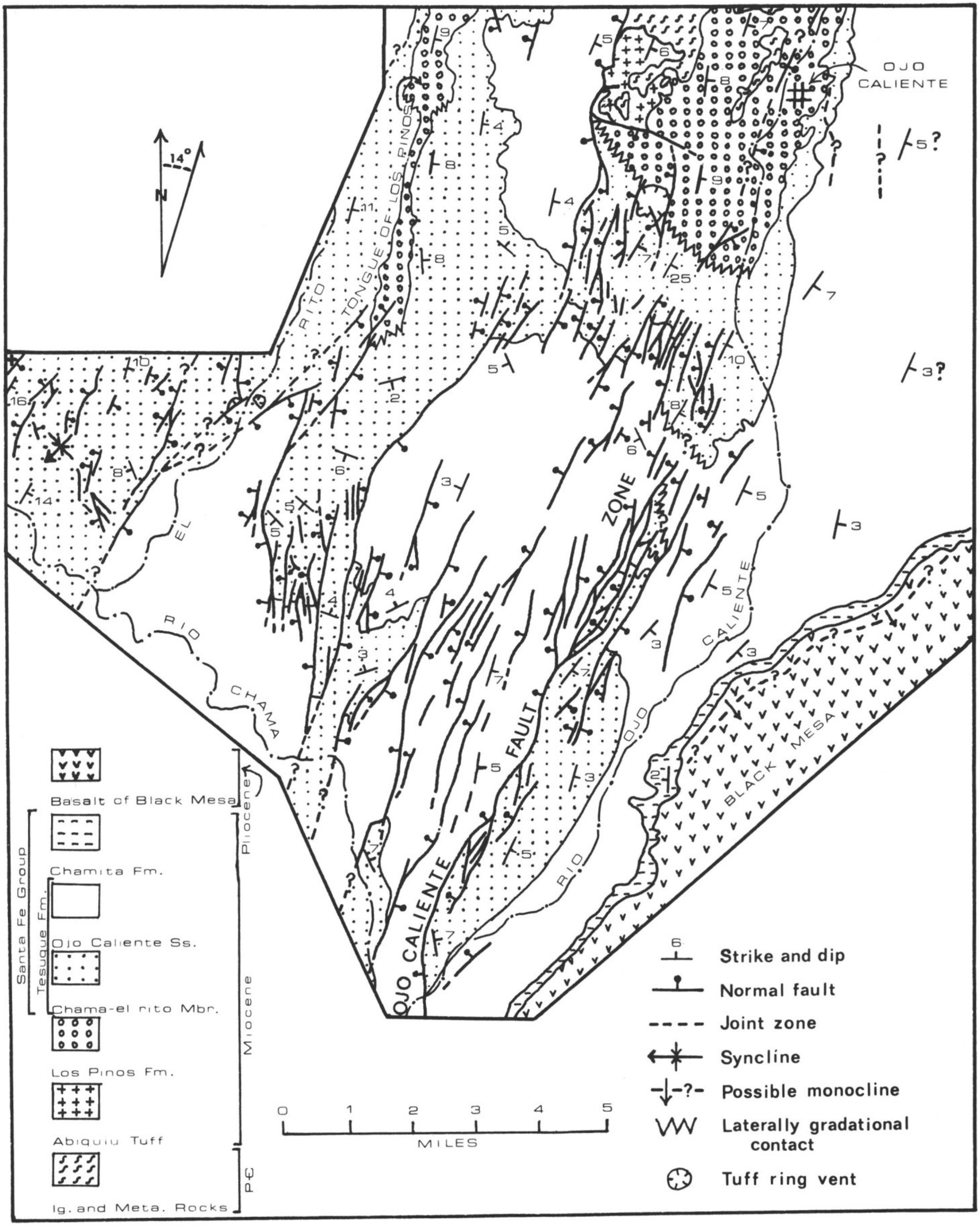

Figure 2. Generalized geologic map of Ojo Caliente-Rio Chama area. Quaternary rock units not included.

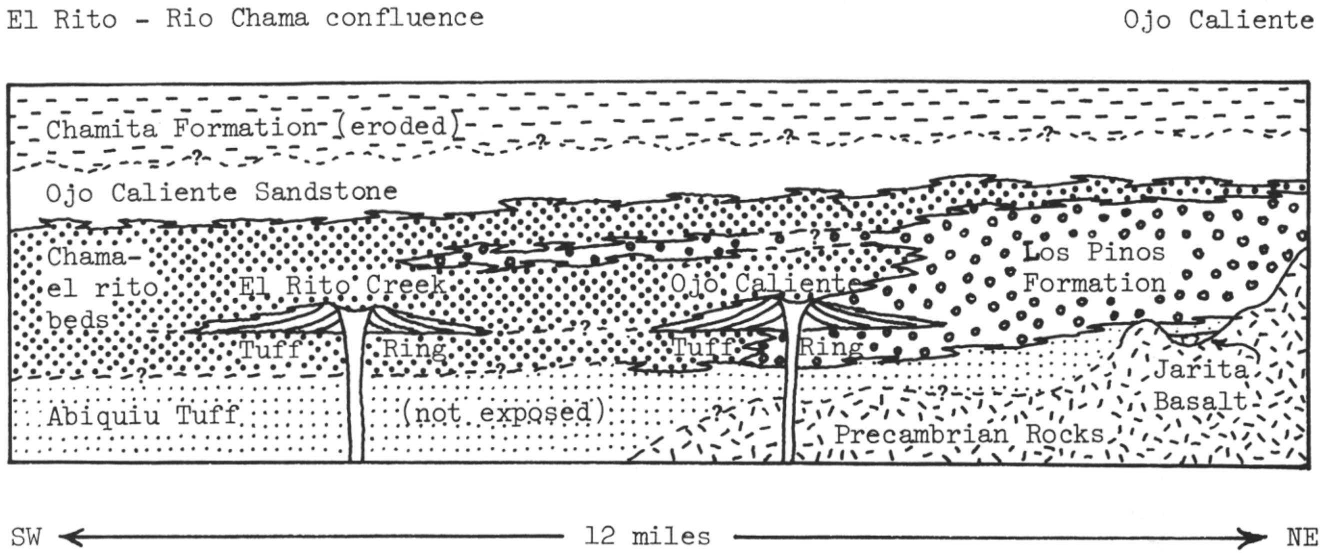

Figure 3. Generalized stratigraphic section from Ojo Caliente to the El Rito-Rio Chama confluence.

Geometry

Ojo Caliente prong

In the north, the homocline is offset by an uplifted ridge of Precambrian rocks (Ojo Caliente prong of Kelley (1952)) which plunges south beneath the Tertiary sediments of the basin. This structural high is the southern extension of the Brazos uplift and forms the topographic crest of a large, south-trending, east-tilted block whose eastern margin has been overlapped by the lower Miocene Cordito (?) Member of the Los Pifios Formation. A major south-trending fault with over 400 m of throw along the west side of the "high" brings the Ojo Caliente Sandstone down against Precambrian rock. Eastward tilting of the block might imply a listric configuration for the western marginal fault, with the dip of the fault flattening to the west at depth.

A regional, complete bouguer gravity map of the Rio Grande rift by Cordell (1976) shows a gravity high plunging south from the Ojo Caliente area, possibly reflecting this buried ridge. However, Cordell's accompanying structure contour map of the top of the Precambrian (based on interpretation of the gravity) shows no ridge, but rather a moderately steep, southwest-sloping surface which flattens into a broad shelf between Ojo Caliente and the Rio Chama. A detailed gravity survey might help define the shape of the subsurface extension of the possible ridge more clearly.

Faults

Throughout much of the area, the southeast-dipping homocline is cut by a series of N25E-trending, high-angle normal faults, the majority of which are downthrown to the west (antithetic to the homocline), mostly with less than 20 m of throw. As a result, the upper Chama-el rito and the lower Ojo Caliente are faulted up to the surface throughout much of the mapped area.

A poorly defined graben in the central and southern part of the area (fig. 2) creates a large exposure of Ojo Caliente Sandstone that tapers in a S25W direction. Another downfaulted block is delineated by a north-tapering exposure of the Ojo Caliente at the confluence of El Rito Creek and the Rio Chama. Total structural relief across these grabens is no more than 100 m.

Fault traces throughout the area are linear to slightly arcuate and a few branch. Many have slightly en-echelon arrangements and some occur in ill-defined groups. Most occur within the Chama-el rito and lower Ojo Caliente Sandstone, partly reflecting a greater difficulty in tracing faults through the middle and upper Ojo Caliente due to its lack of marker beds. Although the general lack of faults in the middle and upper Ojo Caliente Sandstone could also indicate a pre-late Ojo Caliente age to the faults, this conclusion seems unwarranted because I found no other evidence of growth faults or other types of fault-control on the stratigraphy.

Most fault planes appear to be approximately planar, and few, if any, can be seen to steepen or flatten systematically at lower erosional levels. However, local erosional relief on the faults rarely exceeds 100 m. Dips normally are 65°-85° and only a few minor faults dip less than 50°. Dips on any one fault generally vary less than 15°, though a few vary by as much as 25° where traced more than 2 km.

Many faults are narrow zones of very closely spaced, parallel joints and slip surfaces, each of which generally has the same sense of throw. The Tertiary rock units apparently were slightly to moderately indurated when post-Santa Fe faulting occurred. Brecciation commonly accompanies faults of relatively large throw and usually only in the more competent (cemented) beds. These breccia zones may imply that the faults slipped, then were cemented locally by percolating groundwater, and were reactivated, thus brecciating the harder (cemented) areas.

The most intense faulting and cementation occur along the Ojo Caliente fault zone extending N25E from the confluence of the Rio Chama and Rio Ojo Caliente to the town of Ojo Caliente (fig. 2). One fault extends a minimum of 10 km before branching at its northern end and is downthrown approximately 90 m to the west. This fault also forms the eastern side of the south-tapering graben mentioned previously. Many smaller en-echelon faults immediately to the east are also down to the west.

Many of the larger faults may extend down to pre-Santa Fe faults in the Precambrian, and may represent reactivation of the older faults by nearly vertical slippage between the rigid basement blocks during the post-Santa Fe deformation. The major faults at the surface, therefore, may define the margins of the larger basement blocks. One possible example is the Ojo Caliente fault zone which seems to be continuous with the east side of the Ojo Caliente prong and may reflect either post-Santa Fe foundering of this block in the south part of the mapped area or rotational uplift of another basement block east of the fault zone.

Folds

In some areas, strikes of bedding in the Tertiary rocks vary greatly, implying the presence of scattered asymmetric arches, sags and monoclines of apparently random orientations. Most of the folds are too irregular in shape and have dips that are too low to clearly define fold axes without numerous strike and dip measurements. Locating fold axes also is complicated by the lack of dip reversals and structural closure on many of the flexures. Sizes of the folds range from a few hundred meters long with less than 10 m of structural relief to several km long with up to 200 m of relief. Many warps may become sharper at depth and trend downward into faults in the underlying rigid Precambrian rocks. A few of the flexures are strikingly transverse to the northeast regional fault trend, possibly reflecting transverse basement faults similar to the one southwest of Ojo Caliente (fig. 2). Locally, these warps produce sharp increases and decreases in stratigraphic throw where they terminate at fault traces. Except for a couple of narrow monoclines, most folds have dips of less than 15°. One northeast-trending monocline, 5 km south-southwest of Ojo Caliente has southeast dips of up to 40°, possibly reflecting an underlying fault.

Minor drag in the sedimentary rocks occurs along faults of relatively large throw. Dips generally steepen to 10-20° but flatten 50 m from the faults. Most of these folds probably die out at deeper levels immediately above the rigid basement. Folds generally cannot be traced through the Ojo Caliente Sandstone because of eolian crossbedding and lack of planar bedding.

Kinematics

Faults

In general, faults less than 100 m long have less than 5 m of throw; those of about one km length have average throws of 5-25 m; those more than 3 km long generally exhibit 25-100 m of throw, though the west fault of the Ojo Caliente prong has over 400 m of displacement.

On all faults where the sense of throw can be determined, a normal sense of movement is indicated. The amount of oblique slip appears to have been minor on the basis of six relatively good exposures of slickensides (fig. 4). Three exposures show 90° rakes (no oblique motion), two show 80° rakes (one with right-lateral and one with left-lateral motion) and one has a 55° rake (left-lateral motion). Possibly, post-Santa Fe faulting involved minor changes from right- to left- to right-lateral components of movement through time, or perhaps the variations in rake reflect minor mechanical readjustments of the rocks to the regional stress field in which different directions of movement resulted from varying rock strengths from place to place on a local scale. No predominance of either right-lateral or left-lateral fault motion can be inferred from the data. However, the 55°-raking left-lateral slickensides are consistent with Muehiberger's suggestion (this

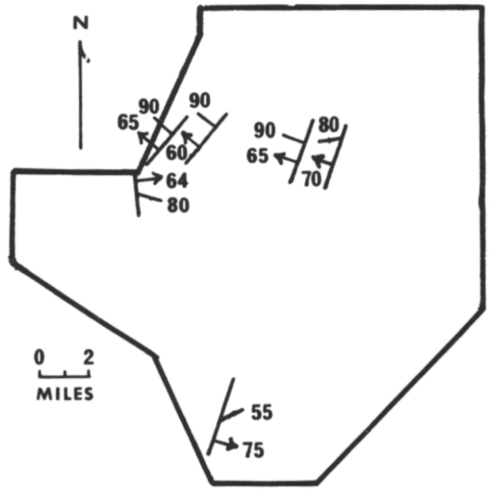

Figure 4. Outline of Ojo Caliente-Rio Chama area showing six normal faults along which slickensides are preserved well. Arrows show fault dips and hatchures give rakes of slickensides.

guidebook) that the N60E-trending Embudo-Velarde fault trend, located to the east, is a left-lateral intracontinental transform fault.

Folds

The irregular shapes and orientations of most folds in the Ojo Caliente-Rio Chama area imply mainly vertical arching and sagging of the Tertiary sediments, probably in response to vertical motions in the underlying Precambrian rocks. Large, gently dipping homoclinal areas at the surface probably overlie the tops of large, slightly tilted basement blocks. Areas of local steepening may overlie faults that allowed differential vertical motion between the blocks. The horizontal component of movement within the folds is small and probably resulted from: (1) minor stretching of the surface beds during arching and sagging over the tops of vertically shifting basement blocks, and (2) extension of the Tertiary sedimentary cover in response to an undetermined amount of northwest-southeast horizontal extension in the basement.

Mechanics

The mechanical behavior of the sedimentary rocks has been one of passive flexing and faulting in response to vertical block-faulting in the underlying rigid basement that occurred when northwest-southeast tension was transmitted through the basement rocks of the immediate area. Shear resulting from differential settling and tilting of the crystalline basement propagated upward through the sedimentary cover to form faults and many of the minor, randomly oriented monoclines, drape folds and broad sags exhibiting tensional characteristics. Some of the faults with less than 15 m of throw may die out downward within the sediments, reflecting small-scale adjustments of the beds during flexing. Major faults at the surface probably formed over faults of relatively large displacement in the basement. Tertiary units exhibit only slight to moderate mechanical strength, and though faults are closely spaced locally, the extensional forces in these rocks were probably of low intensity. Little, if any, evidence exists locally for cornpression during post-Santa Fe deformation in spite of recently discovered active reverse faults along the Embudo fault zone between Pilar and Ranchos de Taos (Muehlberger, this guidebook).

History of Deformation

In the Ojo Caliente-Rio Chama area, two broadly defined deformational events are recognized easily: (1) Eocene (?)-Oligocene (?) downwarping of the basin in which Oligocene to Miocene sediments accumulated, and (2) post-Santa Fe faulting and continued downwarping with rocks as young as or younger than the 2.8 m.y.-old Servilleta Basalt involved.

Local evidence of the downwarping and initiation of the Espanola basin occurs where the Abiquiu Tuff and Los Pinos Formation overlie Precambrian rocks near Ojo Caliente. An angular unconformity between the Abiquiu and underlying Eocene-Oligocene El Rito Formation along the western margin of the basin also may reflect this deformation.

The tensional stress field that later produced the N25E-trending post-Santa Fe faults probably started during Miocene deposition of the Abiquiu Tuff and Tesuque Formation. A basalt dike dated at 9.8 m.y. (Bachman and Mehnert, 1978) intruded a fault that offsets the Abiquiu Tuff west of the town of Abiquiu, therefore indicating a Miocene age for the fault.

Evidence of Miocene jointing occurs in the northwestern part of the Ojo Caliente-Rio Chama area 6.5 km north of the El Rito Creek vent where several basaltic dikes (parallel to the N25E-trending post-Santa Fe faults) intruded the lower Chama-el rito beds but were probably contemporaneous with mid-Chama-el rito deposition. Petrologic similarity of the dikes with the Ojo Caliente and El Rito Creek tuff rings and a small nearby flow in the Chama-el rito, suggests a common age. A small number of vesicles in the dike also may indicate near-surface conditions during injection. For these dikes to be parallel to the post-Santa Fe faults, it seems likely that the dikes intruded a pre-existing, N25E-trending joint set which was forming during mid-Chama-el rito deposition.

Following Santa Fe deposition, the tensional stress field must have intensified, producing the pervasive N25E-trending, post-Santa Fe faults and tilting the Tertiary rocks southeastward toward the basin axis. Post-Santa Fe deformation seems to have climaxed around 3-5 m.y. ago (early Pliocene). The Velarde graben, near the basin axis, offset the Chamita Formation containing 5.6 and 5.2 m.y. old tuffs and was overlapped by the 2.8 m.y. old Servilleta Basalt of Black Mesa (Manley, 1976, 1979; Manley and Naeser, 1977). The N25E-trending faults in the Ojo Caliente-Rio Chama area probably formed at this time and now are overlapped by upper Quaternary stream gravels, none of which is offset clearly in the immediate area. Continued minor downwarping and faulting of the basin are implied by a very gentle southeasterly dip in the Servilleta Basalt at Black Mesa, recent topographic leveling reported by Reilinger and others (1979), and recent local micro-earthquakes. Some Rio Chama terrace gravels appear to have been offset also by faults west of Abiquiu. Kelley (1978) mapped faults cutting the terrace gravels of El Rito Creek near the Rio Chama, but I interpret these as the original edges of stream terraces (May, 1979).

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