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1961, pp. 139-143. https://doi.org/10.56577/FFC-12.139

in:

Albuquerque Country, Northrop, S. A.; [ed.], New Mexico Geological Society 12 th Annual Fall Field Conference Guidebook, 199 p. https://doi.org/10.56577/FFC-12

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OUTLINE OF THE GEOLOGY OF THE JEMEZ MOUNTAINS, NEW MEXICO[1]

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INTRODUCTION

The Jemez Mountains have long been recognized as the site of the Valles caldera, popularly known as one of the largest volcanic "craters" in the world, and for this reason alone the mountains are of unusual interest geologically. They are in addition, however, important for the influence they have had locally on the structural and geomorphological development of the Rio Grande depression, a major structural feature of southern Colorado and New Mexico.

Little has been published concerning either the Valles caldera or the volcanic geology of the Jemez Mountains—although a number of geologists have mapped parts of the area or mentioned it incidentally in reports on adjacent areas (Newberry, 1876; Iddings, 1890; Reagan, 1903; Lindgren, Graton, and Gordon, 1910; Henderson, 1913; Ross, 1931, 1938; Bryan, 1938; Smith, 1938; Church and Hack, 1939; Denny, 1940; Wood and Northrop, 1946; Stearns, 1953; Kelley, 1956). This report constitutes a brief summary of the results of the authors' investigations in the area since 1946, and it is hoped that it will help fill a void that has persisted in the geologic literature of New Mexico for 50 years or more.

Physiographic and Geologic Setting

The Jemez Mountains are along the western margin of the Rio Grande depression and are bounded on the north by the Chama basin, the east by the Espanola-Santa Fe basin, the south by the Albuquerque-Belen basin, and the west by the Sierra Nacimiento. The Jemez Mountains constitute a complex volcanic pile of Tertiary and Quaternary age and consist geomorphologically of a maturely eroded, central mountainous mass surrounded by more youthfully dissected plateaus and mesas. In the midst of the mountains is the Valles caldera, a subcircular volcanic depression 12 to 15 miles in diameter, 500 to 2,000 feet deep, and surrounded by peaks that rise to altitudes exceeding 10,000 feet. Within this depression are the beautiful high-montane valleys for which the region is so well known and from which the mountains take their name [Sierra de los Valles or Valles Mountains]. Valle Grande is the largest and best known of these valleys, but Valle Toledo, Valle San Antonio, and several other valleys to the north and west are equally beautiful, though less accessible. Separating these valleys are a dozen or more dome-shaped mountains; the largest is Redondo, which rises to an altitude of 11,254 feet in the center of the caldera.

The volcanic rocks of the Jemez Mountains unconformably overlie igneous, metamorphic, and sedimentary rocks ranging in age from Precambrian through late Tertiary. On the west, they rest on dominantly Paleozoic and Mesozoic sedimentary rocks that form the eastward-dipping backslope of the Sierra Nacimiento (Wood and Northrop, 1946). On the north, east, and south they overlie middle and upper Tertiary sediments of the Santa Fe group: the Abiquiu tuff of Miocene age (Smith, 1938) and a sequence of arkosic sands and silts of late Miocene and Pliocene age—the Santa Fe formation of Hayden (1869) and as used by Cope (1877), Johnson (1903), Osborn (1909, 1918), Frick (1933, 1937), Bryan (1938), and Denny (1940).

Volcanic Stratigraphy

Volcanism in the Jemez Mountains probably began in early to middle Pliocene time with the eruption of basalt; it continued throughout the Pliocene with the successive eruption of andesite, dacite, quartz latite, and associated rhyolite; and it culminated in Pleistocene time with the catastrophic eruption of tremendous volumes of rhyolitic ash flows. As a result of this culminating series of outbursts, two calderas of slightly different ages formed: the younger and largest is the Valles caldera; the older, here unnamed, was truncated by the younger; the remaining segment is northeast of the Valles caldera near the head of Santa Clara Canyon. Subsequent activity was confined within the Valles caldera and included structural adjustments of the caldera floor and the eruption of rhyolitic domes and flows.

The following is a much simplified description of the stratigraphy of the Jemez Mountains volcanic rocks. The areal distribution and stratigraphic relations of the major units are generalized in Figures 1 and 2.

The earliest basaltic lavas of the Jemez Mountains erupted from numerous centers over a wide area. They formed a field of low coalesced shields, the remnants of which now form Borrego Mesa in the south and Lobato Mesa and Mesa de la Grulla in the north. In the vicinity of Bear Springs a group of rhyolites is interbedded with these early basalts, and on Borrego Mesa rhyolite tuffs associated with these centers are exposed between two sequences of basalt flows.

A thick sequence of andesitic tuffs, breccias, and flows overlies the basalts and rhyolites. These rocks crop out most extensively in the southern Jemez Mountains and are well exposed in Paliza, Peralta, and Cochiti Canyons, in the San Miguel Mountains, locally in Santa Clara Canyon, and in the walls of the Valles caldera. They represent the remnants of coalesced composite cones built upon the earlier basaltic shields.

Overlying but locally interbedded with the andesites is a thick sequence of dacites and quartz latites. These rocks locally attain a thickness of 2,000 feet and individual flows may be as thick as 800 feet. They occur mainly in the central and northern Jemez Mountains and make up most of the peaks surrounding the calderas. Excellent exposures occur in Guaje and Santa Clara Canyons and in upper Rio del Oso and Polvadera Creek. A number of well-preserved and relatively young centers of this group of rocks occurs on the western side of Lobato Mesa and on Mesa de la Grulla. Very late Pliocene or Pleistocene basalt flows are associated with some of these centers. The younger basalts of the Cerros del Rio, east of the Rio Grande, may also be contemporaneous.

[1]Publication authorized by the Director, U. S. Geological Survey. As submitted, this title read: "Outline of the geology of the Valles Mountains, New Mexico." The term "Valles Mountains" has been changed to "Jemez Mountains" throughout the paper. The term "Valles caldera" has not been changed. — **Ed.**

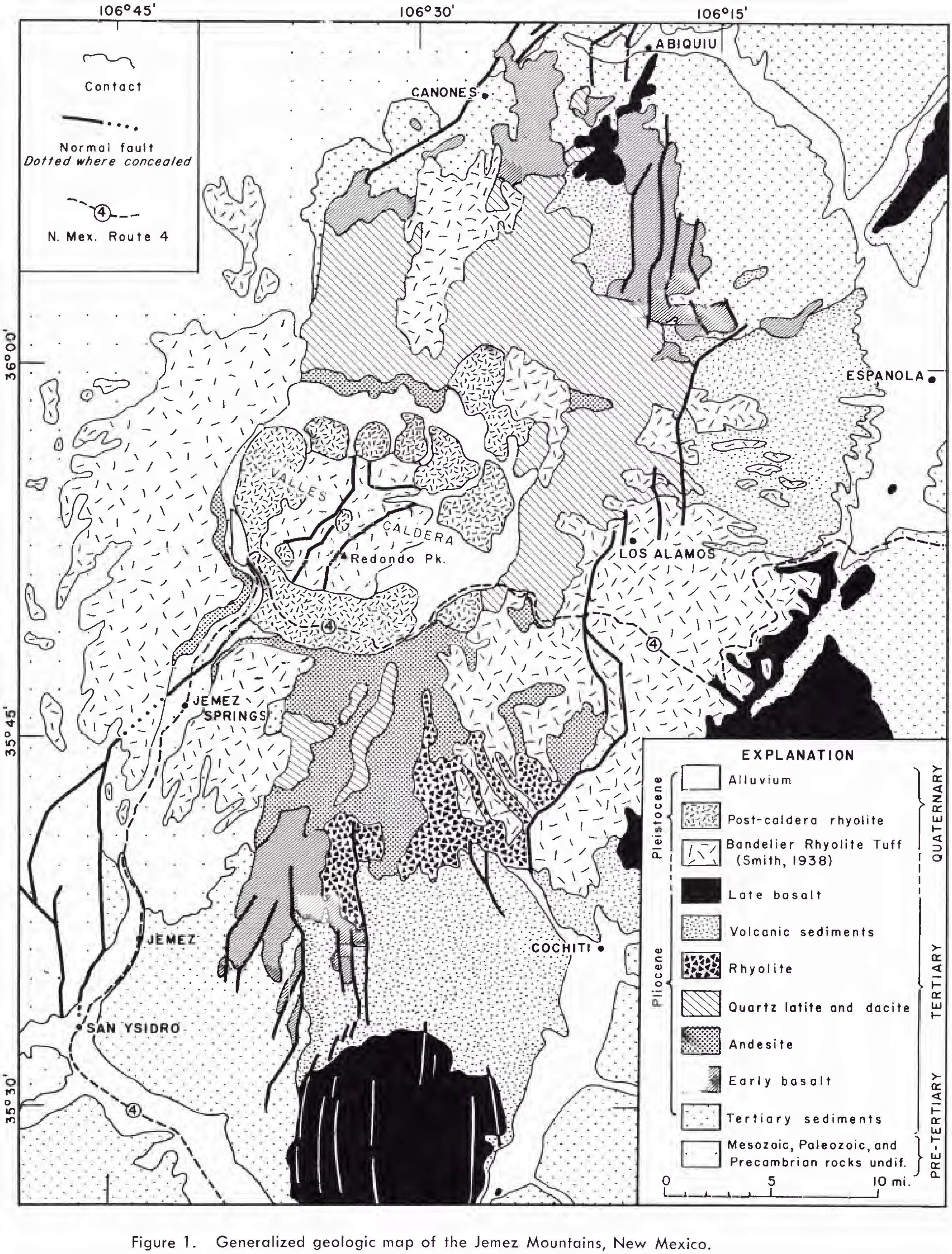

Figure 1. Generalized geologic map of the Jemez Mountains, New Mexico.

In the southern mountains a second group of pre-caldera rhyolites intrudes and overlies the andesites and older dacites. The largest center for these rocks is in the vicinity of Bearhead, where nearly 2,000 feet of rhyolitic tuffs, breccias, and flows occur. The Peralta tuff member (local usage) of Bryan and Upson (see Stearns, 1953, p. 499-500) exposed in lower Peralta Canyon is related to this center.

All the above-mentioned volcanic rocks are interbedded with thick sequences of volcanic sediments. These deposits, mainly fanglomerates, mud-flow deposits, and reworked pyroclastic materials, accumulated as broad fans on the eastern and southeastern flanks of the mountains. Typical of these deposits is the Puye gravel of H. T. U. Smith (1938) which is well exposed along the northeastern margin of the Pajarito Plateau. Genetically comparable but older deposits are exposed farther south in the vicinity of Cochiti Pueblo.

Unconformably overlying all these older volcanic rocks and sediments, which constitute the pre-caldera edifice of the Jemez Mountains volcanic pile, is the Bandelier rhyolite tuff (Smith, 1938). These tuffs are the deposits of hot, turbulent ash flows. They erupted from the crest of the Valles range from centers now obscured, poured down valleys in the higher mountainous terrain, and spread out as broad coalescing fans on the gentler surrounding slopes. These tuffs underlie the Pajarito and Jemez Plateaus on the east and west and Mesa del Medio on the north. They cover an area of nearly 400 square miles, locally attain a thickness of 1,000 feet, and represent the accumulation of more than 50 cubic miles of ash and pumice.

The Bandelier rhyolite tuff is composed of two distinct depositional sequences that are separated locally by a marked erosional disconformity. Each of these depositional sequences is correlative with one of the two calderas in the mountains, the lower sequence having its source in the older caldera at the head of Santa Clara Canyon, and the upper sequence having its source in the Valles caldera. Although the rocks in each of these sequences superficially resemble each other, they may be distinguished by means of a number of diagnostic criteria, the most conspicuous of which is the greater amount of accidental lithic inclusions in the lower sequence.

The youngest volcanic rocks in the Jemez Mountains are the Pleistocene rhyolites that fill the Valles caldera and constitute the volcanic domes of San Antonio Mountain, Cerro Santa Rosa, Cerro del Abrigo, Cerros de los Posos, Cerro del Medio, Cerro la Jara, and several other unnamed peaks, as well as the crater of El Cajete. These volcanic centers form a nearly complete ring within the Valles caldera and very probably correspond to a continuous rhyolite ring dike at depth. The youngest of these centers is El Cajete, and it is of particular interest because from it issued the welded tuff of Battleship Rock in upper San Diego Canyon, the "popcorn" pumice surrounding El Cajete crater, and the glass flow of Banco Bonito. These three deposits represent a related sequence of eruptions that record a continuous decrease in gas content during a waning stage of volcanism.

Interbedded with the caldera rhyolites are a variety of tuffaceous sediments that were deposited in lakes that formed at several stages during the history of the caldera.

VOLCANIC STRUCTURES

The Valles caldera formed as a consequence of collapse of the roof of the magma chamber following eruption of Bandelier rhyolite tuff. (See Williams, 1941, p. 251-252.) The ring fault bounding the subsided caldera block is mostly covered by younger volcanics and alluvium, but existing exposures indicate that it constitutes a complex fracture zone two to three miles wide. Within this ring-fracture zone is a central, initially more or less intact block that is now arched into a steep-sided, slightly elongate structural dome. This dome is essentially a mosaic of radially dipping blocks broken by radial faults and bisected by a northeast-trending longitudinal graben. It is approximately eight miles in diameter and displays a structural and topographic relief of nearly 3,000 feet. The topographic elements comprising the dome are Redondo Border and Redondo (Mountain), the highest point of which is Redondo Peak (11,254 feet). The prominent position of Redondo, which rises 1,000 to 2,000 feet higher than the peaks on the caldera rim, is most striking when viewed from the vicinity of San Ysidro, 25 miles to the south-southwest.

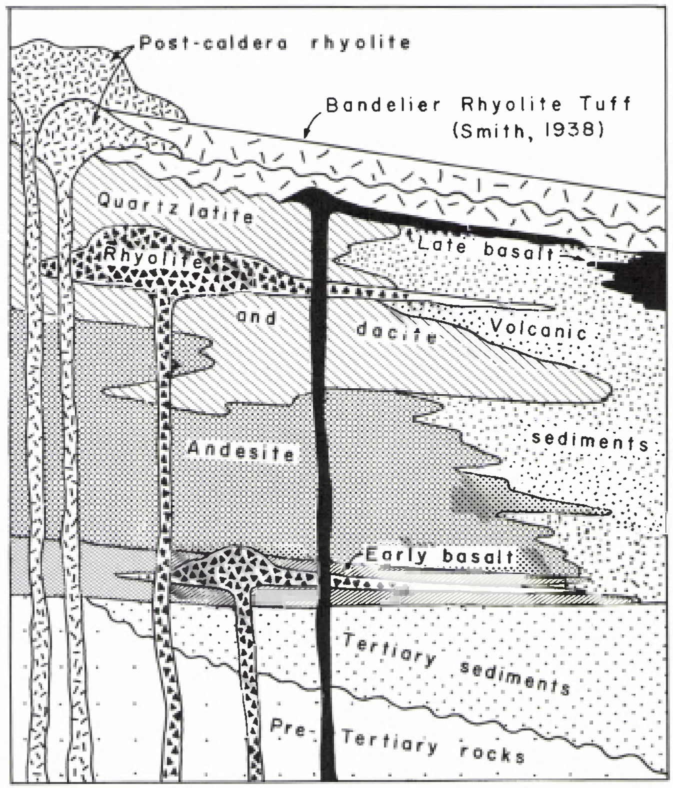

Figure 2. Schematic diagram showing the generalized stratigraphic relations of the Jemez Mountains volcanic rocks.

The Redondo structural dome is not the result of differential collapse of the caldera block, but rather the result of post-collapse uplift of the caldera floor, probably consequent upon a resurgence of new magma from below with accompanying intrusion of a stock or laccolith, or possibly owing to hydrostatic readjustment of the viscous magma that remained in the chamber following eruption of the upper sequence of ash flows of the Bandelier.

During and following the gradual rise of this structural dome, large quantities of viscous rhyolite were extruded from the peripheral ring-fracture zone, giving rise to the ring of volcanic domes that surround Redondo. Because of the spatial and temporal relations of these ring extrusions, it has been suggested (Smith, Bailey, and Ross, 1960) that some ring dikes may be emplaced during post-collapse uplift and doming of the caldera floor rather than during subsidence of the caldera block as suggested by Clough, Maufe, and Bailey (1909) in their classic study of the ring intrusions of Scotland. More detailed evidence and explanation of the mechanics of this interpretation are presented by Smith, Bailey, and Ross (in press).

REGIONAL STRUCTURE

Bryan (1938, p. 204) and Smith (1938, p. 950 and 958) interpreted the older volcanic rocks of the Jemez Mountains (the Chicoma volcanic formation of Smith, 1938) as older than the Abiquiu tuff, and they thought that throughout Abiquiu time the mountains were a highland against which the Abiquiu tuff was deposited. They concluded that the mountains were subsequently buried by sediments of the Santa Fe formation and that the mountains owe their present relief to post-Pliocene uplift along normal faults. Stearns (1953, p. 496) has pointed out, however, that there is no evidence that highlands existed in either the Nacimiento or Valles areas during Abiquiu time and suggested that the Abiquiu tuff fan extended over much of the area now occupied by the Jemez Mountains. There is in fact considerable evidence indicating that volcanism in the Jemez Mountains did not begin until late Santa Fe time: 1) tuffaceous sediments tentatively correlated with the Abiquiu tuff are exposed beneath old volcanics in the west and northwest walls of the Valles caldera, 2) nowhere are the older sediments of the Santa Fe group known to contain volcanic rocks of the Jemez Mountains[2], and 3) wherever the oldest volcanic rocks of Jemez Mountains are exposed, they unconformably overlie faulted and eroded arkosic sediments of the Santa Fe group. This relation suggests that volcanism in the Jemez Mountains did not begin until commencement of the late Santa Fe faulting that determines the present outlines of the Rio Grande depression. Evidential in this respect is the location of the Jemez Mountains—that is, athwart the western margin of the depression at a point where its north-south trend is offset westward by a series of en echelon faults. The tensional environment associated with this offset may well have provided the zone of weakness for the locus of volcanism.

The extreme western margin of the Rio Grande depression in the Jemez area is delineated by a zone of northeast-trending faults that extends from just west of Jemez Pueblo in the south to beyond Canones in the north. The southern segment of this zone is defined primarily by the Jemez fault, which west of Jemez Pueblo brings sediments of the Santa Fe group in steep contact with pre-Tertiary rocks on the west. Northeastward the fault passes into pre-Tertiary rocks entirely and is partly covered by the Bandelier rhyolite tuff of the Jemez Plateau. In San Diego Canyon at Soda Dam, just north of Jemez Springs, the fault brings an isolated mass of Precambrian granite up against Permian sandstones of the Abo formation (Wood and Northrop, 1946). Thence it continues northeastward to the head of the canyon where it presumably intersects the caldera ring fracture zone. The Jemez fault cannot be traced into the caldera area, but the alignment of it with the post-caldera graben between Redondo and Redondo Border suggests that it may have continued into the caldera before dying out, and that it may have predetermined the position and orientation of the graben.

Northwest of the Valles caldera the western margin of the Rio Grande depression is covered by volcanics and is poorly defined. North of the mountains, in the vicinity of Canones, however, it is sharply delineated again by several northeast-striking faults that bring the Abiquiu tuff down to the southeast against older rocks.

Another major fault zone on the west side of the Rio Grande depression extends from Santa Ana Mesa north-northeastward along the eastern side of the Jemez Mountains to Abiquiu. This zone differs from the westernmost zone in that it consists of a series of north-striking faults arranged en echelon to the north-northeast. The southern end of this en echelon zone is delineated by the San Felipe fault zone (Kelley, 1954) which transects the Quaternary basaltic lavas of Santa Ana Mesa. The San Felipe zone continues northward into the southern Jemez Mountains, where it has been active for a considerably longer time and has tilted and displaced downward to the east the older rocks of the volcanic pile.

North of Cochiti the en echelon zone is expressed by the Pajarito fault zone, a series of arcuate faults that sweep around the east side of the San Miguel Mountains and pass northward through Los Alamos to Clara Peak, north of Santa Clara Canyon. The Pajarito fault zone displaces the Bandelier rhyolite tuff 300 feet or more, but displacements in the underlying dacitic rocks exceed 1,000 feet and indicate a long activity. North of Santa Clara Canyon the fault zone continues as a series of antithetic faults that displace the basalts along the eastern edge of Lobato Mesa. Near Abiquiu these north-trending faults meet the northeast-trending faults of the westernmost zone.

The character of faulting in the eastern and western fault zones differs in several important ways. The faults in the western zone generally show normal displacement downward to the east and bound blocks that are tilted westward. The faults in the eastern zone on the other hand commonly are antithetic and bound blocks that are tilted eastward. The faults of the eastern zone furthermore show considerably greater syn-volcanic and post-volcanic displacement than those in the western zone, and as a consequence the volcanic pile thickens markedly to the east. These relations suggest indirectly that volcanism in the Jemez Mountains is related to the initiation of faulting in the Rio Grande depression, and that it consequently post-dates deposition of the Abiquiu tuff and probably most of the arkosic sediments of the Santa Fe group also.

Volcanic and Intrusive Rocks of the Bland Mining District

In the headwaters of Bland and Colle Canyons and extending north into Medio Dia Canyon and south into Peralta Canyon is a group of volcanic rocks intruded by monzonitic and dioritic dikes and sills. The volcanics range in composition from basalt to dacite, and associated with them are tuffaceous sediments and a problematical arkosic sandstone. These rocks are intensely faulted and considerably altered and mineralized. The ghost mining camps of Bland and Albemarle are located in the area (Lindgren, Graton, and Gordon, 1910; Bundy, 1958).

The precise stratigraphic position of this suite of rocks has not been established. They are the oldest volcanic rocks in the Jemez area and have been almost completely buried by younger rocks of the Jemez Mountains volcanic sequence. The intrusive rocks resemble those of the Ortiz Mountains and Cerrillos Hills, east of the Rio Grande, and possibly they are the same age. As such, they would be

[2]Pebbles of volcanic rocks do occur in Santa Fe beds on the east and north beneath the basalts of Lobato Mesa and the Puye gravel, but these rocks are unlike those in the Jemez volcanic pile and appear to have come from a more distant source.

Oligocene in age (Stearns, 1953; Jaffe and others, 1959) and the intruded arkosic sands would belong to the Galisteo formation of Eocene and Oligocene (?) age, or to one of several older formations. However, one inconclusive lead-alpha age determination made on zircons from a fine-grained granodiorite from the Bland area has yielded an approximate age of 19 million years (Jaffe and others, 1959). This middle Miocene age, if valid, would place the intrusives in early Santa Fe time, and the intruded sandstone could be correlative with the earliest sediments of the Santa Fe group.

Because of the uncertainty of the stratigraphic position of these rocks, they have been omitted from the general discussion in this paper.

SUMMARY

The following historical summary is based on the work of Bryan (1938), Smith (1938), and Stearns (1953), supplemented and modified by the authors' observations.

Stratigraphic and structural relations indicate that volcanism in the Jemez Mountains, exclusive of the Bland area, began in early to middle Pliocene time. The area now occupied by the Jemez Mountains was then a basin of sedimentation situated between the Sangre de Cristo Range on the east and the Nacimiento Mountains, probably a subdued upland, on the west. Volcanism commenced along the western slope of the basin and was shortly preceded and accompanied by faulting along a zone extending from the vicinity of Jemez Pueblo to Abiquiu.

It is probable that the ancestral Rio Grande was established as a through-flowing stream during and possibly as a consequence of this faulting. Bryan (1938, p. 207) postulated that this ancestral river flowed in a course west of its present position, and Stearns (1953, p. 501) suggested that it has since been diverted eastward by volcanic accumulation in the Jemez Mountains. This is well demonstrated by the manner in which the Rio Grande flows around the toe of the huge fan that constitutes the Puye gravel, which overlies quartzitic gravels presumed to be deposits of the ancestral Rio. Farther south in the vicinity of White Rock Canyon, the history of the Rio Grande is further complicated by basaltic eruptions of the Cerros del Rio, which temporarily dammed the river, forming a shallow lake in the vicinity of Buckman and Totavi. Drainage in this area was subsequently reestablished to the west. It was again dammed by the Bandelier rhyolite tuff and finally reestablished in its present course.

Volcanism in the Jemez area began with widespread eruption of basalts and continued with the successive effusion of andesites, dacites, quartz latites, and associated rhyolites. Of these older rocks, those in the north are generally younger than those in the south. In Pleistocene time, after a period of quiescence and erosion, catastrophic eruption of hot ash flows from the crest of the volcanic pile resulted in the deposition of the Bandelier rhyolite tuff and the formation of the Valles caldera and a slightly older and smaller caldera to the northeast. Subsequent activity, restricted within the Valles caldera, included structural doming of the caldera floor, producing the central mountains of Redondo and Redondo Border, and contemporaneous extrusion of a peripheral ring of rhyolite domes. Intermittently the caldera was filled by lakes which have since been drained by headward erosion of the Jemez River and San Antonio Creek. Solfataric and hot-spring activity, the vestiges of volcanism, continue today within the caldera, notably at Sulfur Springs, and outside the caldera at several localities in San Diego Canyon.

Although some regional doming probably accompanied intrusion of magma in the Jemez area, the mountains owe their present relief mainly to volcanic accumulation and differential subsidence of the Rio Grande depression.

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