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THE CERROS DEL RIO VOLCANIC FIELD

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INTRODUCTION

The Cerros del Rio volcanic field is located 10 km west of Santa Fe, New Mexico (fig. 1), in Los Alamos, Sandoval and Santa Fe counties. The field includes part of the Caja del Rio and La Majada land grants, part of Bandelier National Monument, and land owned privately and by Los Alamos Scientific Laboratories. Approximately 180 sq km (fig. 2), including part of White Rock Canyon, have been mapped in detail (Aubele, 1978b). Elevations range from 2277 m to 1633 m.

GEOLOGIC SETTING

The Cerros del Rio field is located on the La Bajada-Jemez constriction which separates the Espanola and Santo Domingo basins of the Rio Grande rift (Kelley, 1952; Kelley and others, 1976). At this point, the rift is offset 30 km to the right.

The Pliocene to Pleistocene rocks of the Jemez Mountains partially cover the west boundary faults of the Espanola basin. The upper Tshirege Member of the Bandelier Tuff, erupted from the Valles Caldera of the Jemez Mountains, overlies the distal northern edge of the Cerros del Rio flows (Bailey and others, 1969).

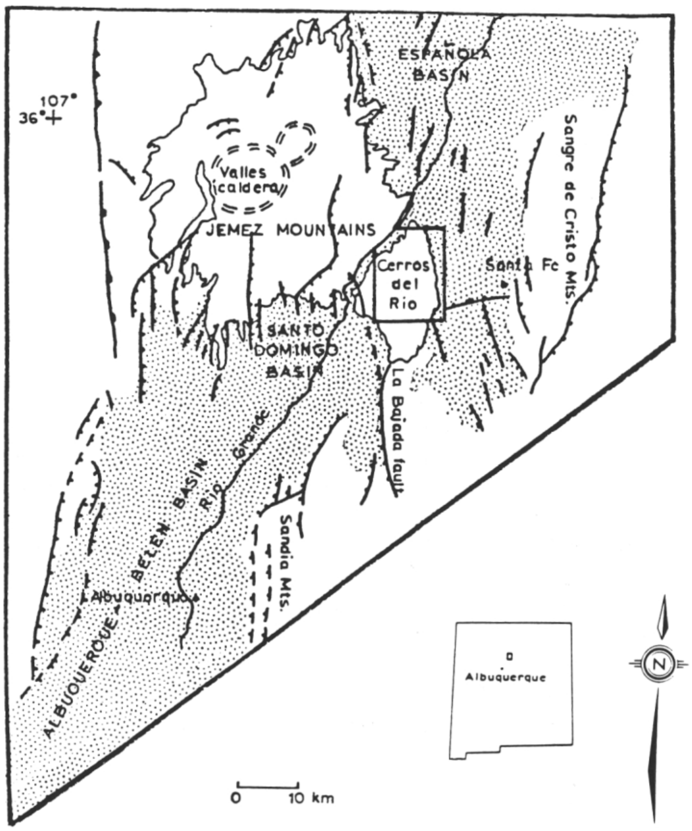

Figure 1. Geologic setting of the Cerros del Rio volcanic field. Sedimentary deposits of the Rio Grande rift (stippled). Area of this report in rectangle (after Woodward and others, 1975).

The Cerros del Rio field ends in an abrupt escarpment on the southwest, 160 m above the fan deposits and stream gravels of the Santo Domingo basin. Aerial photos in this region indicate that the fan and stream deposits overlie basalt flows which dip toward the east at approximately 10°. Projected extension of these flows positions them about 660 m below the basalt capping Mesa Negra de la Bajada, the southernmost flows associated with the Cerros del Rio field. Since the mesa is bounded on the west by the La Bajada fault, it seems reasonable to suggest that the lower basalt was contiguous with, or at least related to, La Bajada mesa flows, and was displaced to the west by movement along the fault, possibly during continued subsidence of the Santo Domingo basin. To the east, the base of the Cerros flows is visible, where it overlies the Pojoaque Member of the Tesuque Formation, Santa Fe Group (Galusha and Blick, 1971).

PREVIOUS WORK

There have been no previous detailed geologic studies of the Cerros del Rio volcanic field, although many geologists have mentioned it in discussions of adjoining areas or collected incomplete laboratory data. The earliest descriptions were concerned only with White Rock Canyon. Iddings (1890) may have described the rocks of the canyon in his report on the "Rio Grande cafion" of the "Tewan Mountains." Lee (1907) and Herron (1916) both attributed the canyon's existence to "sheets of hard igneous rock that protect the underlying sands and gravels." Lee further mentioned that the light-colored rhyolite to the west (the Bandelier Tuff) had given the canyon its name. The volcanic geology of the canyon even was described in early novels of New Mexico (e.g., Bandelier, 1890).

Bryan and McCann (1937, 1938) offered the first descriptions of the Cerros del Rio flows as interbedded with the "Santa Fe Formation," and classified them as residual highlands of basalt and andesite within the Rio Grande depression. A single analysis from "Cerro Montoya, about 10 miles west of Santa Fe" collected by C. S. Ross was included in a compilation of data from the laboratory of the U.S. Geological Survey (Wells, 1937) and probably was collected from Montoso Peak. Denny (1940), in his discussion of the Santa Fe Formation in the Espanola valley, stated that "near Buckman one or two flows of andesite-basalt are interbedded with river deposits." Stearns (1943) mapped two separate flows on Mesa Negra de la Bajada (south of the mapped area) as the Cuerbio basalt of Quaternary age. Emmanuel (1950) used the name Cuerbio basalt to refer to all the flows of the Cerros del Rio. He subdivided the flows into three general units: (1) early mesa basalt (which was assumed to be interbedded with the Santa Fe Formation); (2) younger mesa basalt; and (3) late flows and cones.

Spiegel and Baldwin (1963) recognized two topographic and geologic units in the Cerros. The "high dissected mesas of basaltic andesite and andesite" were classified as Tertiary flows, whereas the flat-lying basalt of a lower-level surface was thought to be younger and interbedded with the Ancha For-

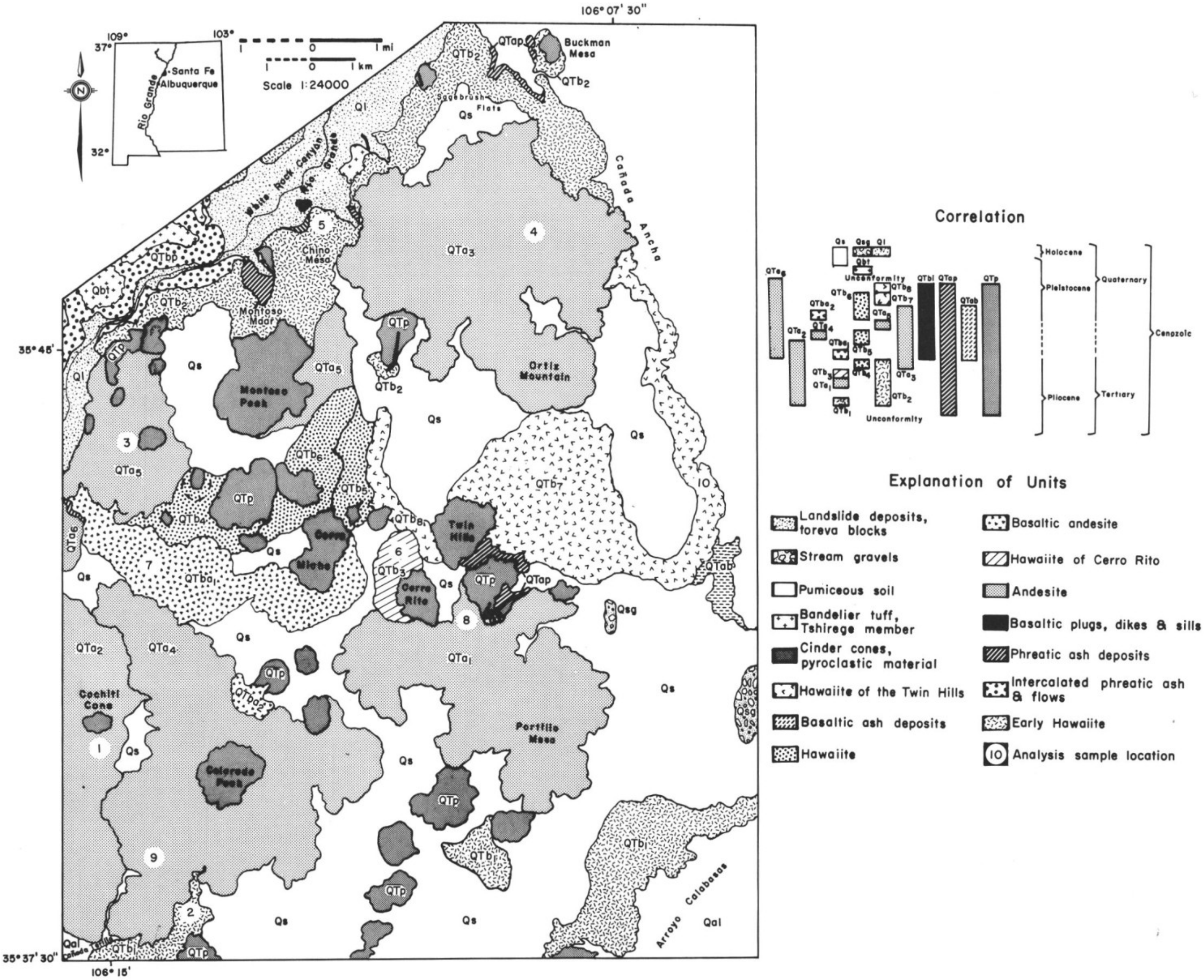

Figure 2. Simplified geologic map of the Cerros del Rio volcanic field.

mation. They also recognized a basalt lapilli tuff beneath the eastern margin of the younger basalt.

Kelley (1948) described the White Rock Canyon basalt flows as "three or four flows ... separated by sand, gravel and silt ... a few tens of feet thick along the west side ... and more than 100 feet thick on the east side of the canyon." He further stated that the western edge of the flows appeared to be 1.5 to 2 km west of the present Rio Grande, and that the initial basaltic eruptions had shifted the river to the west.

Griggs (1964) described the rocks within and bordering White Rock Canyon as the "basaltic rocks of Chino Mesa." He stated that these consisted of "a thick sequence of basaltic to andesitic rocks and minor amounts of poorly consolidated sediments that form Chino Mesa and adjacent parts of the Cerros del Rio." He subdivided this sequence into five units, based on location and field characteristics.

The geologic map of the Jemez Mountains published by Smith and others (1970) includes the Cerros del Rio, and divides its rocks into two units, basaltic lavas and tuffs, and basaltic andesite. R. L. Smith (personal commun., 1976) stated that no detailed work was done in the area.

In their monumental study of the Santa Fe Group, Galusha and Blick (1971) designated the "Cerros del Rio lavas" as younger than the Santa Fe Group, and in part contemporaneous with the Bandelier Tuff. They believed that the "basalt-lapilli tuff" beneath the Cerros flows in Canada Ancha was stratigraphically above both the Pojoaque Member of the Tesuque Formation and the Ancha Formation. Galusha and Blick were the first to describe the yellowish earthlike material "which may be palagonite" frequently found "between lava flows of the Cerros del Rio."

Beginning in 1975, several geologists studied different facets of the geology of the Cerros del Rio. Helene Warren examined a partially excavated pit in the volcanic field (personal corn-mun., 1975). Manley (1976) examined part of the canyon in her study of tephrochronology in the Espanola basin. Brackenridge (1976) and Steve Fosberg (personal commun., 1977) carried out geologically oriented studies of pueblo cultural sites in the canyon. Baldridge (1979) analyzed one andesite flow, a vent agglomerate and a dike from the Cerros by microprobe analysis of fused glass beads (personal commun., 1977). Kelley (1978) included the area in a large-scale map of the Espanola basin. Bachman and Mehnert (1978) briefly described the Cerros del Rio in a geomorphic study of the central Rio Grande region. They obtained three dates on units within the study area, all about 2.7 m.y., and placed the Cerros del Rio flows on the Ortiz surface, stratigraphically above the interfingering Ancha Formation, Puye Formation and river gravels of the ancestral Rio Grande.

STRATIGRAPHY

Previous studies have attempted to generalize the activity of the Cerros del Rio into 2, 3 or 5 periods of eruption. In many cases, the term Cuerbio basalt, which should apply only to La Mesa Negra de la Bajada, has been used to refer to the entire field. However, an understanding of the geologic history of the area can be devised only when the sequential eruption of flows from all the vents is examined.

The activity of the Cerros del Rio field is younger than the deposition of the Santa Fe Group (as defined by Galusha and Blick (1971)), and in part, contemporaneous with the deposition of gravel conglomerate lenses, possibly equivalent to the mid-Pliocene Puye Formation (Bailey and others, 1969), and the deposition of the Otowi Member of the Bandelier Tuff (Smith and others, 1970).

Approximately 60 vents have been identified within the Cerros del Rio volcanic field, and the majority of these is marked by cinder-spatter cone formation. The cones vary in size, shape and state of degradation; however, all of them have the same general structure (Crumpler and Aubele, 1977). There appear to have been two stages of cinder cone formation in the Cerros del Rio: (1) early-stage cinder cones predating the major flows; and (2) late-stage cinder cones marking the final eruptive activity in the area. Early-stage cinder cones are exposed by erosion, especially along the east edge of White Rock Canyon. A northeast-trending line of early cones occurs near the southern boundary of the Ceja del Rio Grant, and is one of the few examples of possible fissure alignment of vents in the volcanic field. Late-stage cinder cones were erupted during the final activity of vents which previously had extruded lava flows.

Intrusions in the area include several plugs, dikes consistently trending to the northeast, and one sill exposed on the east side of White Rock Canyon. Travertine deposits occur on the mesa surface above the sill, where it has uplifted the flows capping Sagebrush Flats.

The eruptive rocks of the Cerros del Rio consist of alkali basalt (hawaiite), basaltic andesite and andesite. Activity began with the extrusion of hawaiite, which forms extensive flows on the south and north margins of the area. The basal flow unit in the north has been dated at 2.6 ± 0.4 m.y. (Bachman and Mehnert, 1978) and is exposed in White Rock Canyon. Cinder cones and phreatomagmatic eruptions occurred simultaneously, and remnants of these vents are exposed in and near White Rock Canyon and in the southern part of the field. This activity was followed by eruptions of andesite flow-domes, first in the south and then in the north. Throughout these eruptions, less voluminous extrusions of hawaiite occurred along a zone of vents trending NW-SE in the center of the field. Following the andesitic eruptions, hawaiite activity continued along the central zone. One of the two stratigraphically youngest flows has been dated at 2.5 ± 0.2 m.y. (Bachman and Mehnert, 1978).

Volcanic activity in the Cerros del Rio field almost had ceased before the formation of the Valles Caldera in the Jemez Mountains. The upper member of the Bandelier Tuff, extruded from the caldera, overlies the hawaiite west of White Rock Canyon and is exposed in one location on the east side. Here, an eroded valley in the hawaiite served as a channel for the tuff, which contacts the underlying basalt and ash unconformably and appears to lap up on the east wall of the canyon as a wedge rapidly thinning to the east.

Extensive airfall deposition of pumice from the Valles eruption must have covered the entire Cerros del Rio field. The pumice probably helped to preserve some of the original volcanic landforms, which now are being exhumed, and contributed to the development of Quaternary soils. In most cases, the blanket of pumice has been eroded and redeposited as small surface deposits scattered throughout the field.

WHITE ROCK CANYON

White Rock Canyon, a 300-m-deep gorge, was cut by the Rio Grande after the eruption of the Tshirege Member of the Bandelier Tuff (1.4 m.y., Bailey and others, 1969). Its present configuration is due to extensive toreva-block slumping and landsliding (fig. 3), which have widened the canyon and repeated the stratigraphic section.

Except in the vicinity of Frijoles Canyon, where the andesite of Montoso Peak (QTa5) is exposed, the volcanic flows present in White Rock Canyon are all flows of QTb2 (early hawaiite). At least four flows of this hawaiite are exposed in the canyon and cap the surface of Chino Mesa and Sagebrush Flats.

Conglomerate lenses exposed in Ancho Canyon consist of rounded cobbles of Precambrian gneiss, quartzite and volcanic rock. This assemblage may correspond to the Totavi Lentil of the Puye Conglomerate (Griggs, 1964). The conglomerate overlies phreatic deposits at the mouth of Ancho Canyon, and a similar lens occurs between two flows south of Buckman Mesa. Therefore, these conglomerate gravels were deposited throughout the eruption of the Cerros.

Phreatic ash deposits, intercalated with the basalt flows, have been exposed by the formation of the canyon (fig. 4). The yellow-tan phreatomagmatic deposits, designated as Santa Fe Group or stream and lake deposits by previous workers, are predominantly accidental materials of sedimentary provenance, thinly layered sand and silt with basaltic ash, palagonite, and fragments of basalt, cinder, chert, quartzite and Precambrian granitic and metamorphic rocks. The chert, quartzite and granitic fragments are probably from early stream deposits underlying the phreatomagmatic deposits. In a few places, the layered sand and silt grades into finely laminated clay, which also contains volcanic and Precambrian fragments, and is interpreted as reworked tuff deposited in small lakes or ponds. The phreatomagmatic deposits vary in thickness from one to tens of meters. Bomb sags, cauliflower bombs and crossbeds interpreted to have been formed by base surge are common (fig. 5).

These deposits clearly are related to the activity of the Cerros del Rio field, since they are interbedded with hawaiite flows. The source of the deposits must have been a series of maar craters which paralleled the present White Rock Canyon.

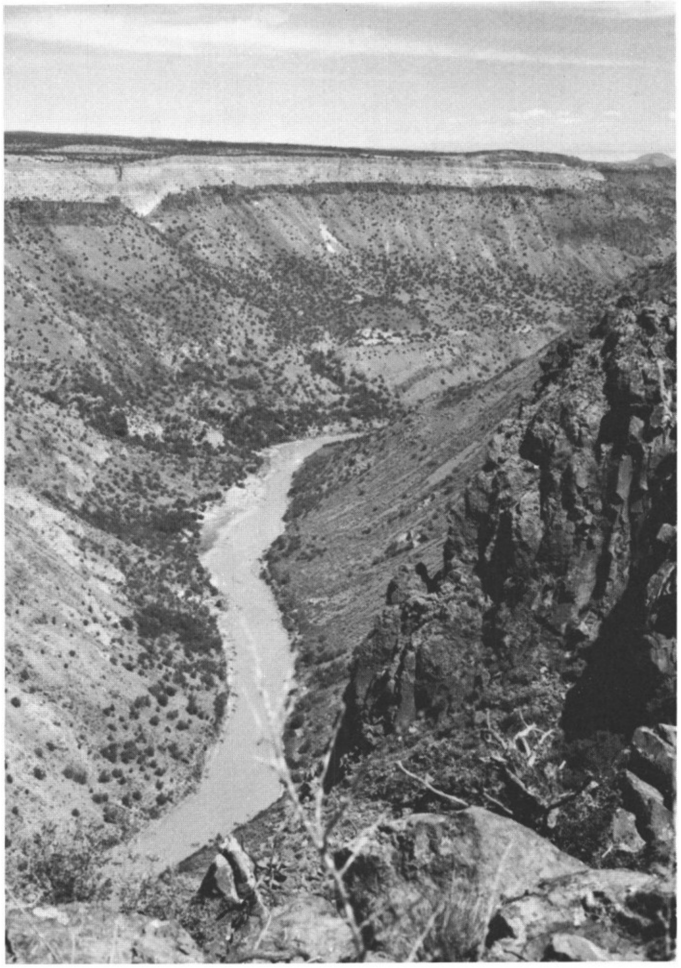

Figure 3. White Rock Canyon. Resistant cliffs of hawaiite (QTb_2) are exposed above colluvial landslide material, and overlain unconformably by the Tshirege Member of the Bandelier Tuff. Direction of view is northeast. The top of the Bandelier is 340 m above the Rio Grande.

At least five of these vents are exposed in varying degrees of dissection in side canyons along the Rio Grande, including Montoso Arroyo, Frijoles Canyon in Bandelier National Monument and Buckman Mesa in Canada Ancha.

North of Montoso Peak, a deeply dissected maar is exposed on the east edge of White Rock Canyon and informally has been named Montoso Maar. This previously unknown maar has been described in preliminary reports by Aubele (1976) and Aubele and others (1976). Total relief is over 200 m, and dissection has exposed several stratigraphic levels and a well-defined ring fracture zone.

The interior of the maar is a mixture of well bedded phreatomagmatic deposits and lenses of inflow breccia (fig. 6). At least two thick sequences of basaltic ash occur within the bedded deposits, which decrease in dip from 60 to 25 degrees toward the center of the maar, where they are horizontal. Excellent crossbedding, which is the result of mantling of one eruptive pulse over another, resembles the base-surge deposits of the Eiffel maars (Lorenz, 1973), as well as of other maars.

The inflow breccia occurs as lenses of poorly bedded ash, sand and cinder, with cobbles and boulders of basalt and river gravel. This material is interbedded with the stratified phreatic deposits and is believed to be mudslide debris which periodically slipped into the crater as it erupted and subsided.

A ring fracture zone, apparently consisting of three or four concentric faults approximately 1 km wide, encircles the maar deposits. Where the stratified deposits or the inflow breccia come into contact with the concentric faults, their dip increases to a maximum of 85 degrees toward the center of the maar. An intrusion, apparently dome-shaped with almost perfect columnar joints, is exposed along the fault zone at the most deeply dissected level of the maar. The columns are approximately 0.3 m in diameter and change in orientation from horizontal to nearly vertical with increased depth.

Several other phreatomagmatic vents, identified as maars, tuff rings, and tuff cones, have been identified within the volcanic field south of White Rock Canyon, and explosive activity appears to have occurred throughout the eruptive history of the field.

PETROLOGY AND PETROGENESIS

Chemical analyses and norms, calculated by the Niggli method, are given for 10 representative samples in Table 1. The petrologic classifications and terms used throughout this study have been based on Irvine and Baragar (1971). The classification systems of Middlemost (1972), Lipman and Mehnert (1975), and Carmichael and others (1974) also agree with Irvine and Baragar's rock nomenclature for these samples. Average modes for all the units and feldspar determinations have aided in the classification.

Hawaiite

The Cerros del Rio hawaiite flows span the entire history of the field. The early hawaiite formed extensive flat-topped areas, but later hawaiite formed long, narrow finger-like flows. The rock is generally gray in hand specimen, with an aphanitic groundmass and olivine phenocrysts. In thin section, trachytic texture is quite common. The matrix consists of andesine-labradorite plagioclase, opaque minerals, olivine and clinopyroxene. The dominant phenocryst is olivine, with local clinopyroxene, and sparse andesine and quartz.

Four of the Hawaiite flows were analysed chemically. Si02 varies from 47.5 to 49.1 percent and the alkali content is high. In addition, the samples are nepheline and olivine normative. Chemical plots (fig. 7) place the rocks in the al kalic class, with sodic affinities. More detailed classification places the alkalic basalt into the hawaiite class. Similar rocks described from the Basin and Range province have been classified as alkali basalt (Leeman and Rogers, 1970) and as hawaiite (Best and Brim- hall, 1974).

No basanites were identified within the field. However, the hawaiite of Cerro Rito (QTb3) has high normative nepheline (7 percent) and relatively low Si02 (42 percent), and could be classified as a basanite if it were not for the high alkali content.

Andesite

The andesite of the Cerros del Rio forms sprawling masses, 60 m thick, which resemble dissected mesas (fig. 8). These flow-domes are thinly foliated in the interior and become increasingly glassy and massive toward the top. The rock varies from dark gray to black, with abundant andesine and hornblende phenocrysts. There is little vertical variation in mineralogy within the flow-domes, except for an increase in glass near

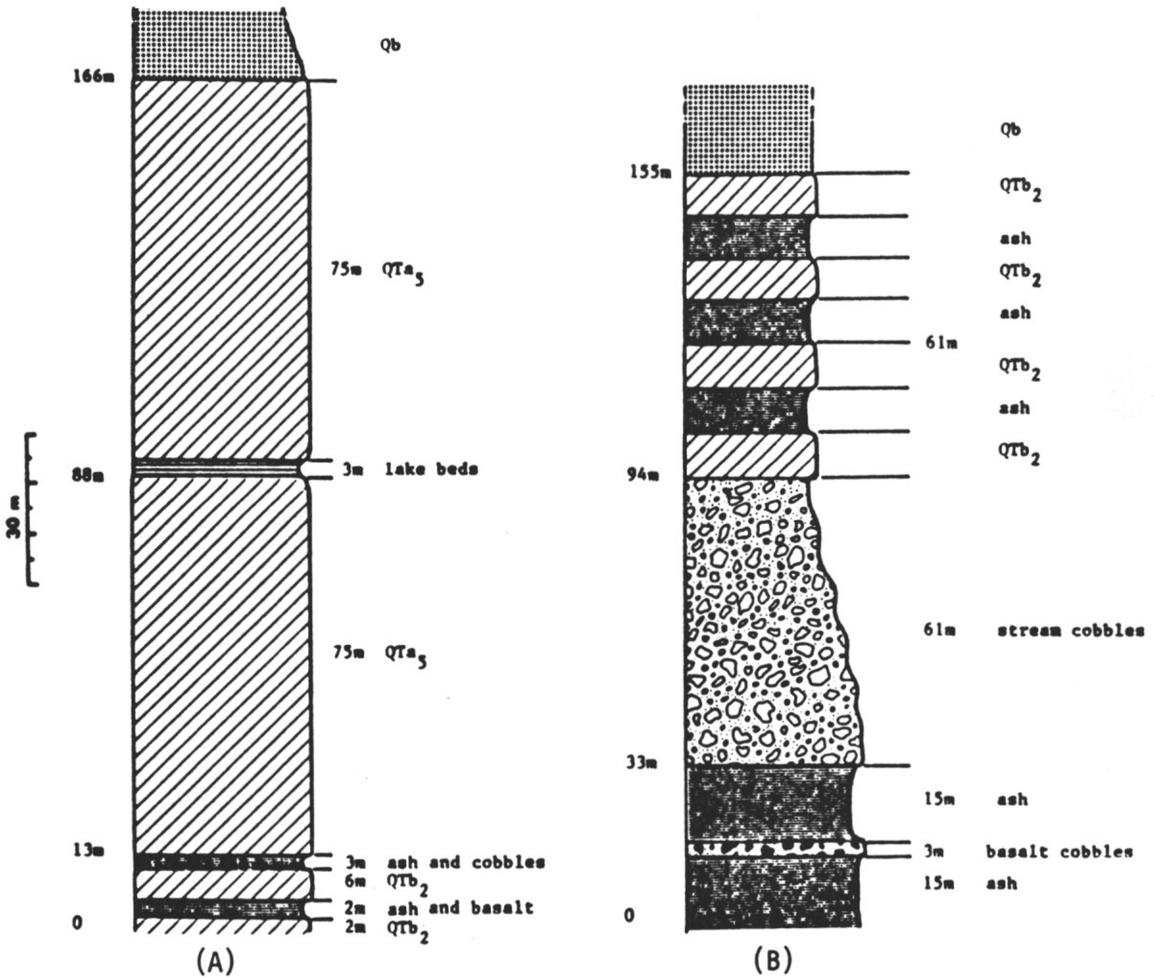

Figure 4. Stratigraphic sections of (A) Frijoles Canyon and (B) Ancho Canyon, at their junction with White Rock Canyon. Qb = Bandelier Tuff, QTb_2 = early hawaiite, QTa_5 = andesite from Montoso Peak. The ash contains accidental sand, silt and basaltic fragments of phreatic origin.

the top, but there is quite a bit of lateral variation. In thin section, the rock is fine-grained, with a matrix of oligociase-andesine plagioclase, opaque minerals, and sparse olivine and pyroxene. The dominant phenocrysts are andesine and hornblende. A few olivine, orthopyroxene, clinopyroxene and quartz phenocrysts occur.

Sample specimens 1, 3, 4, 8 and 9 (Table 1 and fig. 7), which were classified as subalkalic, plot in the calc-alkalic andesite field following the classification system of Irvine and Baragar (1971). The rocks range from 59.24 percent to 60.95 percent 5i02, and are similar chemically to andesites of the Cascades and San Francisco Peak, Arizona, especially in the ratio CaO:Na20:K20 (6:4:2). They differ from Icelandite (tholeiitic andesite) in low FeOT content.

Basaltic Andesite

Basaltic andesite is a term which is used frequently, but often is defined inadequately or obscurely. Coats (1968) suggested that it should be applied to mafic volcanic rocks with phenocrysts of labradorite-bytownite and Si02 content of 54 percent to 58 percent. In the Irvine and Baragar (1971) classification, basaltic andesite straddles the alkalic-subalkalic

Figure 5. Crossbedding interpreted to have been formed by base surge at the base of the phreatomagmatic section in a side canyon to White Rock Canyon.

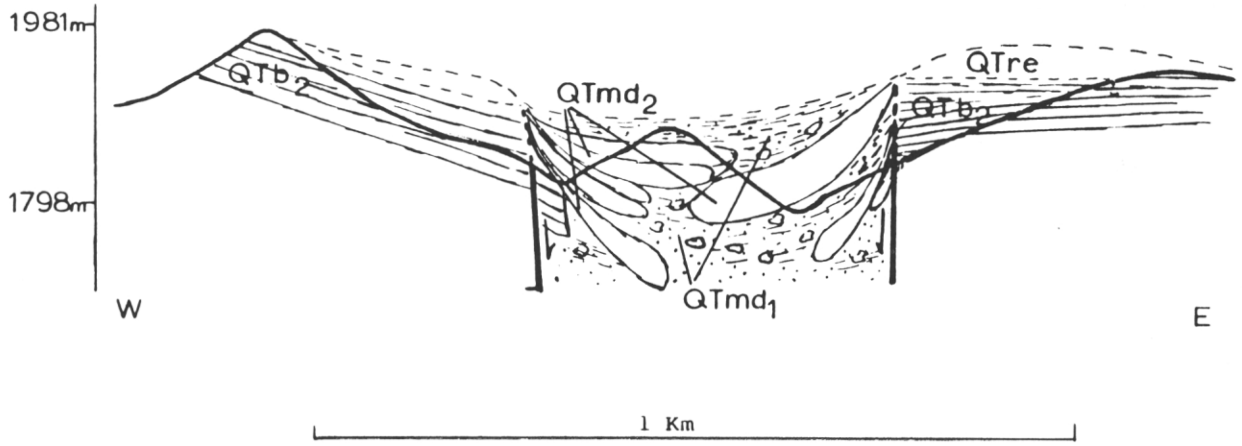

Figure 6. Schematic E-W section and topographic profile (heavy line) of Montoso maar. Dashed lines represent the postulated original maar crater before erosion. QTre = rim ejecta, $QTmd_1$ = well bedded maar deposits, $QTmd_2$ = inflow breccia, QTb_2 = early hawaiite.

*Table 1. Chemical analyses and calculated norms of the volcanic rocks of the Cerros del Rio volcanic field, New Mexico (analyses by J. C. Aubele). *Gravimetric analyses of SiO_2 performed by John Husler, U.N.M. †S. I. (solidification index) = $(MgO \times 100)/(MgO + FeO_T + Na_2O + K_2O)$. ‡Norms calculated with adjusted values of percent Fe_2O_3, such that Fe_2O_3 = percent TiO_2 + 1.5 (after Irvine and Baragar, 1971).*

	1	2	3	4	5	6	7	8	9	10
SiO_2*	60.16	49.11	59.24	60.09	50.18	47.52	56.44	59.73	60.95	48.63
TiO_2	.84	2.07	.70	.78	.93	1.58	1.14	.88	.73	1.92
Al_2O_3	15.93	17.41	15.91	16.92	15.61	16.30	17.03	16.04	15.73	16.29
Fe_2O_3	2.51	4.44	2.53	2.10	3.83	4.47	2.80	3.32	2.58	3.55
FeO	3.59	6.54	2.66	3.53	5.61	5.43	3.82	2.21	2.63	7.41
MgO	3.26	5.40	3.66	2.80	6.58	6.77	3.17	2.64	3.42	6.85
CaO	5.34	8.24	5.75	5.21	8.67	8.44	5.95	5.01	5.43	8.32
Na_2O	3.94	3.95	4.12	4.22	4.10	4.07	4.39	4.14	4.22	3.83
K_2O	2.53	1.69	2.44	2.60	1.72	2.22	2.40	3.17	2.34	1.27
MnO	.10	.16	.09	.09	.14	.16	.09	.09	.09	.15
H_2O+	.92	.35	1.18	1.08	.004	1.25	.68	1.35	1.04	.04
H_2O–	.09	.22	.16	.18	.07	.14	.24	.08	.12	.06
P_2O_5	.37	.86	.58	.45	.74	.96	.67	.72	.39	.72
BaO	.07	.05	.08	.08	.05	.08	.08	.09	.07	.04
SrO	.09	.11	.10	.09	.12	.13	.11	.13	.08	.10
Total	99.74	100.60	99.20	100.22	98.35	99.52	99.01	99.6	99.82	99.18
S.I.†	20.6	24.5	23.8	18.4	30.1	29.5	19.1	17.1	22.5	29.9
normative mineralogy‡										
q	10.84	.00	9.25	9.85	.00	.00	5.13	9.76	11.19	.00
or	15.14	9.98	14.65	15.48	10.23	13.22	14.40	19.06	13.95	7.54
ab	35.83	34.42	37.60	38.19	32.40	24.28	40.03	37.83	38.25	34.34
an	18.55	24.78	18.00	19.70	19.24	19.81	19.98	16.10	17.23	23.63
ne	.00	.62	.00	.00	2.80	7.54	.00	.00	.00	.14
di	4.97	8.69	6.05	3.02	15.69	13.26	4.80	3.94	6.19	10.78
hy	10.23	.00	9.89	9.32	.00	.00	9.82	8.00	8.99	.00
fo	.00	8.95	.00	.00	9.70	10.51	.00	.00	.00	11.35
fa	.00	4.15	.00	.00	4.51	3.90	.00	.00	.00	4.43
il	1.18	2.88	.99	1.09	1.30	2.21	1.61	1.24	1.02	2.68
ap	.78	1.79	1.23	.94	1.55	2.02	1.42	1.53	.82	1.51
mt	2.47	3.73	2.33	2.40	2.55	3.24	2.80	2.53	2.35	3.59

Rock type, specimen number and locality

1) Andesite (CD-1), vent 31 (QTa_2), south of Cochiti cone
2) Hawaiite (Me10a), southern hawaiite (QTb_1), near Cañada Tetilla
3) Andesite (MaM16), Montoso Peak (QTa_5), west of Montoso Peak
4) Andesite (WF505), Ortiz Mountain (QTa_3), north of Pankey Peak
5) Hawaiite (WE11L), early northern hawaiite (QTb_2), south of vent 48
6) Hawaiite (MB61), Cerro Rito (QTb_3), north of vent 5
7) Basaltic andesite (Mc26c), Cerro Micho ($QTba_1$), west of vent 11
8) Andesite (MDP21), Cerrito Portillo (QTa_1), west of Tor tuff ring (vent 41)
9) Andesite (ME12c), Colorado Peak (QTa_4), south of Colorado Peak
10) Hawaiite (AGF1), Twin Hills vent (QTb_7), north of Portales Pond

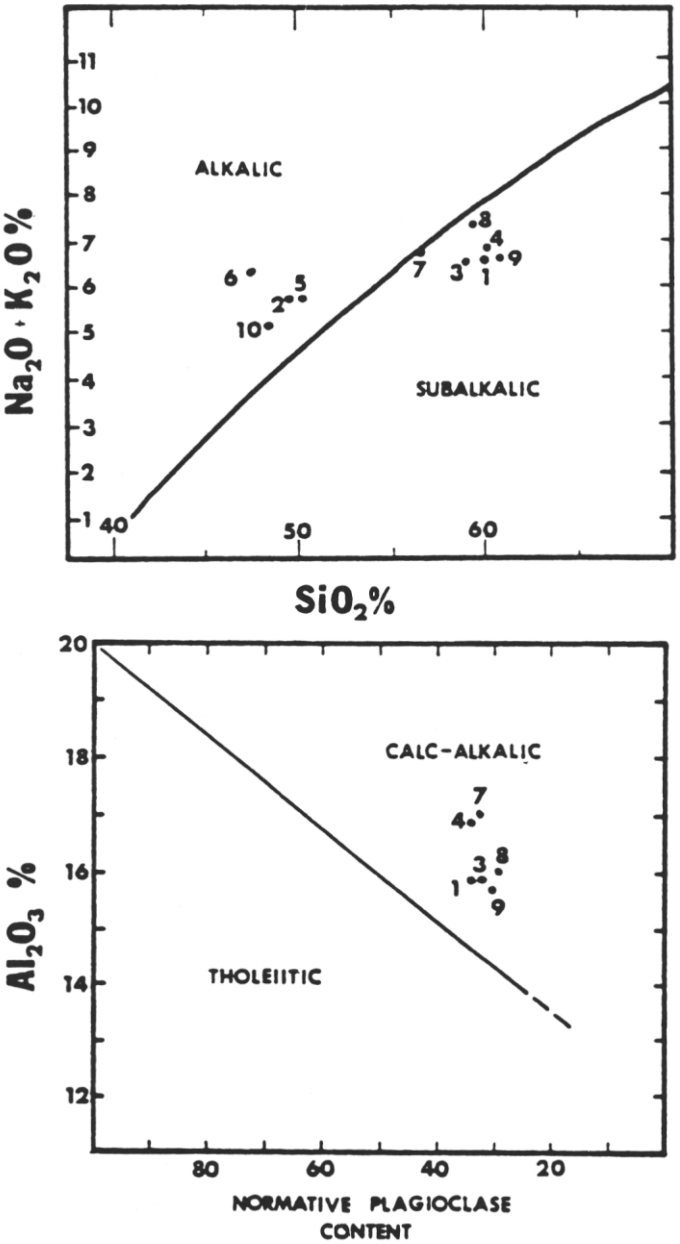

Figure 7. Rocks of the Cerros del Rio volcanic field classified according to Irvine and Baragar (1971). Numbers correspond to Table 1. Numbers 1, 3, 4, 8 and 9 are classified as andesite; numbers 2, 5, 6 and 10 as hawaiite; and number 7 as basaltic andesite.

boundary. Lipman and Mehnert (1975) described basaltic andesite as having an SiO2 content of around 52 percent and normative quartz and hypersthene.

Sample specimen 7 is classified as basaltic andesite on the basis of these criteria. The two basaltic andesite flows resemble the later hawaiite in flow morphology. The rock is black and aphanitic. Constituent minerals include a matrix of oligoclase-labradorite, opaque minerals, olivine, clinopyroxene and orthopyroxene. Dominant phenocrysts are olivine and clinopyroxene, with sparse andesine and quartz.

SiO2 content is 56 percent. As in the hawaiite, total alkalies are about 6 percent; however, the rock is quartz and hypersthene normative. Petrographically and chemically, it resembles rocks classified as basaltic andesite elsewhere in the western United States (Best and Brimhall, 1974; Leeman and Rogers, 1970).

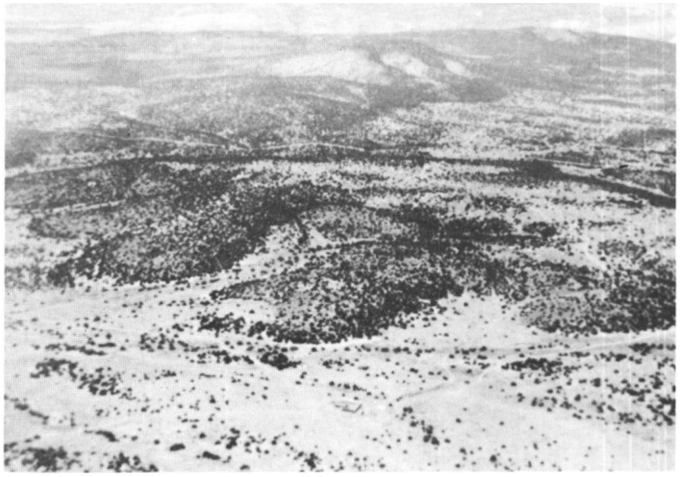

Figure 8. Aerial view, looking west, of the andesite flow lobes of Colorado Peak (QTa_4). Width of picture is approximately 4 km and the flow lobes are about 30 m thick. Colorado Peak is in the background.

Plagioclase and Quartz Phenocrysts

Andesine and quartz phenocrysts, which are present in almost all of the rocks in the Cerros del Rio field, may be an important indicator of the origin and evolution of the hawaiite and andesite. The plagioclase occurs as large (up to 6.0 mm) grains, which may have twinning and/or zonation, and are rounded, embayed and partially resorbed.

Individual grains of embayed, fractured and resorbed quartz are 0.5 to 5.0 mm. Each quartz grain has a uniform optical orientation and always is surrounded by small ('\,0.06 mm) acicular clinopyroxene (possibly augite) which forms an outward-radiating rim or reaction corona (fig. 9). The quartz is scattered sparsely throughout the rocks, appearing in some thin sections of the same flow and not in others. Identical quartz phenocrysts have been described in a "quartz-bearing basaltic andesite" from the western Grand Canyon area (Best and Brimhall, 1974). Two theories have been presented to account for the presence of the quartz phenocrysts: (1) high-pressure minerals, and (2) contamination. Best and Brimhall (1974) "assumed a cognate, high pressure origin," and experimental work by Nicholls and others (1971) confirms that quartz is a possible high-pressure phenocryst in lavas under certain conditions.

Other workers, however, have postulated origin by contamination. Doe and others (1969) considered "quartz xenocrysts armored with clinopyroxene" to be a "definitive indication of contamination." Lipman and Mehnert (1975) discussed "xenocrystic basaltic andesite" in the southern Rocky Mountains, and postulated crustal contamination of silicic alkalic basalt.

The quartz in the Cerros del Rio appears to be the result of contamination. Evidence to support this conclusion includes: (1) the presence of microscopic inclusions of intergranular quartz grains resembling a metamorphosed sandstone and microscopic granitic inclusions, and (2) the presence of identical quartz grains in both the hawaiite and andesite, which apparently formed at different depths and followed different

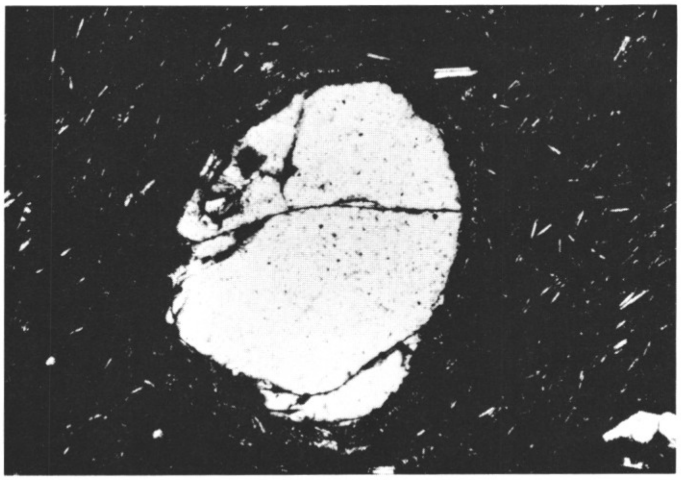

Figure 9. Rounded, embayed and partially resorbed quartz grain surrounded by acicular clinopyroxene, commonly found in the hawaiite and andesite of the Cerros del Rio volcanic field. Width of picture is 2 mm.

evolutionary trends. The resorbed andesine also could be due to crustal contamination. If the quartz does represent contamination, then this contamination ceased near the end of the activity of the field. The three youngest hawaiite flows are the only rocks which do not contain the quartz phenocrysts.

Petrogenesis

A plot of the major oxides against Kuno's (1968) solidification index, where the index decreases as silica content increases, demonstrates that the hawaiite and andesite of the Cerros del Rio form two distinct groups (fig. 10). This suggests that the hawaiite and andesite have been derived from different sources and have followed different evolutionary trends. The basaltic andesite plots in the andesite group in all elements except TiO2 and Fe01. In a standard AM F diagram, the two groups plot between the Cascade trend of Carmichael and others (1974) and the Hawaiian trend of MacDonald and Katsura (1964). Neither group is enriched sufficiently in FeO to approach the Hawaiian tholeiitic trend.

The eruption of alkalic basalt with associated calc-alkalic andesite occurs in many volcanic fields described in the western United States (Crumpler, 1978; Ulrich and McKee, 1978; Zimmerman and Kudo, 1979), but very few explanations have been suggested regarding their relationship.

Some contamination of the andesite of the Cerros del Rio is probable, based on the presence of quartz and andesine phenocrysts identical to those found in the hawaiite. There is no strong evidence that this occurred as part of a mechanism for origin of the andesite through contamination, although the final hawaiite flows, which erupted after the andesite activity had ceased, do not contain the quartz phenocrysts.

SUMMARY AND INTERPRETATION

Phreatomagmatic deposits in the vicinity of White Rock Canyon have been cited as evidence of a through-going drainage in the area at the time of the eruptive activity of the Cerros. In addition, the thickness of the volcanic units in this area implies that the flows filled a valley or depression in the vicinity of the modern canyon.

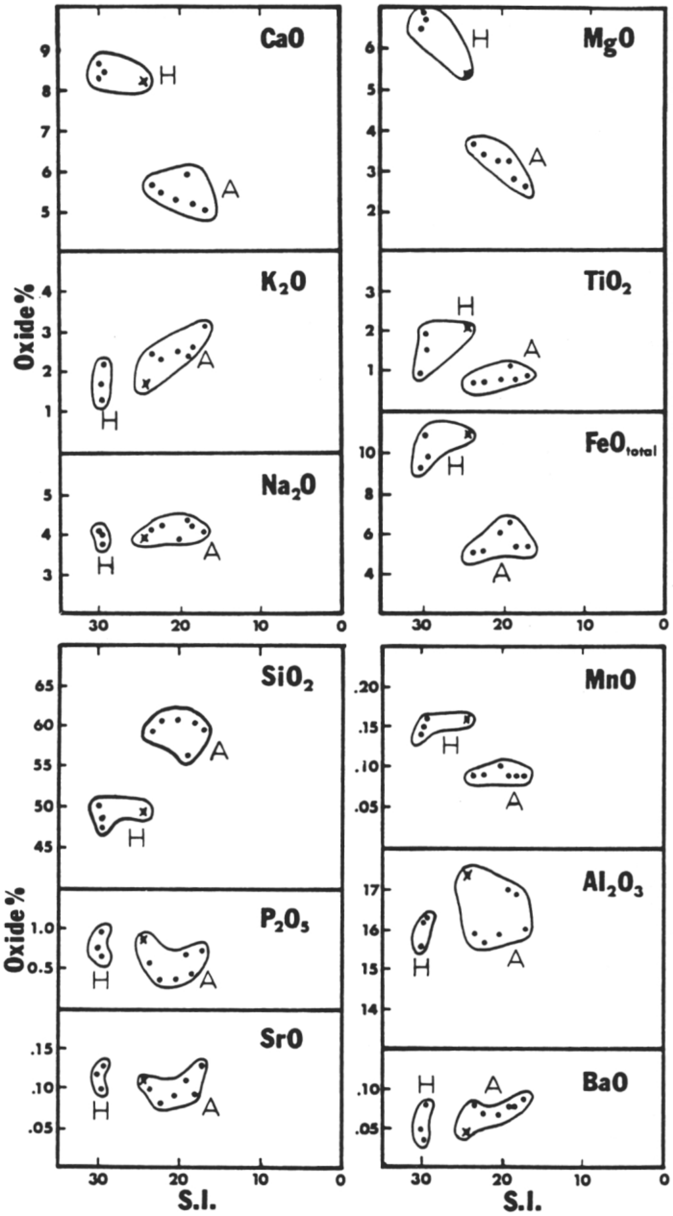

Figure 10. Major oxides of hawaiite (H) and andesite (A) plotted against solidification index of Kuno (1968). S.I. = $(MgO \times 100)/(MgO + FeO_T + Na_2O + K_2O)$. QTb_1 (plotted by x) plots alternately in both groups.

The petrologic implications of the Cerros del Rio activity to the Rio Grande rift have been discussed previously (Aubele, 1978a). However, a consideration of the structural implications of basin subsidence may be the key to understanding the entire region.

The Cerros del Rio field is located on the Jemez-La Bajada constriction, which is formed in part by the La Bajada fault, and acts as the boundary between the Española and Santo Domingo basins. Movement along the fault seems to have displaced the basalt of Mesa Negra de la Bajada downward to the west and tilted it toward the northeast on the upthrown side. This tilting probably is due to the subsidence of the Espaliola basin to the northwest, as well as movement along the fault. The Pojoaque Member of the Tesuque Formation (Santa Fe

Group), which underlies the Cerros del Rio to the east, shows consistent northwesterly dips of 4 to 8 degrees. The general trend of the Cerros hawaiite eruptions is to the north, as though they were following a gentle gradient in that direction. The directions of all these dips appear to intersect near the center of subsidence of the Espanola basin, as discussed by Reilinger and York (1979). Continued subsidence, over a long period of time, of the Espanola basin may be inferred by the steeper dips measured in the Pojoaque than those seen in the Cerros lava flows.

The evidence of old and superimposed drainage patterns also can be attributed to the subsidence of the basins and uplift along the La Bajada fault. Through-going streams in the vicinity of the modern Rio Grande and Santa Fe River were truncated by the subsidence of the basins and subsequent eastward tilting of the uplifted block to the east of La Bajada fault. Ponding of the drainage, which once flowed southwest, resulted in extensive lake deposits (or swamp lands) in the Cienega and White Rock areas. Lake beds are exposed beneath the distal southern and eastern edge of the early hawaiite (QTbi) along Arroyo Calabasas and the southern end of Canada Ancha. South of the mapped area, lake beds appear beneath cinder cones at the "Camel Tracks" locality near the Santa Fe airport.

To the east of the Cerros, a younger north-trending drainage pattern is superimposed on an older southwest-trending series of channels. As the northern gradient became predominant, and after the eruption of the Cerros cut off drainage to the northwest, Canada Ancha became the dominant channel to the Rio Grande.

The Rio Grande and Santa Fe River reacted to the change in base level, due to uplift along the fault, by cutting narrow gorges. The Rio Grande, trapped between basalt flows and the Bandelier Tuff, and ponded many times by flows and maar eruptions, began to downcut to form White Rock Canyon. Where the uplift was steepest, along the original trace of the fault, the canyon became narrow and deep. To the north, near Sagebrush Flats, the river was able to meander and the canyon was wider. The Santa Fe River, and a new pattern of southeasterly drainage, moved to the south around the volcanic field to drain into the reestablished Rio Grande.

The northwest-trending line of vents, which dominantly erupted hawaiite across the center of the field, may reflect a flexure line between the subsiding Espanola and Santo Domingo basins. Extensional fractures would have served as logical conduits for the rapid rise of alkalic magma from deep sources.

The relative age relationships of the subsidence, reorganization of drainage and eruption of the Cerros del Rio field have been partially established by field work. Radiometric dating and careful geomorphic analyses of drainage patterns and gradients should enable geologists to decipher the entire history of subsidence in this region.

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