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CENOZOIC VOLCANIC ROCKS OF SOCORRO COUNTY

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INTRODUCTION

Volcanic rocks of Cenozoic age are widely distributed throughout all of western Socorro County, as shown in Figure 1. All mountain ranges of this area, with the exception of the northern Magdalena Mountains and Ladron Peak, are composed largely of extrusives and related intrusive rocks of volcanic association, interspersed with terrestrial volcanic sediments. The most impressive pile is that of the San Mateo Mountains, in the southwestern portion of the county, with a north-south length of 46 miles, an east-west width of 21 miles, and maximum relief of more than 4800 feet.

East of the Rio Grande, volcanic rocks have a very restricted areal distribution in a series of relatively small isolated fault blocks and several basaltic flow fields with individual source vents.

These rocks lie on the eastern periphery of the Datil–Mogollon volcanic field, the most extensive tract of volcanic terrane in New Mexico. Correlative units are known from reconnaissance mapping to extend westward into the White Mountains of east-central Arizona and southwestward across the area drained by the Gila River system (Willard, 1957a, 1957b, 1958; Willard and Weber, 1958; Weber and Willard, 1959a, 1959b; Willard et al., 1961; Elston, 1960; Dane and Bachman, 1957; 1961; Wilson and Moore, 1958; Wilson et al., 1960). The distribution, lithologic character, and correlation of major units within this sequence, from northwestern Socorro County westward across northern Catron County, have been summarized by Willard (1959). Detailed mapping across the type area of the original Datil Formation of Winchester (1920) by Tonking (1957) and Givens (1957) provides a standard section for correlation in the area. Local detailed mapping of the complex volcanic sequence in the Magdalena district by Loughlin and Koschmann (1942) provides a base for extension southward of volcanic units in the Magdalena Mountains.

For the purpose of this paper, the writer has drawn on the contents of the references cited, reconnaissance mapping in the area east of the Rio Grande during the spring of 1963, and casual observations over the period of years of his familiarity with the region. Although certain patterns of distribution and lithologic characteristics are beginning to emerge, the bolder outlines and regional correlations stemming from reconnaissance work and the finer fabric and refinement of concepts from local detailed work, much more remains to be done before we can begin to assume an understanding of the volcanologic history of the area. The work most needed at the present stage of our knowledge is extension of geologic mapping on a 15-minute quadrangle basis across the large tracts for which only reconnaissance coverage is available, accompanied by petrographic studies of representative rock suites.

The accompanying generalized map, Figure 1, shows the volcanic rocks of the area subdivided into five major units. These units are of formational or higher rank and provide a convenient framework for the discussion that follows. The three oldest units, lower volcanic group, Datil Formation, and basaltic sequence, are also significant in being separated by regional unconformities, and probably should be accorded group status. The two youngest units, volcanics in the Santa Fe Group and Quaternary basalts, are less markedly separated by recognizable unconformities of more local extent, and the distinction between basaltic rocks that should be placed in the Santa Fe and those designated Quaternary is not sharply drawn. Stratigraphic relationships of the described units are shown diagrammatically in Figure 2.

LOWER VOLCANIC GROUP

The rocks of this sequence are undistinguished by a formal name and have been referred to variously as the lower volcanic group, older andesites, and by other designations of convenience. They are present only locally within the area but may have had an original distribution that was much greater, having since been reduced by the several erosional intervals that followed.

The principal areas of outcrop are in the vicinity of Magdalena, at the northern end of the Sierra Cuchillo, and at the southern tip of the San Mateo Mountains. Much of the lowland between the southern end of the Bear Mountains and the northwestern part of the Magdalena Mountains is underlain by these rocks, but outcrops are extensively veneered by later basin fill sediments and alluvium, and relationships with older rocks are obscure. Prominent rock types in this area include black, greenish black, pur-

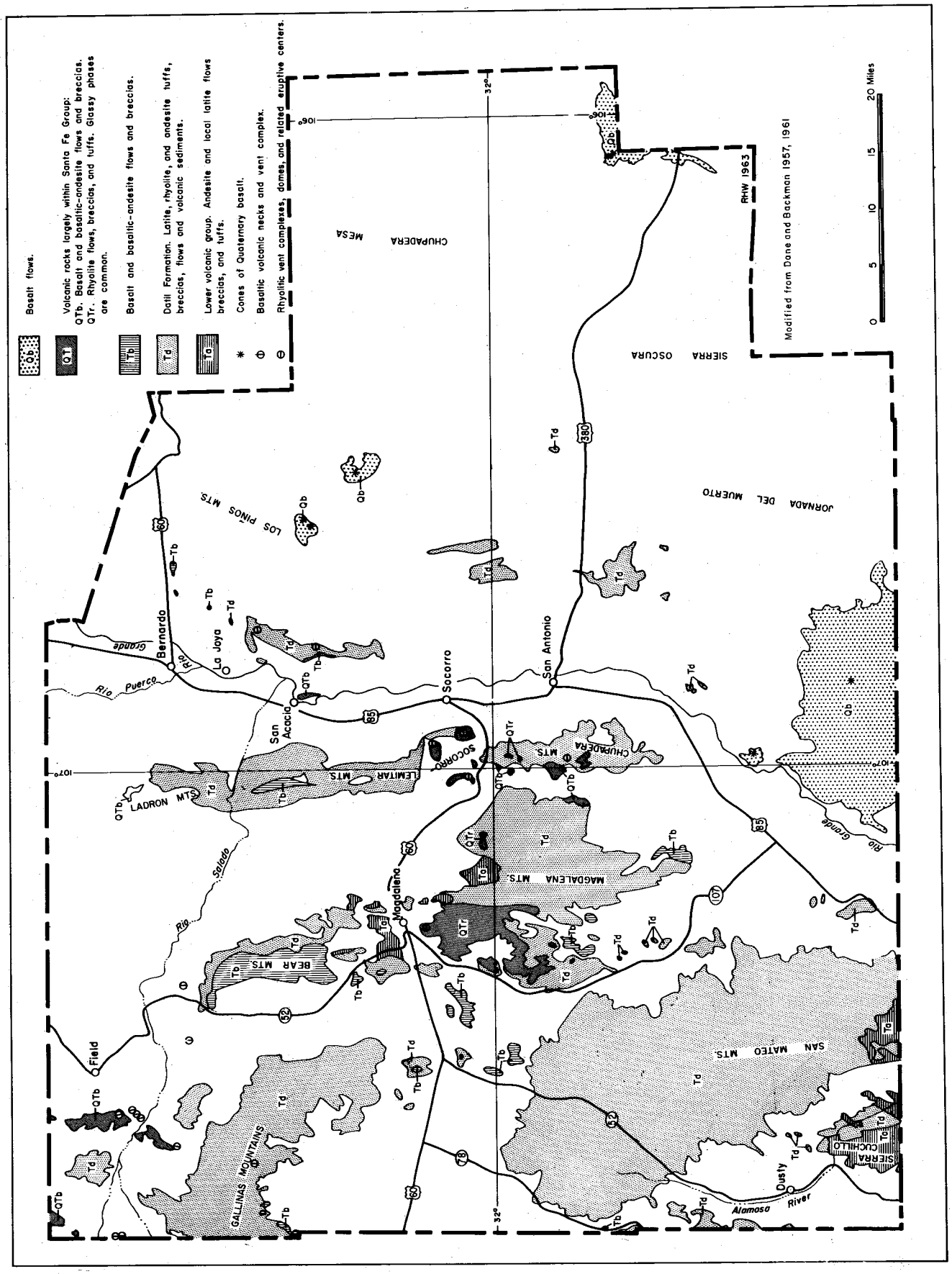

FIGURE 1
Distribution of volcanic rocks in Socorro County, New Mexico.

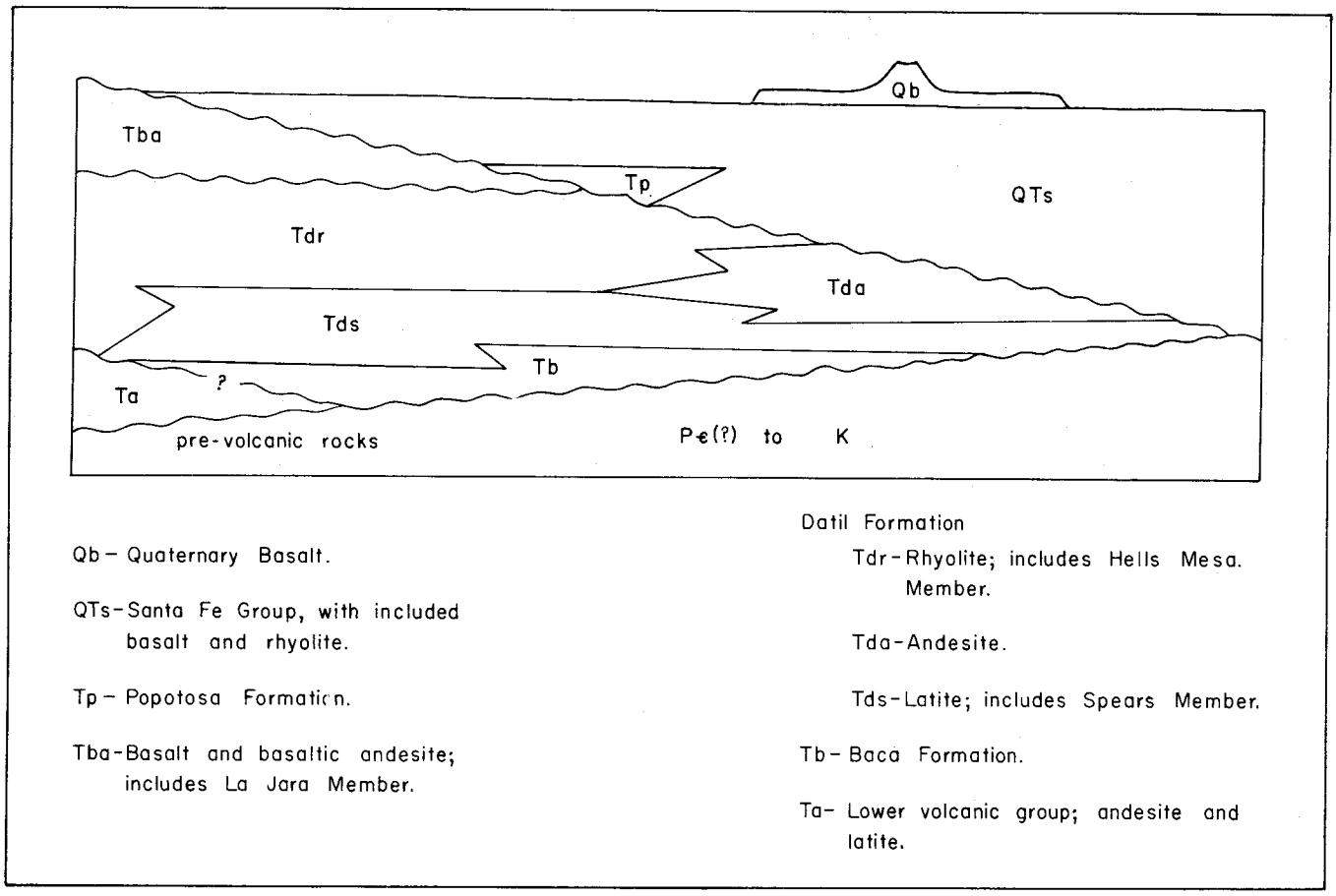

FIGURE 2
Diagrammatic stratigraphy of Cenozoic rocks in Socorro County.

ple, and gray pyroclastics and flows, with pyroclastic rocks apparently predominant. Massive gray to grayish white latitic tuff beds are reported to be interlain with the andesites in the Magdalena district and along the eastern front of the Black Range, and flows of reddish brown banded latite are present near Apache Warm Springs (Willard, 1957a, 1959).

Inasmuch as the lower group is in all likelihood post-Mesaverde Group in age, it could overlie rocks of that group, but exposures showing this relationship are unknown. South of Kelly, purple andesite breccias and tuffs rest directly on the Abo Formation, whereas farther northward, altered greenish gray to purple latite tuffs, breccias, and flows rest upon the Sandia and Madera formations (Loughlin and Koschmann, 1942). If these volcanics are correlatable with the lower group, a profound unconformity is present at its base.

Stratigraphic relationships with the Baca Formation have not been observed, as the two units have nowhere been found in contact. Willard (1959) believes that it is older than the upper part of the Baca and older than or equivalent in age to the lower part. Pebbles of the lower group have not been found in the Baca in this area; hence, proof is lacking that the Baca is younger. Overlying rocks in the Magdalena area are rhyolite tuffs of the Datil Formation and gravels of the Santa Fe Group. In the northern Sierra Cuchillo and southern San Mateo mountains, the lower group is overlain by rhyolite tuff breccias and other units of the lower part of the Datil Formation and by conglomerates of the Gila–Santa Fe Groups.

DATIL FORMATION

As shown in Figure 1, the Datil Formation occupies an area of outcrop exceeding that of all other volcanic units combined. Similarly, the aggregate thickness probably exceeds that of all other units.

The original Datil Formation was defined by Winchester (1920) to represent the sequence of volcanic and sedimentary rocks that ". . . is the mountain-forming series of the Datil Mountains. . . ." The measured type section in the northern Bear Mountains did not, however, include the upper volcanic

sequence in that range (Tonking, 1957). The basal portion of an approximately equivalent section in Baca Canyon on the eastern side of the Bear Mountains was subsequently separated from Winchester's Datil Formation and assigned to a separate unit designated the Baca Formation (Wilpolt et al., 1946). The tangled web of circumstances attending these earlier refinements of the stratigraphic nomenclature for these rocks has been accorded thorough discussion by Kelley and Silver (1952), Tonking (1957), Givens (1957), and Willard (1959), and in a topical article in this guidebook. It suffices here to note that the description by Wilpolt did not include volcanic-derived material in the type Baca and that Givens was unable to recognize volcanic fragments in the Baca in the area west of the type locality. The present writer suggests that the lowest stratigraphic unit above the Baca that contains fragments of volcanic rocks marks the base of the Datil Formation in this area. An exception would be the possible local occurrence of fragments of the lower volcanic group in the Baca, but this relationship has not been recognized in the area.

Tonking (1957) subdivided the Datil Formation in the Bear Mountains into three members, expanding the Datil upward to include 150 or more feet of rhyolite tuff and at least 1200 feet of basaltic-andesite and andesite that Winchester omitted from his measured section. The three members were distinguished as the Spears Member, at the base, overlain successively upward by the Hells Mesa Member and La Jara Peak Member. Willard (1959) correlated La Jara Peak Member with the Mangas basalt, a post-Datil sequence much more prominently developed westward and southward across Catron County. This interpretation is accepted herein, and if the correlation is correct, there is little question that La Jara Peak Member should be excluded from the Datil Formation. Figure 1 shows La Jara equivalents separate from the Datil under the symbol Tb.

Although individual members of the Datil are recognizable throughout most parts of Socorro County, units not represented in the Bear Mountains must also be accommodated. Therefore, the following discussion of recognizable units will follow the lithologic subdivisions indicated in Figure 2.

LATITE

The lowest recognized subunit of the Datil Formation from the Bear Mountains westward through the Gallinas Mountains and eastward into the Jornada del Muerto is a sequence of predominantly latitic volcanics and volcanic sediments. In the Bear and Gallinas mountains they are referred to the Spears Member of the Datil Formation and consist of quartz latite tuffs, breccias, agglomerates, flow breccias, and volcanic sediments resting disconformably on the Baca Formation. Colors range from gray through shades of green, blue, purple, and red. Locally included blocks of limestone, sandstone, and shale up to more than 100 feet in diameter were interpreted by Givens (1957) as float blocks in tuff. The thickness in the type section of the Spears Member at Hells Mesa is nearly 1350 feet (Tonking, 1957).

East of the Rio Grande, a sequence so strikingly similar as to be undoubtedly correlatable is exposed in a narrow westward-tilted range of hills that extends southward from Cibola Canyon southeast of La Joya, along the east side of the Joyita Hills, and the west side of the Valle del Ojo de la Parida. These rocks are almost entirely fragmental, including both pyroclastic and sedimentary deposits that range from mudstones through coarse conglomerates and from tuffs through coarse tuff breccias. Colors range from pale gray through various shades of green, purple, and red. At and near the base are conglomerates almost identical with those in the underlying Baca Formation, and locally indistinguishable except for the presence of characteristic clasts of porphyritic latite, many of which contain conspicuous amounts of hornblende. Nonvolcanic pebbles, cobbles, and boulders include granite, gneiss, quartzite, jasper, Paleozoic limestone, red siltstone and quartzitic siltstone from the Abo Formation (locally conspicuous and up to several feet in diameter), and others ranging in age from Precambrian to Cretaceous.

The upper part in many places contains intercalated andesite flows, flow-breccias, and minor tuff, which also interfinger to a lesser extent with the overlying tuffs and welded tuffs of the rhyolite sequence.

Sepiolite is widespread as a replacement(?) of minor slip and fault gouge in the latite and upper beds of the Baca Formation from this area southward.

Equivalent rocks are present in the two small, isolated, westward-tilted, fault block ranges at the northwest edge of the Jornada del Muerto, extending into the northern edge of the Carthage quadrangle. There, however, recognizable pyroclastic rocks are subordinate to crudely bedded volcanic conglomerates, graywackes, and mudstones. Reddish hues are also more conspicuous. The underlying Baca Formation here is evidently very thin and contains channel conglomerates with boulders of granite and gneiss up to 8 feet in diameter. The contact between the two grades upward within a few feet from granitic

conglomerate through granitic sandstone into purplish red volcanic graywacke. Dikes of andesite are fairly prevalent as intrusives into the latitic beds, connecting upward with flows or sills in the overlying rhyolite tuffs and welded tuffs.

Still farther south, latite conglomerates and pyroclastics overlie the Baca Formation along the southeast side of the Carthage coal field, extending under the andesite-capped peaks clustered about Cerro Colorado. The latitic beds, which here, too, are clear-cut Spears Member equivalents, were mapped by Wilpolt and Wanek (1951) with the underlying Baca Formation. The two units are readily differentiated here by the abrupt appearance of porphyritic latite pebbles and cobbles at the base of the volcanic unit. The contact is well exposed in a roadcut on U.S. 380 a short distance past the Baca coal mine (SE¼ sec. 11, T. 5 S., R. 2 E.) where the basal conglomerates of the volcanic sequence contain abundant nonvolcanic clasts. East of Red Tank, in the SW¼ sec. 22 and the NW¼ sec. 27, pale pinkish gray to purplish gray latite conglomerate and sandstone contrast with underlying red mudstones and sandstones of the Baca.

Other scattered small outcrops are known along the ridge southeast of Prairie Spring and at the northwestern foot of the Little San Pascual Mountains, thus indicating a very appreciable regional extent for this unit.

Reconnaissance mapping in the San Mateo Mountains by Max E. Willard and John H. Schilling (Willard, 1957; Dane and Bachman, 1961) has shown that latite breccias and flow-banded latite have a prominent distribution there. These latites are underlain by massive rhyolite tuff and tuff breccia and, locally, by andesites of the lower volcanic group.

Preliminary results of a K-Ar age determination on biotite from latite tuff breccia in Cibola Canyon indicate that it is Oligocene in age (Robert D. Walker, personal communication, July 1963). Analogies between the Galisteo Formation and the Baca Formation have been pointed up by a number of persons. A further analogy is apparent between the Espinaso Volcanics of Stearns (1953), which transitionally overlie the Galisteo, and the lithologic and environmental similarities of the Spears Member equivalents, which are locally transitional with the underlying Baca. The late Eocene age suggested for the Espinaso may not be far removed from the indicated Oligocene age of the Spears. (Final results of K-Ar age determinations on the latite tuff breccia from Cibola Canyon were received while this paper was in press. The indicated latest Eocene age of 37.1 m.y. is fully compatible with the inferred age of the Espinaso Volcanics. *See* paper by Burke et al. elsewhere in this guidebook.)

RHYOLITE

Rhyolitic tuffs, welded tuffs, breccias, and minor flows are a conspicuous component of the Datil Formation in most volcanic sections of the County. The cliff-forming Hells Mesa Member of the Bear Mountains (Tonking, 1957) is quite characteristic of the lithology and topographic expression of these rocks. Tuffaceous varieties are particularly widespread, whereas recognizable flows have a limited distribution. Welded tuffs are especially prominent in many outcrops because of both their extensive lateral continuity and their resistance to weathering. The planar structure so common in the welded tuffs in many places has been mistaken for flow banding. Phenoclasts of sanidine, plagioclase, quartz, and biotite, with less common hornblende, are usually conspicuous, and locally so abundant as to constitute crystal tuffs. Volcanic sediments are locally interlain with the pyroclastics. Vitrophyres and other massive glassy phases are locally present. Although colors range widely from white in the vitric and pumiceous lapilli tuffs to dark red, purplish, and brown in the more highly welded tuffs and flows, pale grays, tans, and pinkish shades are particularly common.

The rhyolites range widely in thickness from about 250 feet in the northern Bear Mountains to more than 600 feet in the eastern Gallinas Mountains. Reconnaissance observations by Tonking (1957) indicate that the Hells Mesa Member may aggregate more than 2000 feet in thickness in the Gallinas Mountains. Thicknesses of several thousand feet are indicated for the San Mateo Mountains, where rhyolitic rocks are present in several intervals that extend from the base of the Datil section to the highest parts of the range. Rocks of andesitic and of latitic composition are interlain with the rhyolitic units of the San Mateos (Willard, 1957; Dane and Bachman, 1961), as in other sections of the area.

Intrusive phases of the rhyolites occur locally as plugs and possibly endogenous domes, as well as dikes. Plugs and vent complexes of massive flow-banded rhyolite, tuffs, and breccias have been noted in the central Chupadera Mountains, and in the narrow volcanic range east of the Joyita Hills and west of the Valle del Ojo de la Parida (fig. 1). Plugs and volcanic domes in the Socorro Mountains may be in part attributable to the Datil Formation, although they have been considered to correlate with a post-Datil rhyolitic assemblage. The great rhyolitic piles

of the San Mateo and southern Magdalena Mountains may reveal associated vent assemblages when these areas are studied in more detail, although the chance of concealment by their own eruptives is very great in thick sections such as these.

Potassium-argon age determinations have been made recently on biotite and volcanic glasses from the Datil rhyolites. The data are summarized elsewhere in this guidebook (Weber and Bassett). A sample from the base of the Hells Mesa Member in the type locality has an indicated age of about 30 million years. If the maximum indicated age of the Socorro perlite is significant, and pertainable to Datil rhyolites, an age of about 33 million years should be noted. Preliminary data on rhyolite tuff, collected by Roy W. Foster from the Hells Mesa Member in the Gallinas Mountains, indicate an Oligocene age (R. D. Walker, personal communication, July 1963).

ANDESITE

Andesites and basaltic andesites are far less prominent components of the Datil Formation in Socorro County than to the west in Catron County. As noted earlier, the basaltic andesites and andesites of La Jara Peak Member in the Bear Mountains (Tonking, 1957) have been assigned to a post-Datil sequence (Willard, 1959), leaving that area without recognized equivalents of the Datil andesites. Givens (1957) has indicated no equivalents in the Gallinas Mountains. Similarly, the San Mateo and southern Magdalena mountains sequences do not contain Datil andesites that were mappable on a reconnaissance basis.

Porphyritic andesite flows mapped by Miesch (1956) in the northern Chupadera Mountains are intercalated with rhyolitic extrusives quite low in the section, but the correlation of these rocks with the Datil Formation is not established. Vesicular gray to black and red andesites and basaltic-andesites also are present to the north in the Socorro and Lemitar mountains, but again correlation with the Datil is not certain. Basalt or basaltic andesite flows and pyroclastics overlapped by the Popotosa Formation at the northern end of the Lemitar Mountains have been assigned in this paper to a later basaltic sequence. The possibility that the basaltic rocks are a part of the Datil has not, however, been clearly contradicted.

East of the Rio Grande, Datil andesites and basaltic andesites are sparsely present and locally conspicuous. From Cibola Canyon southward along the Joyita Hills and the base of the narrow volcanic ridge bordering the Valle del Ojo de la Parida, andesite and basaltic andesite flows, breccias, tuffs, and intrusives are a minor, though prevalent, component of the upper part of the latite pyroclastic and sedimentary sequence. They also extend into the basal portion of the overlying rhyolitic tuffs. Dark vesicular flows and flow breccias with plagioclase and augite phenocrysts are prominent at the top of the latitic sequence in Cibola Canyon south of Los Alamos Spring. The andesites here are directly overlain by Santa Fe Group gravels and pinch out farther south as a tongue in the latite clastics. Farther southward at the southwest edge of Valle del Ojo de la Parida (sec. 35, T. 1 S., R. 1 E. and sec. 11, T.2 S., R. 1 E.) porphyritic augite andesite flows and flow breccias intertongue with the upper part of the latite sequence, and the lowermost part of the overlying rhyolite tuffs and welded tuffs. Large plagioclase laths and coarse prisms of augite are conspicuous in most sections, and vesicular phases are common. Colors are generally dark gray to black, purplish gray, bluish gray, and red. Local fine-grained phases, at least in part intrusive, are medium gray with small hematized ferromagnesian phenocrysts. Similar rocks are sparsely exposed in windows through the terrace deposits and Santa Fe Group sediments that blanket the highly dissected region extending southward from Arroyo de la Parida.

Andesitic flows apparently become more prominent in the section southward, perhaps in part due to erosional stripping of overlying rhyolites. Cerro Colorado and adjacent peaks are capped by andesite, and rhyolites are absent here. A basal flow of highly porphyritic, purplish gray, vesicular andesite overlies massive to nodular pale gray latite tuff or tuffaceous sandstone. Platy plagioclase phenocrysts in the andesite are aligned with the contorted flow banding and accompanied by coarse prisms of augite. Vesicles are coated to partly filled with quartz, calcite, and heulandite, a feature common to related andesites in the areas previously described. The upper part of the lower flow is bleached and altered. Overlying the basal flow is a massive, fine-grained, medium gray to mottled gray-buff, porphyritic andesite with small vesicles lined with cristobalite, calcite, hornblende, biotite, and hematite. Other isolated outcrops of andesite extend southward into Sand Mountain and faulted blocks at the western foot of Little San Pascual Mountain.

Two other small isolated ranges to the north represent a northward extension of the Cerro Colorado belt. In the western fault block in T. 3 and 4 S., R. 2 E., andesite dikes that cut the latitic sequence spread out upward into flows or sills intercalated

with rhyolite and welded tuffs. In the northern part of the range, larger irregular masses appear to cut the tuffaceous rhyolites intrusively. An isolated outcrop related to this belt lies 12 miles to the southeast, where an outlier of andesite rests on latite breccias.

A formerly much greater distribution of Datil andesites in this area is indicated by these scattered outcrops along the northwestern edge of the Jornada del Muerto. Lithologic similarities with the andesitic pile of the Sierra Blanca, nearly 50 miles to the southeast, are to be noted. The relationship of the Sierra Blanca andesites to underlying terrestrial sediments of the Cub Mountain Formation (the upper part of which contains graywackes of possible volcanic derivation) suggests analogies with the relationship of the Datil andesites to subjacent latitic sediments underlain by the Baca Formation. An adequate basis for correlation is lacking at present, but the observed features do provide a stimulus to speculation.

BASALT AND BASALTIC ANDESITE

Unconformably overlying the various lithologic units of the Datil Formation in many areas in Catron County is a laterally extensive, and locally thick, sequence of basalt and basaltic andesite flows and flow breccias. Willard (1959) has referred to this sequence as the Mangas basalt, in consequence of its impressive development in the Mangas Mountains. The most extensive known field of these rocks in Socorro County is along the crest and western slopes of the Bear Mountains, where Tonking (1957) described them as the upper member of the Datil Formation, La Jara Peak Member. As already noted, Willard has made an acceptable argument for excluding La Jara Peak Member from the Datil Formation, which usage will be followed herein.

In the Bear Mountains, these rocks consist of fine-grained, dark to medium gray basalt and porphyritic basaltic andesite, locally vesicular and oxidized red. Phenocrysts of hematite and iddingsite are conspicuous in the lower part (Tonking, 1957). Amygdules, locally present in the vesicular phases, consist of calcite, quartz, chalcedony, and heulandite. Both flows and flow breccias are represented, with thin volcanic sandstone and conglomerate beds of Santa Fe lithology intercalated in the upper part. The type section totals 1175 feet, and the maximum thickness may reach 2500 feet. Volcanic necks in the area, such as La Jara Peak, are considered by Tonking to be the sources of some of the flows. La Jara Peak Member overlies the Hells Mesa Member with apparent conformity in the Bear Mountains and is in turn overlain by Santa Fe Group basin fill and by pediment gravels.

Similar and correlative rocks overlie rhyolite tuffs around the northern and eastern periphery of the Plains of San Agustin, where Willard and Givens (1958) note the characteristic presence of pseudomorphic phenocrysts of iddingsite. Other isolated outcrops were mapped by J. H. Schilling around the western and southern periphery of the Magdalena Mountains (Dane and Bachman, 1957).

A narrow band of aphanitic medium gray to black basaltic andesite flows and flow breccias extends for several miles southward from near the Rio Salado immediately north of the Lemitar Mountains. Vesicular phases are prominent, locally oxidized to shades of red, and in part filled with amygdules of calcite. The flows are overlapped on the west by the playa phase of the Popotosa Formation along a steep cliffline contact, the steepness of which has been accentuated by westward tilting of about 30 degrees. A fault truncates the eastern margin, bringing Popotosa and Santa Fe beds or pediment gravels into juxtaposition with the base of the andesite. Near the northern end of the outcrop, the fault truncated the source vent leaving the southwestern side well exposed by subsequent erosion. Both inner and outer cone-slope beds of lapilli tuff are well preserved, overlain by oxidized scoriaceous ejecta, which is in turn surmounted by flows and flow breccias. This is as revealing an exposure of an exhumed volcanic cone as one could hope for! Correlation of the vent and associated flows with the basaltic sequence under discussion is not conclusive because of the incompletion of the writer's mapping in the area, but the lithologic characteristics and relationship to the Popotosa strongly suggest this interpretation.

Basaltic andesites are sparsely distributed east of the Rio Grande. Capping Turututu (Black) Butte, and in the low hills to the west, are gray to black, brown, and red fine-grained, vesicular and amygdaloidal flows, flow breccias, and possible intrusive bodies that are tentatively assigned to this sequence. Lithologic similarities with some andesites in the Datil Formation are, however, to be noted. The rocks on Turututu Butte overlie pale gray, massive welded rhyolite tuff that dips gently northwest. Similar flows and flow breccias with local basal ash overlie the Hells Mesa welded rhyolite tuffs along the western border of the Valle del Ojo de la Parida, dipping westward in approximate conformity with the rhyolites.

POPOTOSA FORMATION

In the years that have intervened since Denny (1940) mapped and described the Popotosa Formation, named from exposures in Cañada Popotosa at

the southern foot of Ladron Peak, there has been considerable speculation concerning its stratigraphic position and possible correlation with the Santa Fe Group and with the Datil Formation. Unfortunately, these points have not been fully resolved.

The lower part of the Popotosa consists of gypsiferous dull red to brown volcanic sandstone, siltstone, and silty claystone with lenses of white to grayish brown water-laid tuff. A bed of pale cream-colored bentonite 6 to 8 feet thick in Popotosa Canyon has been partly explored as a potential source of drilling mud. The upper part is massive, crudely bedded conglomerate and sandstone with poor sorting and has a striking resemblance to lower portions of the Gila Conglomerate in the vicinity of Reserve. Pebbles of andesite and basaltic andesite predominate. Locally, however, fragments of Paleozoic limestone, Precambrian granite and gneiss, Cretaceous(?) sandstone, and rhyolite tuff and welded tuff are common. The rhyolitic rocks resemble those of Hells Mesa equivalents of the Datil Formation. A very minor fraction consists of porphyritic latite that is highly characteristic of the Spears member of the Datil Formation.

The assemblage of included fragments, bedding characteristics, overlap onto what are believed to be post-Datil andesite flows, and apparently near-conformable relationship with the overlying Santa Fe gravels indicates that the Popotosa is probably a basal playa-fanglomerate facies of the Santa Fe. Denny believed that the alluvial fan deposits of the Popotosa were derived from the west, which would point to the Bear Mountains as a possible source.

Spiegel (1955, p. 40) inferred an age equivalence between the Popotosa and the Abiquiu(?) Formation of Stearns (1953). The age of the Abiquiu(?) was inferred by Stearns to be early or middle Miocene on the basis of long-range extrapolations, and it was correlated with the lower Santa Fe. Later, DeBrine, Spiegel, and Williams (1963) correlated the Popotosa with the Spears Member of the Datil Formation, stating that "The Popotosa overlies the Baca Formation in the Bear Mountains and the Baca(?) Formation east of the Rio Grande." (After this paper went to press, mapping by the writer in the eastern and southern foothills of Ladron Peak tends to confirm the correlation suggested by DeBrine, Spiegel, and Williams (1963). Overlying a few feet of coarse sandstones, arkoses, and conglomerates that resemble the Baca Formation, containing pebbles, cobbles, and boulders of locally derived Precambrian crystalline rocks and Paleozoic limestone, is a sequence of dull red, purple, and bluish gray andesite conglomerate and local breccias and flows. The conglomerates in one area contain an abundance of typical Spears Member latite pebbles and cobbles. These beds appear to grade laterally and vertically into lithologies characteristic of the Popotosa beds as described by Denny (1940). Thin shattered plates of Paleozoic limestone underlie this sequence at several places in sinuous fault contact over brecciated Precambrian granite and amphibolite, with imbrication suggesting thrust movement. The basaltic andesite flows at the northern end of the Lemitar Mountains and east of Ladron Peak accordingly should probably be shown with the Datil Formation in Figure 1. The stratigraphic relationships of the Popotosa in Figure 2 also appear inappropriate at this time.)

Evans (1963, p. 60), in reporting the results of field and laboratory study of the Popotosa in the vicinity of Loma Blanca, states that "The Tertiary Popotosa playa deposits and conglomerates were tilted and probably faulted before the Tertiary Santa Fe Group was deposited." Evans made no correlation with elements of the Datil Formation, nor with the Santa Fe Group.

VOLCANICS IN THE SANTA FE GROUP

Eruptive and intrusive volcanic rocks are intercalated with basin-fill clastic rocks that have been correlated with the Santa Fe Group at a number of places in Socorro County. These volcanics include two major lithologic assemblages, basaltic and rhyolitic, which will be treated separately in the following paragraphs.

BASALT AND BASALTIC ANDESITE

Flows and flow breccias, locally with associated intrusives, extend upward throughout most of the various local sequences of the Santa Fe Group. These rocks are not readily differentiable from the earlier post-Datil basaltic rocks, at lower stratigraphic levels, nor from basalts of Pleistocene age that overlie the Santa Fe Group. Possibly the distribution shown in Figure 1 includes correlatives of both earlier and later units. Tonking (1957) observed interfingering between the upper part of La Jara Peak Member and clastic sediments of Santa Fe aspect. Givens (1957) assigned basalts capping D Cross, Tres Hermanos, Table Mountain, and Blue Mesas to the Santa Fe. Large phenocrysts of augite, olivine, and feldspar are visible in these rocks. Givens considered the basaltic plugs of D Cross, Tres Hermanos, and Table Mountain to be of different age from the basalt flows because of differences in the indices of refraction of laboratory-fused glasses. The common presence of

fresh olivine differs from its scarcity in the older basalts, where iddingsite pseudomorphs prevail. Vesicles are commonly unfilled or lined only with caliche.

Similar, but less porphyritic dark gray to black olivine basalt flows cap clays and fanglomerates assigned by Miesch (1956) to the Santa Fe along the western side of the southern Socorro–Chupadera mountains chain, extending across the southern Socorro Mountains in the immediate vicinity of the Socorro perlite deposit. The flows at the northern end of this belt were probably erupted from fault-aligned vents in sec. 14, 23, and 26, T. 3 S., R. 2 W. Although the vent basalts are overlapped by gravels capping the Santa Fe in this area, it appears probable that both the gravels and the basalts are of Quaternary age.

At San Acacia, a massive microvesicular to macrovesicular, medium to dark gray, fine-grained, basaltic andesite flow, with a cobbly basal flow breccia and local subdued pillow structure, rests on laminated to thick-bedded fluviatile silty clays and silty sands. Silica-pebble channel gravels of Rio Grande type are locally present on the surface of the flow. Fan-gravels, sheet wash, and fine-grained alluvium with a well-developed caliche zone overlap the eastern edge. The dip appears to be gently southeastward, rather than westward as indicated by Denny (1940). Denny states that this flow is ". . . presumably of Santa Fe age," which there is no denying if the underlying and overlying sediments are included within the Santa Fe Group designation. Here, however, it appears possible that the underlying fluviatile beds are Pleistocene flood-plain deposits of the Rio Grande and that the flow may be of Pleistocene age.

RHYOLITE

Tuffs, breccias, flows, volcanic domes, and intrusive rocks locally interfinger with at least the basal parts of beds that have been assigned to the Santa Fe Group.

The largest coextensive belt of these rocks extends southward and southwestward from Magdalena Peak, about 1¾ miles south of Magdalena. Magdalena Peak is evidently an eruptive center for some of the extrusive units of the area. Other centers are indicated locally by relationships farther south. Glassy phases, including bodies of perlite, vitrophyre, vitric tuff, and welded vitric breccia, are prevalent in this sequence. Local detailed mapping of a perlite body and associated rhyolite flows illustrates some of the characteristic structural and petrographic features of these rocks (Weber, 1957). A potassium-argon age determination on perlite from the Stendel deposit provided an indicated age of about 14 million years (Weber and Bassett, 1963), which is in accord with the putative age of the lower Santa Fe Group in the Rio Grande trough. It also supports Schilling's assignment of these eruptives to the Santa Fe Group (Dane and Bachman, 1957, 1961).

Other localities where related rhyolites are believed to occur lie along the Chupadera–Socorro mountains chain. Intrusives and vent-associated extrusives of rhyolitic composition there are aligned roughly parallel with the structural axis of the range. Relative age of these rhyolites is not easily determined because of the absence of good stratigraphic indicators and the restricted lateral distribution of individual masses. According to Miesch (1956), rhyolite was observed in this area interlayered with the base of the Santa Fe by Jack Waldron. The Socorro perlite deposit was believed to correlate with the Santa Fe rhyolites, but recently obtained potassium-argon dates are inconsistent and contradictory to this correlation.

There are undoubtedly other areas in Socorro County that contain representatives of this assemblage, but where these late rhyolites rest on or are associated with the earlier Datil rhyolites, recognition is difficult.

QUATERNARY BASALT

Basaltic flows, each with associated cones, are widely scattered in the area east of the Rio Grande. The majority of these flows emerged onto erosion surfaces at or near the present surface and have not been buried by later deposits attributable to the Santa Fe Group. Local residual soils, windblown sand and silt, and minor alluvium only partially mantle their surfaces. Cones are clearly recognizable on each flow, ranging from intact to moderately eroded. All are older than the Carrizozo flow, and are considered to be Pleistocene in age on the basis of soil development and archaeological evidence.

JORNADA BASALT FLOW

The largest individual flow field extends from south-central Socorro County southward into Sierra County on the west side of the Jornada del Muerto. The western edge of the flow forms the east bank of the Rio Grande from Fort Craig southward to the northern tip of the Fra Cristobal Range. Kottlowski et al. (1956, p. 72) referred to this flow field as the Jornada basalt flow. Reconnaissance mapping by Kottlowski (Dane and Bachman, 1961) indicates a maximum east-west length of about 24 miles and a maximum north-south width of about 12 miles. The western margin is at or near the present river level,

where it consists of a single massive flow of medium to dark gray, vesicular to microvesicular olivine basalt, with an observed thickness of 5 to 30 feet along the northern portion. The flow here overlies riverine gravels. The margins are mantled by aeolian sands and silts with a well-developed soil zone characteristic of that on the Jornada surface. Local discontinuous patches of resistate pebbles suggest traces of former stream drainage across the western edge. Inward from the margins, surficial aeolian deposits grade into silt sizes, and thin brown residual soils and local alluvium are patchily distributed.

The vent is located slightly east of the center of the flow, rising about 150 feet in a broad but conspicuous cone approximately one mile in diameter. Within an outer cone are a series of nested spatter cones largely separated by moats floored by lava pools. The second cone inward, possibly the foundered apex of the outer cone, has an exterior slope of 20 degrees, as does the innermost cone. Segments of two intermediate cones are visible. The innermost cone rises nearly 90 feet above the lava pool at its southern base and encloses an intact symmetrical crater 250 feet across and about 30 feet deep. The walls are composed of black agglutinated spatter of scoriaceous glass. Crusted bombs are sparse. Rare exotic ejecta of white quartzitic sandstone are encased and injected by black vesicular glass with an index of refraction of about 1.576, indicating a silica content of 51 to 53 percent (Williams et al., 1955, fig. 7).

The warmth of the water pumped from Crater Well, about one mile southwest of the cone center, indicates abnormal heat flow at that point.

The flows are evidently agglutinates of highly gas-charged fluid lava erupted as fire fountains. Flow surfaces are encrusted with clots of spatter that distinguish them from typical pahoehoe surfaces, such as those of the Carrizozo flow. A partially collapsed lava tunnel that extends south-southwestward for about one mile from the southern base of the cone probably served as a drainageway for lava pools in the cone. The maximum observed width, within reach of daylight, is about 65 feet, with a height estimated at 30 to 40 feet. A considerable amount of bat guano has been extracted and marketed from accessible portions of the tunnel, an activity that was greatly impeded by a jumble of collapsed roof blocks.

MESA PRIETA FLOW

Mesa Prieta (Black Mesa of modern maps) is a small, isolated flow remnant about one mile north of the northwestern tip of the Jornada flow, abutted by the Rio Grande at its western base. The former townsite of San Marcial lies buried beneath flood deposits that inundated the area north of Mesa Prieta on August 13, 1929. A small cone, breached to the south, surmounts the eastern edge of the flow. The mesa cap consists of dark gray to nearly black, fine-grained, slightly to moderately vesicular, quartz-bearing olivine basalt. It overlies cross-bedded riverine sands and gravels of the uppermost Santa Fe Group. Soils of the Jornada surface overlie the basalt.

That this flow is older than the Jornada flow is indicated by its extrusion onto a local surface about 250 to 300 feet higher than that underlying the Jornada flow. The prominence of this flow-capped mesa makes it a conspicuous landmark to travelers on U.S. 85, about 3.5 miles to the northwest.

MESA REDONDA FLOW

Mesa Redonda is an isolated, arcuate, basalt-capped mesa about 21 miles east-northeast of Socorro. The mesa cap on the southeast consists of two flow units, separated by rubbly flow breccia, aggregating 50 feet thick. The flows are composed of fine-grained, massive and subcolumnar to platy olivine basalt or basaltic andesite. Olivine phenocrysts are partially altered to iddingsite. A pale gray color and distinctly trachytic texture distinguish the middle portions of the flows, particularly the upper one. A basal reddish brown basaltic ash 0 to 10 inches thick rests directly on variegated red to white gypsiferous silts and sandstones of the Yeso Formation. Two units exposed farther north consist of a basal massive to platy flow overlain by a nodular lapilli flow(?). The nodular unit extends westward to a breached cone that is identified as Pyramid Crater on the map of Wilpolt and Wanek (1951). Here, the dissected remnant of a cinder cone with a rim diameter of roughly one-half mile was built up of finely vesicular brown, red, and purple lapilli, blocks and crusted bombs up to 4 feet in length. An abrupt knob of nodular, crudely bedded pyroclasts that rises roughly 75 feet above the present rim of the cone may be correlatable with the nodular flow(?). Several dikes radiate outward from the knob.

The degree of dissection of the cone, the development of a stony residual soil on the flow surface, and the prominence of the caliche zone at the base of the soil and at the base of the flows, plus the prevalence of iddingsitic alteration, point to an appreciably greater age for these flows than for those described previously.

An isolated, though petrogenetically related, flow field lies five miles northwest of the edge of Mesa Redonda. A lower mesa here is capped by a flow that rests on beveled fault blocks of folded Bursum, Abo,

and Yeso formations and the Madera Limestone. Wilpolt and Wanek (1951) reported that this flow also overlies Quaternary pediment gravels. Only one flow unit was recognized, underlain and overlain locally by pyroclastic scoria. The flow is pale gray and slightly trachytic in texture in the center, grading upward and downward into chilled borders of fine-grained, dark gray to nearly black olivine basalt. Two vents were recognized at the eastern edge, aligned on the buried trace of the Montosa Fault. Dissected cone rims consist of lapilli, blocks, and spindle-shaped bombs from 1 inch to 4 feet in diameter. A plug of mottled nodular basalt is exposed in the southern vent. The northern crater appears to have contained a lava pool that spilled northward over the rim, and may have breached the south wall.

BROKEN BACK FLOW

The Broken Back flow is located in extreme southeastern Socorro County and northwestern Lincoln County at the southeastern toe of Chupadera Mesa. The flow extends southward roughly ten miles in the floor of a modern valley and eastward about seven miles into the upper Tularosa Valley, where it is overlapped by the Carrizozo flow. The flow (probably multiple) is poorly exposed because of a cover of alluvium that thickens southward. Exposed portions consist of fluidal olivine basalt of fine grain, showing general similarity to the basalt of the Carrizozo flow. Two adjacent, steep-walled cinder cones at the northwest edge of the field are obvious source vents. The southeastern of the two cones rises 200 feet to the crest, which contains an intact crater. Scoria has been mined from an open pit for use as lightweight aggregate, exposing in section the structure of the outer slope. The northwestern cone rises 50 feet higher from a broader base and is breached on the southeast.

That this flow is older than the Carrizozo flow (which is probably Recent) is clearly shown by overlap by the Carrizozo flow to the east and the greater degree of weathering and alluviation of the Broken Back flow. Alluviation of this valley probably was influenced by clogging of the master drainage in the Tularosa Valley by the Carrizozo flow.

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