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Preliminary notes on the geology of part of the Socorro Mountains, Socorro County, New Mexico

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1963, pp. 185-196. https://doi.org/10.56577/FFC-14.185

in:

Socorro Region, Kuellmer, F. J.; [ed.], New Mexico Geological Society 14 th Annual Fall Field Conference Guidebook, 204 p. https://doi.org/10.56577/FFC-14

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PRELIMINARY NOTES ON THE GEOLOGY OF PART OF THE SOCORRO MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

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The Socorro Mountains are three miles west of the town of Socorro, New Mexico. They are a portion of a continuous block of older rocks forming the west boundary of the Rio Grande depression in the Socorro region. Topographically, they are bounded by Nogal Canyon to the north, the Rio Grande depression to the east, Socorro Canyon traversed by U.S. Highway 60 on the south, and the Snake Ranch flats to the west (fig. 1). Only the portion of the

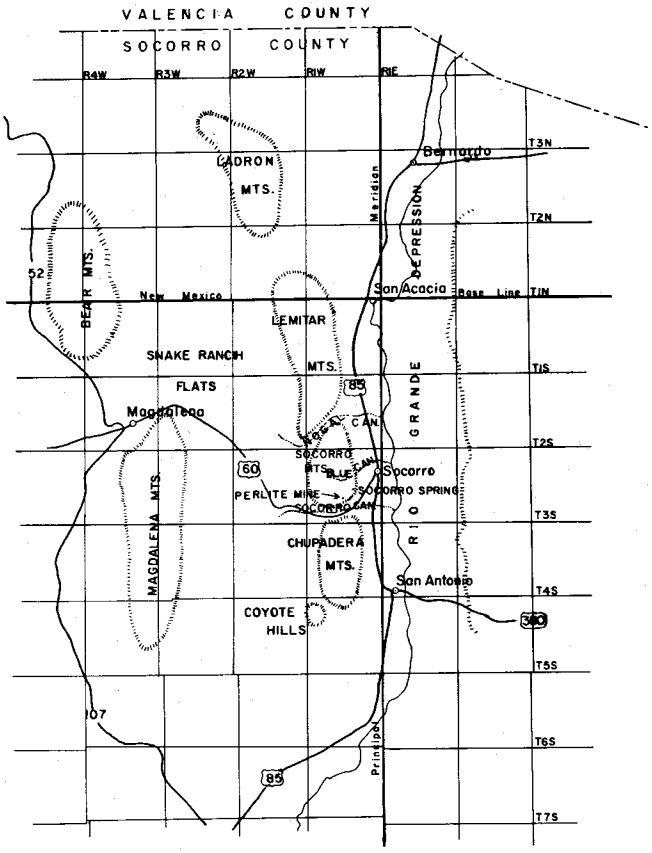


FIGURE 1

Index map.

Socorro Mountains in the immediate vicinity of Socorro Peak is considered in this discussion. The accompanying geologic map (fig. 2) includes all or portions of sections 4 through 9 and 16 through 18 inclusive, T. 3 S., R. 1 W., New Mexico Base and Meridian.

All the Socorro Mountain block north of Blue Canyon lies in a withdrawn area to which access is restricted by the New Mexico Institute of Mining and Technology. Prior arrangements are necessary for examination and entry. South of Blue Canyon, most of the eastern portion of the block is private property or restricted by NMIMT so that the only part of the mountains open to entry is the southwest corner. A good surface road extends from the campus of NMIMT to installations in Blue Canyon. Several graded dirt roads provide access to the mountain front and to seismic installations in old mine tunnels along the base of the eastern face. A steep jeep trail passable in dry weather extends from Blue Canyon to the top of Socorro Peak. Other ranch roads branching from U.S. Highway 60, which traverses valleys on three sides of the mountains, provide rough access to the southern and western sides of the block. No point in the Socorro Mountains is more than two miles from some form of access road.

The writer is indebted to many students who have mapped and collected in the area and particularly to Lawrence Herber and John Shenk who compiled much of the map (fig. 2). Grants from the National Science Foundation Undergraduate Research Participation Program and support from the State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, are also gratefully acknowledged. Discussions with other staff members of NMIMT have been particularly helpful in clarifying ideas of the complex volcanic stratigraphy. Dr. Allan R. Sanford, geophysicist at NMIMT, has kindly made seismological and gravity data available as an indirect check on some of the conclusions.

The abrupt eastern margin of the Socorro Mountains has relief in excess of 2000 feet a mile, while to the north, south, and west the slopes are more gentle. Along the eastern foot of the Socorro Mountains, the elevation is about 5000 feet above sea level. The western edge of the mountains along the southeastern corner of the Snake Ranch flats averages about 5800 feet above sea level. The highest point in the mountains is a peak 7284 feet above sea level, one quarter mile northwest of Socorro Peak. The topography is irregular; hills and mesas of resistant materials stand high above dissected portions of soft-

er rock. The arroyos are steep and narrow and often choked with talus debris.

Exposures are limited because of the resistant nature of some of the rock units. Large areas may be masked by a veneer of blocky talus often a few tens of feet in thickness, and occasionally several hundred feet thick. The softer rocks contain large percentages of bentonitic mud and clay and thus provide ideal surfaces for landsliding whenever moisture is available. The best outcrops are found in the deeper canyons, along the steep eastern face, and near the crests of some of the higher peaks.

Vegetation is scant. Cactus (prickly pear and cholla, principally), scrub juniper and pinon, creosote bush, rabbit bush, and mesquite are the common plants. In the flatter areas, numerous grasses flourish when sufficient moisture accumulates. Total precipitation on the campus of the NMIMT averages about 8 inches a year. Perhaps 12 to 14 inches fall on the higher elevations of the Socorro Mountains; half of this precipitation is snow, accumulated during the months of December, January, and February, and the balance falls as heavy thundershowers, usually during July and August. The average mean temperature is 57°F; summer maxima may exceed 100°F and winter minima are occasionally below 0°F. The average daily range of temperatures in the Socorro Mountains is probably near 45°F. Such temperature extremes along with the lack of moisture have contributed greatly to the talus accumulations which mask many of the critical areas.

GEOLOGY

Precambrian, Pennsylvanian, Tertiary, and Quaternary rocks are exposed in the Socorro Mountains. A gentle plunge to the south coupled with the westward tilt of the block restricts exposures of the Precambrian and Pennsylvanian units to the eastern face of the mountains east and north of Socorro Peak. The Tertiary beds are predominantly volcanic sediments intruded by numerous dikes, sills, and plugs of rhyolite, trachyte, perlite, and andesite. Breccias, tuffs, agglomerate, and ash are common, although very few exposures of actual flow materials have been identified. The Quaternary materials are chiefly unconsolidated sediment derived from the other exposures and collected in talus fans, stream terraces, landslide debris, and alluvium.

Several faults cut the mountains, usually of a few feet to a few tens of feet displacement. Nearly all are parallel to the eastern margin of the block which is a fault-line scarp exhibiting an aggregate vertical displacement of several thousand feet. Folding is confined to local drag on faults, although many of the acidic intrusions exhibit intricate contortions in their flow banding.

STRATIGRAPHY

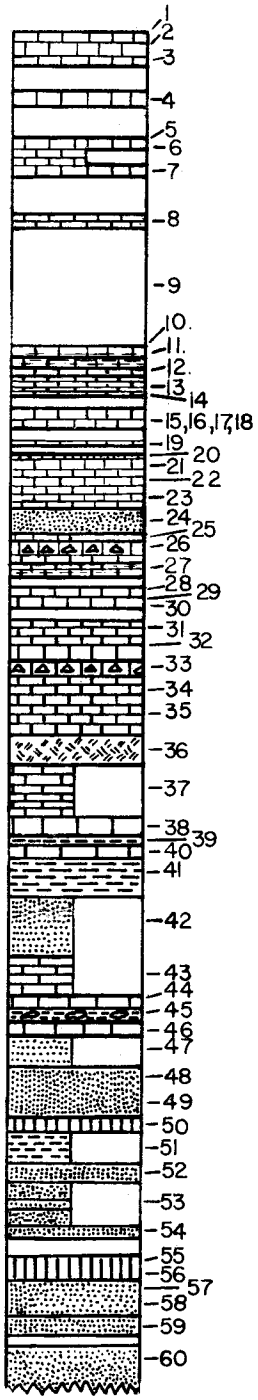
PRECAMBRIAN ROCKS

A small outcrop of dark green argillite is exposed in SW¼SW¼S4 (fig. 2). Locally, narrow bands of quartzite are interbedded. Woods Tunnel, driven between 150 and 200 feet below this outcrop and about 150 feet south of it, does not cut the argillite. However, the tunnel has a total length of more than 1200 feet, mostly in granodiorite gneiss and chlorite schist, and does intersect the prominent fault which forms the eastern boundary of the argillite on the surface. Such patches of one type of metamorphic rock in larger bodies of another type are common in the Precambrian rocks of both margins of the Rio Grande depression a short distance north of Socorro Peak, so this relationship is not unusual. The Precambrian outcrop areas to the north in the Lemitar and Ladron mountains are much more extensive and the differences in elevation and exposure may reflect a regional southward plunge of the Precambrian surface.

The argillite is foliated and dips gently (22 degrees) to the southeast. A prominent joint system dips 35°NW and with the uniform grain of the rock makes selection of possible bedding surfaces difficult. The argillite is overlain unconformably by quartzite and shale correlated with units of the Pennsylvanian rocks.

PENNSYLVANIAN ROCKS

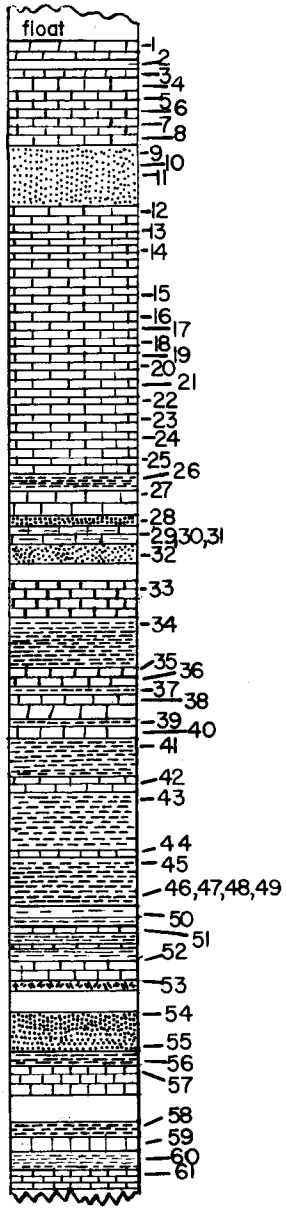
The Sandia formation was named by Gordon (1907) and designated as the lower formation of the Magdalena group. It has apparently been generally restricted to those clastic beds which form the upper part of the Derryan series or the lower part of the Desmoinesian series of Thompson (1942). The Madera limestone was similarly designated the top formation of the Magdalena group by Gordon (1907) and generally included the remainder of the Desmoinesian as well as the Missourian and Virgillian series of Thompson (1942). Kottlowski (1960) gives an excellent summary of the Pennsylvanian rocks in southwestern New Mexico and southeastern Arizona and on pages 56-58 summarizes the exposures in the Socorro–Lemitar mountains and discusses their relationships with other outcrops in the vicinity. Equivalents of parts of the Sandia and Madera formations are probably present in the Pennsylvanian rocks of Socorro Peak, but because of the



scale: 1" = 100'

1. gr. dense to x-lline, cherty units containing fusilinids.
2. dense gr. to x-lline with interbedded cherty, argillaceous lms. beds.
3. massive, black, dense, crinoids, heavily fractured.
4. gr., fragmental to coarsely x-lline, locally laminated.
5. gr. generally massive, detrital crinoids & brachs.
6. gr. dense, bedded.
7. dark gr. to black, dense, somewhat fragmental, some small black carbonaceous laminae
8. gr., fragmental, fine grained, laminated, fusilinids and brachs. weathering gives "algal limestone" appearance.
9. some bedded bk., dense lms., non-fossil.
10. detrital (fossil-frag., crinoids, fusilinids), alt. beds of bk lms. and bk fissle sh.
11. semi-nodular, dk. gr., dense with prolific fauna.
12. dk. gr., dense to fragmental, prolific fauna on bedding planes
13. arenaceous, fine grained, detrital fossils, poorly sorted qtz. grains.
14. gr., dense, contains lms. fragments.
15. gr., dense, conchoidally fractured.
16. nodular, gr., dense, discontinuous bedding
17. gr., x-lline beds seperated by more dense, irregular, nodular units
18. bk. sh. at base overlain by 1' fractured lms. unit.
19. dk. gr. to bk, massive, fragments of crinoids, fusilinids and brachs.
20. calcareous sand zone, dk. gr. to brn.
21. arenaceous, inhomogenous, grades upward into ss., ss grades laterally to lms.
22. dk. gr., dk. brn. weathering surface, brachs and bryozoans.
23. dk. gr., dense, few shaly partings.
24. li. gr., qtzose, coarse at base, finer grained upward, clay content decreases upward.
25. appears to be dense dk. gr. to blue gr.
26. dk. gr. to blue, dense, upper parts consist of 85 % chert.
27. dk. gr., dense to fragmental, units seperated by shaly partings.
28. dk. gr., dense, massive, shaly partings at base.
29. brn. to dk. gr., x-lline to fossil fragmental, small corals present.
30. dk. gr. to gr. bk., dense units seperated by shaly limestone partings.
31. gr., dense, massive
32. dk. gr. at bottom grades upward to blue, chert at center, massive, fusilinids.
33. gr. blue to brn.; gr. to dk. gr., dense, massive, 40 % chert at top.
34. buff to gr. to dk. gr., dense, little shale, some cal. argill. partings, few fusilinids
35. gr., li., brn., streaked brn., gr. to dk. gr., dense, fossil fragments, corals (1" x 4"), with long axis ll to bedding, fusilinids, shaly partings.
36. white rhyolite dike.
37. appears to be gr., dense lms. with gr. interbedded shales.
38. gr., x-lline to fragmental, crinoids and brachs.
39. dk. gr. to bk., fissle, non-fossiliferous, becomes argill. and fossil at top.
40. brn., dk. to bk., dense, massive, non-fossilif.
41. bk., somewhat fissle, dense, non-fossilif.
42. greenish, argill., fine-grained qtzite.
43. dirty, brn. to green, fossilif., H_2S odor
44. gr. to dk. gr., dense, massive, flinty, crinoids, bryozoan. and brachs. on bedding
45. nodules of dk. gr. dense lms. in weathered shale. 2,8" gr., x-lline lms. beds in middle.
46. gr., dense, massive, siliceous, fossil. grades downward to li. gr. dense rk. with scattered detrital grains. grades downward to dk. gr., dense, siliceous lms. with sparce fossil. gr. to reddish gr. shaly qtzite. at base.
47. fine-grained, isolated outcrops.
48. brn. gr. to gr. to reddish gr., massive qtzite., coarser at top., middle is wh. some rounded Fe, clay cemented sands.
49. gr. to spotted red to dk. gr., fine-grained, laminated shaly quartzite
50. gr. to reddish gr., massive flinty unit with argill. band at center. some blue qtz. grains.
51. gr., fine-grained to dense shale with interbedded massive 1' qtzite. units.
52. red gr. to gr. fine-grained, bedded qtzite; few argill. beds.
53. gr., fine-grained shaly qtzite.; massive qtzite. at center; shaly at base.
54. banded red & gr., fine-grained, massive qtzite. argill. at center.
55. red to gr. to bk., masse, fissle at center; underlain by banded red to gr., dense, flinty mater.
56. brn. to dk. gr., flinty beds seperated by coarse argill. material, crinoids, bryozoans, brachs
57. at top; gr. shaly, fine grained, fissle qtzite.; at center, gr., massive, coarse-grained qtzite base; gr. shaly, somewhat fissle, quartzite.
58. red to gr., med.-grained, massive, qtzite.; with 1" layer of fine sand in clay matrix..
59. red to gr., clean qtzite. with shaly partings.
60. red to gr., clean, massive, med.-grained qtzite, no fossils.

FIGURE 3
Stratigraphic column, section I.



1. gr. to dk. gr., fine-grained to fragmental, fusilinids, some chert.
2. rust brn., silic., crinoidal, appears to be dk. gr. lms. at base.
3. dk. gr., dense, fragmental, crinoids and bryozoa.
4. brn. to gr., dense, massive, non-fossil.
5. dark gr., dense, fragmental at base, abundant fusilinids
6. li. gr. to dk. gr., dense, argill. zones.
7. grn. gr. to gr., massive, frag., brachs., crinoids and bryozoa.
8. alt. li. gr. and gr. lms. with dk. gr. fissle shale, nodular in places.
9. argill. qtzite., well indurated.
10. dirty qtzite. with shale frags., poorly indurated.
11. li. gr. to wh., coarse, some clay.
12. li. gr. to dk. gr. to bk., dense. fragmental, fusilinids.
13. gr. to dk. gr., non-fossil.
14. massive, some nodular. and cherty beds.
15. gr., dense to fine-grained, massive.
16. gr., fine-grained fragmental, discontinuous chert beds seperate lms.
17. gr., massive, chert lenses.
18. dk. gr., no chert, no fossils.
19. small amts. of chert and shale, few fusilinids.
20. blu. gr. to blk., dense, corals and fusilinids in chert
21. blu. gr. to dk. gr. to blk., alter. lms. and blk. shale, fusilinids and corals.
22. blu. gr. to dk. gr., dense, brach. frags.
23. blu. gr. to bkl., dense, fusilinids.
24. blu. gr. to bkl., dense lms. alt. with dk. gr. partly fissle shale
25. blu. gr. to dk. gr., dense, few brachs and corals.
26. blk. to gr., fissle shale with blk. dense lms. at base
27. gr., dense, some chert, brachs and corals
28. buff brn., wh., gr., massive, poorly sorted
29. alt. blk. fissle shale and dk. gr., dense, argill. lms.
30. li. gr., massive lms., grades laterally to nodular lms.
31. li. gr., nodular.
32. li. gr., x-bedded, some clay and Fe cement.
33. gr. to dk. gr., dense to x-lline, massive, corals.
34. blk., fissle, shale.
35. buff to rust brn., dense, brachs and bryozoans
36. dk. gr. to blk., chert nodules, bkl shale at base.
37. dk. gr. to bkl., dense, crumbly, some chert.
38. blu. gr. to bkl., massive, fossils, dk. gr. shale partings
39. gr. to bkl., fissle, brachs.
40. li. gr., fine-grained, frags, shaly partings.
41. gr. to blk., fissle, cal., few dense lms. beds.
42. gr. brn. to chocolate, fine-grained to x-lline, brach frags., shale partings.
43. gr. to gr. bkl., fissle, cal. shale.
44. rust. brn. to blk., dense seperated by shale partings
45. gr. blk. to blk., fissle, cal. shale with few dense, thin lms. bands.
46. blk., dense lms. with shale partings in middle.
47. brn., dense, massive lms.
48. gr. to blk., dense, fissle shale, non-fossil.
49. brn. to blk., dense, lms.
50. rust brn. to blk., dense, argill. lms.
51. gr. to blk., fissle shale with gr. fossil. lms in middle.
52. dull gr. to brn. to blk., dense, coral lms.
53. dull gr. to brn. to blk., dense, somewhat nodular lms., overlies white rhy. dike.
54. alt. fine-grained sand and finer argill. mater., cal.
55. brn. to gr., sorted sand.
56. shaly soil over brn. to dk. gr. fissle shale.
57. alt. blk., dense, lms. with blk. cal. shale
58. blk., fissle shale over li. buff, dense lms. over dk. gr., dense, cal., fissle shale.
59. buff to blk., dense, nodular lms.
60. dk. gr. to blk., fissle, cal. shale over blk., dense, fossil. lms. over dk. gr. to blk., dense, cal, fissle shale.
61. buff, dk. gr. to blk., dense, massive, fossil. lms.

FIGURE 4

Stratigraphic column, section II.

locally, as north of the Torrance Mine dump, conglomerate and finer sandstone grade directly into red mudstone.

The trachyte tuff is usually white to gray on fresh surface because of the clay-mineral alteration of the groundmass. When andesitic fragments are abundant, the tuff becomes reddish-purplish gray weathering to a bluish gray. Other areas show extensive hematitic or manganiferous staining and the tuff may be red, brown, yellow, or mottled black and white. Along the front of the range just north of Blue Canyon, some areas of the tuff are pale green from an unknown staining of the matrix material.

The basal contact of the trachyte tuff is a surface of low relief (2 feet) on the quartzite, shale, and limestone of the Pennsylvanian rocks. A thin soil may be present with fractured andesitic cobbles up to 4 inches in diameter. Where the basal part is not conglomeratic, fine tuffaceous sandstone or siltstone marks the contact. The upper contact of the trachyte tuff is gradational into red mudstone. The thickness is variable ranging from less than 1000 feet above Woods Tunnel to more than 1700 feet north of the Merritt mine.

Red mudstone. Red sandy mudstone underlies much of the hummocky terrane south of Socorro Peak. It is also exposed in the Workman Tunnel and in the lowermost workings of the Merritt and Torrance mines. Similar red mudstone exposures are known around the southwest corner of the Socorro Mountains where nearly 500 feet of siltstone, fine sandstone, and mudstone crop out. Nearly all areas underlain by red mudstone are masked by a thick blanket of landslide and talus debris from the more resistant volcanic rocks which either intrude or overlie the sediments. The red mudstone has more than 50 percent clay minerals and when wet provides an excellent lubricated surface for gravity sliding.

The red mudstone is massively bedded sandy siltstone and mudstone with local medium-grained sandstone lenses which fill scour zones in the mudstone. Much of the coarser material is tuffaceous, but there is no indication that all of the material is volcanic-derived. Although red is the predominant color, many of the interbedded sandstones are gray, white, or buff. Locally, the mudstone and siltstone may be bluish gray, green, or buff in color. Coarse-grained material is very sparse, although a red pebbly conglomerate is exposed at the contact with the Socorro Peak intrusive mass in section 8 south of the radio towers on the peak. Some outcrops of the red mudstone contain considerable gypsum, but the distribution is patchy.

The upper contact of the red mudstone is rarely exposed and the overlying rocks are not everywhere the same. In Blue Canyon and south toward Socorro Spring, the red mudstone is overlain by rhyolite breccia and conglomerate. At the southwest corner of the Socorro Mountains above Socorro Canyon, the red mudstone is overlain by basalt which may be Quaternary in age. West of Socorro Peak in a narrow canyon in the SW¼NE¼ of section 7, the red mudstone is apparently overlain by pumice conglomerate. Such variability suggests either a considerable erosion interval after the deposition of the red mudstone or a quite irregular surface of deposition for the red mudstone. The former seems more likely, considering the grain size and bedding structures of the red mudstone. East and north of Socorro Peak, rhyolite breccia rests directly on trachyte tuff without any intervening red mudstone. In the thickest occurrences there is probably less than 1000 feet of red mudstone present.

Rhyolite breccia. Massive rhyolite breccia is exposed on the east face of the Socorro Mountains forming the rugged escarpment near the crest of the range. DeBrine, Spiegel, and Williams (1963) report that much of the western part of the Lemitar Mountains is composed of the same material. Good outcrops of a conglomeratic facies of the breccia are exposed in Blue Canyon on the west side of the NMIMT research area. Probably half the talus boulders on the eastern face of Socorro Peak are derived from the rhyolite breccia.

The rhyolite breccia has several facies, some of which may be flow breccias, but predominantly it is either conglomerate or agglomerate. The matrix is generally fine-grained and clastic although, locally, it may be welded or glassy. It is red-pink in color, usually from hematitic staining of the matrix material, although most of the fragments are also red to purple or reddish brown or buff. The fragments are andesite, red dense rhyolite, felsite, and some fragments that appear to be of the same composition as the breccia itself. The fragments range in size from a fraction of an inch to more than a foot in diameter. Bedding is vague or absent in the breccia facies, but the conglomeratic facies shows a crude stratification with lenticular layers several inches to several feet in thickness. Near the top of the unit east of Socorro Peak a layer of andesite conglomerate about 5 feet thick is interbedded with the breccia. The total thickness of the breccia does not exceed 500 feet.

Rapid variations in facies both laterally and vertically are common. A 450-foot thickness of the breccia changes into conglomerate with andesite and

rhyolite boulders within a distance of 500 feet along the strike of the outcrop. The lack of red mudstone beneath the breccia east of Socorro Peak and the presence of andesite fragments in both the trachyte tuff and the rhyolite breccia suggest that they may be parts of the same sedimentary-volcanic sequence. Present information can neither confirm nor deny this assertion.

DeBrine, Spiegel, and Williams (1963) suggest that the rhyolite breccia is intermediate between the Datil formation and the overlying Santa Fe deposits. However, the principal intrusive rocks in the Socorro Mountains are younger than the rhyolite breccia and most of these intrusives have lithologic relationships which are more closely allied to the Datil rocks than to any later sequences. Additional study will be required to clarify this problem.

Pumice conglomerate. One small exposure of pumice conglomerate is found in section 7. South of Blue Canyon in the area surrounding the Great Lakes Carbon Company perlite mine, there are extensive exposures of perlite conglomerate which may be related to the pumice conglomerate. No other rocks of this type have been observed in the Socorro Peak area.

The pumice conglomerate contains fragments of gray perlite, gray pumiceous rhyolite, and gray pumice apparently derived from the pumiceous rhyolite, in a groundmass of pumice, pumiceous rhyolite, and quartz. Small amounts of purplish andesite and red mudstone are scattered throughout. Biotite is common in the groundmass which is locally reddish from hematite staining. Perlite fragments are about 1 inch in diameter, and the pumiceous rhyolite cobbles are from 6 to 8 inches in diameter. A few quartz-rich rhyolite fragments and gray rhyolite fragments from 1 inch to 3 inches in diameter are present. Perlite, pumice, and pumiceous rhyolite comprise about 75 percent of all the fragments, which suggests the close relationship with the perlite south of Blue Canyon.

Neither the base nor the top of the pumice conglomerate is exposed. The attitude suggests that it overlies the red mudstone in section 7. South of Blue Canyon, a similar conglomerate in the Great Lakes Carbon Company perlite mine rests upon the perlite intrusive from which it was derived and is in fault contact with Santa Fe beds. The only exposure in the mapped area is less than 100 feet thick.

Andesite. At the mouth of Blue Canyon and in scattered exposures along the eastern face of Socorro Peak, the trachyte tuff and red mudstone rocks are intruded by andesite. The usual form of the intrusion is irregular dikes showing extensive alteration. Spheroidal weathering is common and often the dikes grade outward from an ovoid fresh zone to material which cannot be distinguished from andesite tuff or conglomerate.

In hand specimen, the less-altered specimens are aphanitic-porphyritic with a dense reddish gray to purplish gray groundmass in which are set chalky-white phenocrysts of feldspar up to one-eighth inch in length. The phenocrysts are tabular or lathlike and have no marked orientation, although, locally, lineation is sometimes present. As alteration becomes more intense the groundmass decomposes into a soft, purplish, clayey mass and the phenocrysts are no longer separable from the main mass of the rock.

Thinsections of the andesite show the lathlike phenocrysts to be oligoclase with some potash feldspar in more rounded forms. The dark minerals have been completely altered to chlorite, sericite, hematite, and magnetite. The relict textures suggest that biotite and hornblende may have been the principal ferro-magnesian minerals.

Porphyritic Rhyolite. North of Blue Canyon along the boundary between sections 9 and 16, porphyritic rhyolite forms the main body of three steep north-south ridges. Foliation measurements on sheeting structure and scattered flow layering are generally steeply dipping and show a random strike pattern. Small exposures south of the main mass have contacts with the andesite suggesting that the porphyritic rhyolite intrudes the andesite. Intrusive relationships are also shown with the trachyte tuff and its conglomeratic facies.

The porphyritic rhyolite is pale buff to red to pink on weathered surface and pinkish gray to red on fresh surface. The groundmass is dense and aphanitic and the quartz and feldspar phenocrysts are uniformly small (less than 1/16-inch in diameter). Sparse glassy layers give the rock a slightly streaked appearance, and in the central portions of the ridges there are layers which are 75 percent spherulites and porphyritic rhyolite breccia; the breccia apparently is an autobreccia in this instance. Two feldspars are probably present and the phenocrysts are more than 50 percent quartz.

Other porphyritic rhyolites are exposed south of Blue Canyon and a small dike cuts the trachyte tuff and conglomerate northwest of the Torrance mine dump. Fragments of rhyolite porphyry are found in the rhyolite breccia, but the two units are not in contact, unless tuffaceous conglomerate exposed near the corner of sections 8, 9, 16, and 17 is correlative

with the rhyolite breccia. Here tuffaceous conglomerate rests upon the rhyolite porphyry with depositional contact.

Banded trachyte. Flow-banded trachyte or rhyolite is exposed in two small plugs near the center of section 9. The Torrance, Merritt, Boarding House, and Silver Bar mines and the Byerts Tunnel follow and explore veins which cut flow-banded trachyte and rhyolite. No other exposures of similar rock types have been found in the mapped area.

Banded trachyte is characterized by thin (½-inch to 2-inch thick), slabby, flow layering in dense, aphanitic, purplish gray to gray porphyritic rock. The phenocrysts are principally feldspar, although there are zones in the rock in which quartz is abundant. The total amount of quartz is very small, and in some instances it may be secondary; hence, the name *trachyte*. Banded trachyte is often mottled or streaked with clots of phenocrysts or inclusions which have been flattened and drawn out parallel to the flow layering. Interbedded with the banded trachyte is a dark reddish brown massive trachyte or latite. It is best exposed in Byerts Tunnel, although fragments of it may be found on the surface around the other mines. The phenocrysts in the banded trachyte are principally orthoclase or sanidine, and in the massive trachyte plagioclase is more abundant. Since much of the rock is aphanitic or glassy and the phenocrysts represent less than 20 percent of the total volume, variations in composition of these crystals are not unusual.

Exposures in the mines are badly shattered and the foliation is not always clear. However, the two small plugs west of the mines near the center of section 9 show nearly vertical foliation with considerable contortion. Along the contacts of the plugs, the foliation is parallel to the contact for more than half of the exposed distance. Lasky (1932) suggests that the southernmost plug is a feeder and the remainder of the exposures are flows from that source. Foliations measured in the mines are often steeply dipping and apparently not consistent with such a view. The jumbled nature of the surface material and the shattering observed in the underground workings suggests that the mine area may be a complex of landslide blocks, some of which may have dimensions of several hundred feet on a side. At least, it is no longer clear whether the rocks are flows or detached portions of the intrusive plugs which have undergone considerable rotation and gravity sliding in arriving at their present positions.

Socorro Peak calcitrachyte. The main mass of Socorro Peak and the adjacent high points of the Socorro Mountains expose a well-foliated, locally glassy and perlitic, dense aphanitic-porphyritic rock of peculiar composition. Most of the higher peaks are bounded by clifflike exposures, although the peaks themselves may be flat and rolling with relatively subdued topography.

Large pinkish phenocrysts of feldspar and smaller dark phenocrysts of biotite and amphibole are imbedded in a dark gray to black glassy or aphanitic matrix. Microscopic examination shows the feldspar phenocrysts to be labradorite (An_{58}) and the amphibole, basaltic hornblende. Flame spectrophotometer analysis of the glassy matrix suggests that K_2O is in excess of Na_2O in the cryptocrystalline material, and thus much of the groundmass must be potash feldspar rather than additional plagioclase. The labradorite phenocrysts show considerable reaction with aphanitic matrix and obviously the rock has not reached equilibrium. Following Johannsen (1932), the rock is termed *calcitrachyte*.

The high peaks which expose the Socorro Peak calcitrachyte have steeply dipping foliation near the contacts with the older rocks and relatively flat-lying (less than 20 degrees) foliation within the interior of the outcrop. The structure suggests a mushroom-like intrusion of the calcitrachyte which bulged outward as well as upward as the apex of the intrusion was reached. Preliminary work by R. D. Walker on Rb-Sr dating of the calcitrachyte indicates that the intrusive is too young to be amenable to the Rb-Sr method. The geologic evidence also suggests that it is the youngest rock unit within the mapped area aside from unconsolidated terrace gravel, talus, and alluvium.

QUATERNARY ROCKS

Siliceous sinter. West and north of Woods Tunnel at elevations from 5300 to 5600 feet, a narrow layer of siliceous sinter crops out. The exposure pinches out to the south and disappears beneath alluvium to the north; it is so resistant to weathering that large slump blocks of it are found as much as 200 feet below the outcrop. Some of these might be interpreted as fault blocks.

The siliceous sinter is layered, often with sharply contorted beds, and is about 50 percent crystalline quartz or chalcedony and 50 percent amorphous silica. In the central part of the mass, only silica can be identified. However, near the contacts the silica only partially replaces the shale and limestone of the Pennsylvanian beds through which it cuts and vague bedding relicts can be identified. Occasionally, fossils from the Pennsylvanian rocks have been silicified. Where sandstone from the Pennsylvanian has

been replaced, a fine granular quartzite has resulted.

Contacts between the siliceous sinter and the enclosing Pennsylvanian sediments are vague and gradational. However, the sinter transects both the dip and strike of the beds. In its northernmost outcrop the sinter is seen to rest unconformably upon steeply dipping limestone beds (50°W) in a shallow channel. The deposit plunges 3 degress northward and probably represents a spring deposit associated with the final stages of volcanism which filled an early postvolcanic erosion channel.

Alluvium. Much of the Socorro Mountains is mantled with a thick coating of talus debris and soil. In the larger arroyos gravel and alluvial deposits have been recently dissected by intermittent stream wash leaving crumbling banks and terraces of unconsolidated material. Particles of all the rock types are found in the alluvium, a particular type being locally abundant near areas of its outcrop. Some of the coarse talus cones are remarkable for their thicknesses which may exceed 20 feet on slopes exceeding 15 degrees.

STRUCTURE

The Socorro Mountains are a part of a long, narrow fault block beginning with the Ladron Mountains to the north and continuing through the Lemitar Mountains, the Socorro Mountains, and dying out to the south in the low hills of the Chupadera Mountains and the Coyote Hills. This fault block forms the western boundary of the Rio Grande depression and plunges gently to the south. The structural relief ranges from nearly 25,000 feet near Ladron Peak to less than 5000 feet southeast of the Coyote Hills. The Socorro Mountains are tilted westward at an average dip of about 20 degrees. Gravity measurements (A. R. Sanford, personal communication) along the eastern and western boundaries indicate an asymmetric pattern in which the deepest part of the down-dropped portion of the Rio Grande depression is within two miles of the present topographic front; the western margin steps down into the Snake Ranch flats over a distance of four or five miles and with less total relief.

Folding is poorly developed within the Socorro Mountains. Reversals of dip occur in the Pennsylvanian beds, but these are usually associated with small faults and are due to drag or possible landsliding on the shales. Some local warping of the sediments has occurred around the margins of the intrusive Tertiary volcanics.

Faulting is much more prominent. Several old shafts in the edge of the talus at the base of the range probably were sunk on fractures parallel to the main fault zone which is responsible for the uplift of the block. A reasonable interpretation of the gravity and seismic data (A. R. Sanford, personal communication) would place nearly all the structural relief between Socorro Peak and the valley to the east in a zone less than a mile wide within two miles of the present mountain front. The great bulk of the visible fracturing is confined to the eastern face of the mountain east of Socorro Peak.

WOODS TUNNEL FAULT

The Woods Tunnel fault strikes N. 25°E. in its southerly outcrops and strikes a few degrees west of north near the northern end. It dips 45°E throughout its length. It is a normal fault with the east side downthrown. Trachyte tuff is downthrown against Pennsylvanian beds, and lower Pennsylvanian quartzites and shales are downthrown against Precambrian argillite. A throw of 900 feet can be calculated on the trachyte tuff–Pennsylvanian contact, but this figure does not allow for relief on the contact nor for possible movement during deposition of the tuff. No other boundaries can be correlated with certainty across the fault. A minimum of 200 feet of throw is possible on the Pennsylvanian–Precambrian contact, assuming that the Precambrian rocks are buried beneath a thin veneer of alluvium and talus at the base of the mountain front north of Woods Tunnel.

Several prospect pits have been dug along the Woods Tunnel fault. Barite is the principal mineral introduced, and in several places the veins thus formed may be two or three feet thick. In other areas along the fault, barite stringers less than 1 inch thick may be scattered throughout several feet of shattered rock. Mineralization did not extend so deep as the level of Woods Tunnel, since the fault zone was intersected by the tunnel but contained no barite. Mineralization also dies out to the north and south of the Precambrian outcrop, more rapidly northward.

The Woods Tunnel fault is lost in talus and alluvium about 1500 feet north of the Precambrian outcrop in section 4. It can be traced for nearly 3000 feet southward and then appears to end at the northwestern banded trachyte plug in the center of section 9. The deposit of siliceous sinter may be offset by the northern extension of the Woods Tunnel fault so that movement may be relatively recent. No data other than post-Pennsylvanian are available regarding initial displacements.

SECTION 9 FAULT

The section 9 fault strikes N. 45° W. and dips 60°NE. From the point near the center of section

9 where it is cut off by the Woods Tunnel fault, the section 9 fault follows a narrow gully in the NW¼ of the section nearly to the top of Socorro Peak. It does not cut the Socorro Peak calcitrachyte and cannot be accurately traced beyond the northwest corner of section 9. The section 9 fault shows reversed displacement with the southwest side downthrown. Rhyolite breccia is downthrown against trachyte tuff and trachyte tuff is downthrown against Pennsylvanian sediments. The throw on the trachyte tuff–Pennsylvanian contact is at least 400 feet, assuming no drag on the contact surface. Throw on the rhyolite breccia-trachyte tuff boundary is perhaps less than 200 feet, although the relations at this contact are complicated by andesite intrusions.

Barite mineralization occurs near the northwestern end of the fault where several prospect pits expose the shattered zone. The mineralization does not extend below an elevation of about 6100 feet.

SECTION 16 FAULT ZONE

Beginning in Blue Canyon and extending northward nearly to the center of section 9, a series of short en echelon faults occupy a zone from 300 to 500 feet wide. Individual fractures can rarely be traced more than a few hundred feet and sometimes only a few tens of feet. Most of the fractures are steeply dipping (more than 75 degrees) and the strike is generally a few degrees east or west of north. Rhyolite porphyry, trachyte tuff and conglomerate, andesite, and banded trachyte are cut by the fault zone, but measurements of displacements could not be made. The throw across a single fracture is probably only a few feet, but the aggregate displacement across the zone may be several hundred feet.

Barite stringers fill some of the faults, although the thicknesses of individual seams are rarely more than 1 to 2 inches. The mineralization is less persistent than the fractures which it occupies. However, the better showings are at the northern and southern ends of the section 16 fault zone.

GEOLOGIC HISTORY

The Socorro Mountains were a part of the broad central New Mexico shelf which accumulated considerable thicknesses of clastic sediments during Precambrian time. Subsequent igneous intrusion and metamorphism, perhaps in several cycles, created the argillites, gneisses, and schists of the Woods Tunnel area.

Early Paleozoic time is not represented by any sedimentation in the Socorro Mountains, although several cycles of deposition and erosion might have occurred. Mississippian rocks are known to the west in the Magdalena Mountains and to the north in the Ladron and Lemitar mountains, so it is likely that some Mississippian limestone was deposited and subsequently removed by erosion from the Socorro Mountain block.

During Pennsylvanian time sandstone, limestone, and shale accumulated under marine conditions. The earliest Pennsylvanian beds (Atokan) were never deposited, so this region must have gradually been inundated during Pennsylvanian time. It may have been close to a fluctuating shore line, throughout most of the later Paleozoic. There is every reason to believe that a complete Pennsylvanian section and perhaps a Permian section as well were deposited over the Socorro Mountain block. Complete sections are known only a few miles to the east and west and these sections do not indicate a local source area as might be expected if the Socorro Mountains were a positive block during the late Paleozoic.

The absence of Permian, Triassic, and Cretaceous rocks in the Socorro Mountains is probably the result of early Tertiary erosion. West-central New Mexico underwent a gentle east-west arching, perhaps beginning in the late Permian, which was well developed by late Triassic time. This positive area, which maintained a control over Mesozoic sedimentation in northwestern and central New Mexico, has been variously called the *Navajo Highland* (Smith, 1951) or the *Mogollon Highlands* (Harshbarger, Repenning, and Irwin, 1957). The proximity of the Socorro Mountains to the northeastern margin of the Navajo Highland may have resulted in some thinning and variation in the Triassic and Cretaceous rocks over the Socorro Mountain block.

The close of the Cretaceous period marked a radical change in the depositional environment. The orogenic movements which have been termed the *Laramide orogeny* had widely varying effects both in space and time. In the region around the Socorro Mountains, basins were developed, and the gravels and sands of the Baca formation were deposited. As a prelude to the asymmetry now observed, the Socorro Mountains apparently were uplifted and the Mesozoic and Permian rocks which had accumulated earlier were stripped off, probably contributing to the type Baca section at the north end of the Bear Mountains to the northwest (Tonking, 1957). Uplift and stripping continued down to the lower part of the Desmoinesian limestones of the Pennsylvanian.

The area had been reduced to a relatively smooth surface when early in the Tertiary, volcanic activity developed and deposited a thick layer of tuff and tuffaceous sediments (trachyte tuff) over the entire

block. The Socorro Mountains were not involved in this early activity since no vents of the proper composition have been located in the area. Erosion was active during this deposition because limestone and andesite conglomerates are included within the trachyte tuff section. It is also clear from this evidence that Pennsylvanian rocks had been exposed by the Laramide uplift and stripping because the limestone cobbles from the conglomerates are derived from Desmoinesian rocks. As the early volcanic activity waned, sedimentation continued over the Socorro Mountain block with the deposition of red mudstone and channel sandstone. Recurrent uplift may have eroded some of the red mudstone.

The Socorro Mountains now became a volcanic center and porphyritic rhyolite was intruded and perhaps later erupted to form part of the rhyolite breccia. Numerous other volcanic centers beyond the limits of the present mountains must have existed, since some of the rhyolite breccia contains well-rounded conglomerate cobbles indicating considerable transportation. Faulting probably was initiated with the volcanism, although there is no evidence bearing directly on this point. Continued volcanic activity resulted in the intrusion of the banded trachyte which may have given rise to some flows whose remnants are now preserved in the Merritt, Torrance, Silver Bar, and Boarding House mines. At some time during the volcanic activity, or perhaps earlier, development of the Rio Grande depression began. Part of its position was apparently already determined by the late Cretaceous or early Tertiary positive nature of the Socorro Mountains.

Coincident with or immediately following the outlining of the Socorro Mountain block as a marginal feature of the Rio Grande depression, intrusion of the Socorro Peak calcitrachyte took place. This intrusion was apparently accompanied by perlite intrusions south of Blue Canyon. The Socorro Peak calcitrachyte did not develop extrusive equivalents, but the perlite masses breached the surface and nué ardente type eruptions coupled with reworking of the glowing ash and tuff debris by fluviatile processes gave rise to perlite and pumice conglomerate and tuffaceous sandstone.

Faulting was probably more or less continuous during the volcanic activity and the last stages of volcanism saw the introduction of weak mineralizing solutions which deposited barite, fluorite, quartz, calcite, hematite, and a very small amount of silver, probably in the form of argentite.

Continued development of the Rio Grande depression resulted in a continual uplift and tilting of the Socorro Mountains to the west and the consequent erosion of material into the valley. Oversteepening of the eastern face gave rise to gravity sliding which dislocated the vein systems of the silver mineralization and resulted in their present anomalous position. Recent erosion and faulting have resulted in the present topographic configuration. The present seismic activity (Sanford, 1963) suggests that the visible structures in the block are not important factors in the present stress pattern.

ORE DEPOSITS

The Socorro Mountains were the scene of intensive mining activity from 1885 to 1893. Silver was the principal mineral sought and the district, comprising the Merritt, Silver Bar, and Torrance mines (the only ones with appreciable production), produced between $750,000 and $1,000,000 in silver. Practically all the ore was secondary cerargyrite from the oxidized portions of the veins.

The Merritt and Silver Bar mines are accessible at the present time, but the drifts are heavily timbered and information is limited. The Torrance mine has been caved shut for many years. Lasky (1932) states: "The Torrance segment lies in a down-faulted wedge between two northward-trending faults which dip toward each other, one about 50°W. and the other about 80°E. . . . The vein is lost in the wedge at the contact of the trachyte with the chocolate-colored clay which forms the top member of the underlying Tertiary sediments. This contact is about 125 ft. below the surface and dips about 10° to the east. . . . A short drift into the north wall of the shaft on the first level discloses much fractured rock of the clay series, so presumably the vein has been cut off here. There are no other workings in this mine north of the shaft."

The veins dip from 35 to 50 degrees west and strike nearly north-south. They are extremely variable in thickness and grade. Although Lasky (1932) reports the average silver content to be between 15 and 20 ounces a ton, recent sampling usually indicates less than 2 ounces a ton. Local pockets of a few pounds of material have assayed as high as 75 ounces a ton. Vein thicknesses in the Merritt mine range from 4 feet to about 9 inches over distances of less than 100 feet both horizontally and vertically.

The trachyte-clay contact referred to by Lasky (1932) is interpreted by this author as a gravity sliding surface, and thus the veins lie in dislocated blocks without "roots." The Byerts Tunnel, which was driven about 125 feet below the Merritt main level, encountered more than 200 feet of talus inward from

the portal before reaching solid rock. No vein structures comparable to those in the Merritt or Silver Bar were cut. Extreme brecciation and shattering is characteristic of all rock types in the Byerts Tunnel.

The great majority of the faults along the eastern face of Socorro Peak contain weak barite mineralization. Locally, high-grade exposures of several feet thickness are present, but little or no continuity has been shown by any of the prospect workings. The Gleeson prospect exposes a barite vein which averages more than 2 feet in thickness for nearly 150 feet at the base of the northwesternmost banded trachyte plug. These exposures may represent the "roots" of the more productive veins in the Merritt, Torrance, and Silver Bar mines.

The prospects for additional ore reserves are limited. Barite might be developed as a saleable product if cheap processing methods were developed in a centralized location. Mining of the ore would still be very expensive because of the scattered and sporadic nature of the veins.

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