GEOLOGY OF THE EASTERN MAGDALENA MOUNTAINS
WATER CANYON TO POUND RANCH
SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The Water Canyon to Pound Ranch section of the eastern Magdalena Mountains has had a complex Oligocene to Miocene volcanic history. Three overlapping ash-flow tuff cauldrons formed here during Oligocene time. The North Baldy cauldron formed first in the central range, erupting the Hells Mesa Tuff (32 m.y.); no younger cauldron fill is exposed. The Sawmill Canyon cauldron (A-L Peak Tuff source) subsequently collapsed in the southern Magdalena Mountains, overlapping much of the North Baldy cauldron. The unit of Sixmile Canyon (andesitic lavas, rhyolitic lavas, laharic breccias, and ash-flow tuffs) partially filled this caldera, as did the Lemitar Tuff which was erupted from the Socorro cauldron centered in the Chupadera Mountains. Thicknesses of the Lemitar Tuff (800 to 1500 feet) are also probably controlled, in part, by Socorro cauldron subsidence. The western Socorro cauldron margin is probably a hinge zone in the western part of this study area where more intense silicification, fault rotation, and intrusive activity are locallized. The western part of the Socorro cauldron remained high and received none of the moat deposits found farther east. Later basaltic andesites and the tuff of South Canyon accumulated to thicknesses as great as 1000 feet and buried some early faulting. Graben formation, erosion, and silicic volcanism (20.0 m.y.) followed on Water Canyon Mesa and a similar sequence of events (block faulting, erosion, and silicic

volcanism (11.8 and 10.5 m.y.)) occurred later in the Pound Ranch area.

Block faulting, beginning before 20.0 m.y. and continuing to the present, has produced two distinctive structural domains in this area. West-dipping, down-to-the-west faults of a southern field of tilted blocks interfinger along South Canyon with north-trending, north-plunging graben systems on Water Canyon Mesa. The structural transition lies over a projection of the buried Sawmill Canyon cauldron margin which may control this change.

Plagioclase has been replaced with potassium-rich minerals in all silicic units older than 12 m.y., except along Water Canyon. One or more hydrothermal systems are envisioned to have produced this alteration. Manganese-oxide mineralization occurs as botryoidal coatings and void fillings in brecciated zones of silicic units throughout the map area. At least some of the manganese mineralization post-dates the upper Pound Ranch lavas (10.5 m.y.); alteration of feldspars in mineralized breccia zones suggests that the mineralization was associated with conduits along which the hydrothermal fluids circulated.

INTRODUCTION

Geographic and Physiographic Setting.

This study covers a region of about 25 square miles in the southeastern Magdalena Mountains. The center of the area is located approximately 10 miles southeast of Magdalena and 12 miles southwest of Socorro in central Socorro County, New Mexico. The general location is shown in figure 1 and the detailed relationships to geographic and physiographic features, surrounding studies, and routes of access are shown in figure 2.

Physiographically, the northern Magdalena Mountains are a complex, west-tilted fault block with exposures of Precambrian, Paleozoic, and Tertiary rocks. The eastern boundary is a northwest-trending normal fault zone on which there has been late Quaternary movement. In the central and southern Magdalena Mountains several overlapping cauldrons greatly complicate the Tertiary volcanic stratigraphy; no pre-Tertiary units are exposed in this part of the range. Block faulting, partially contemporaneous with the latest stages of Oligocene volcanism and continuing to the present, has further obscured the geologic relationships. Four cauldrons are known to exist at this time in the southern and central Magdalena Mountains; several detailed studies, in addition to this one, are in progress (see Fig. 2).

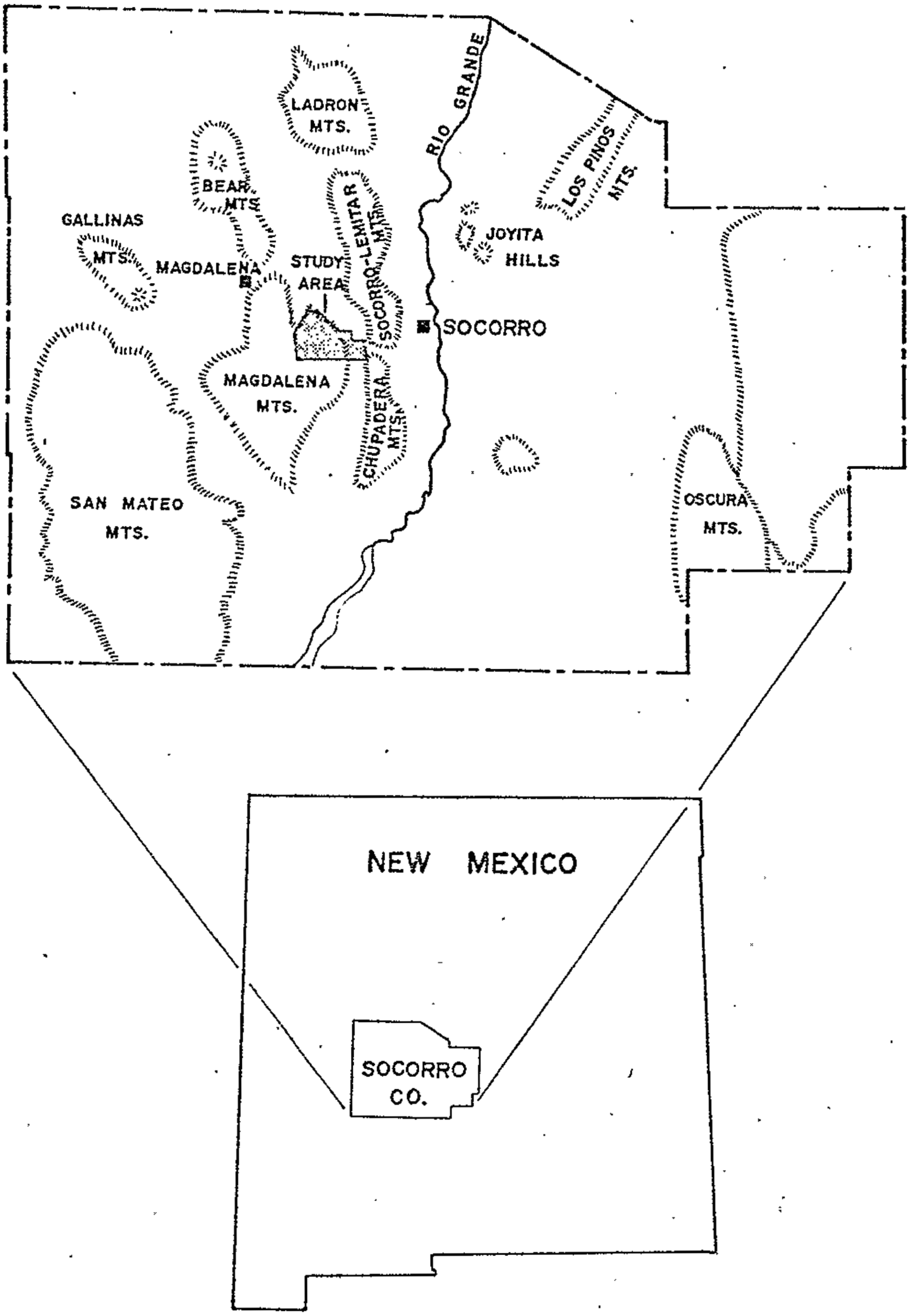
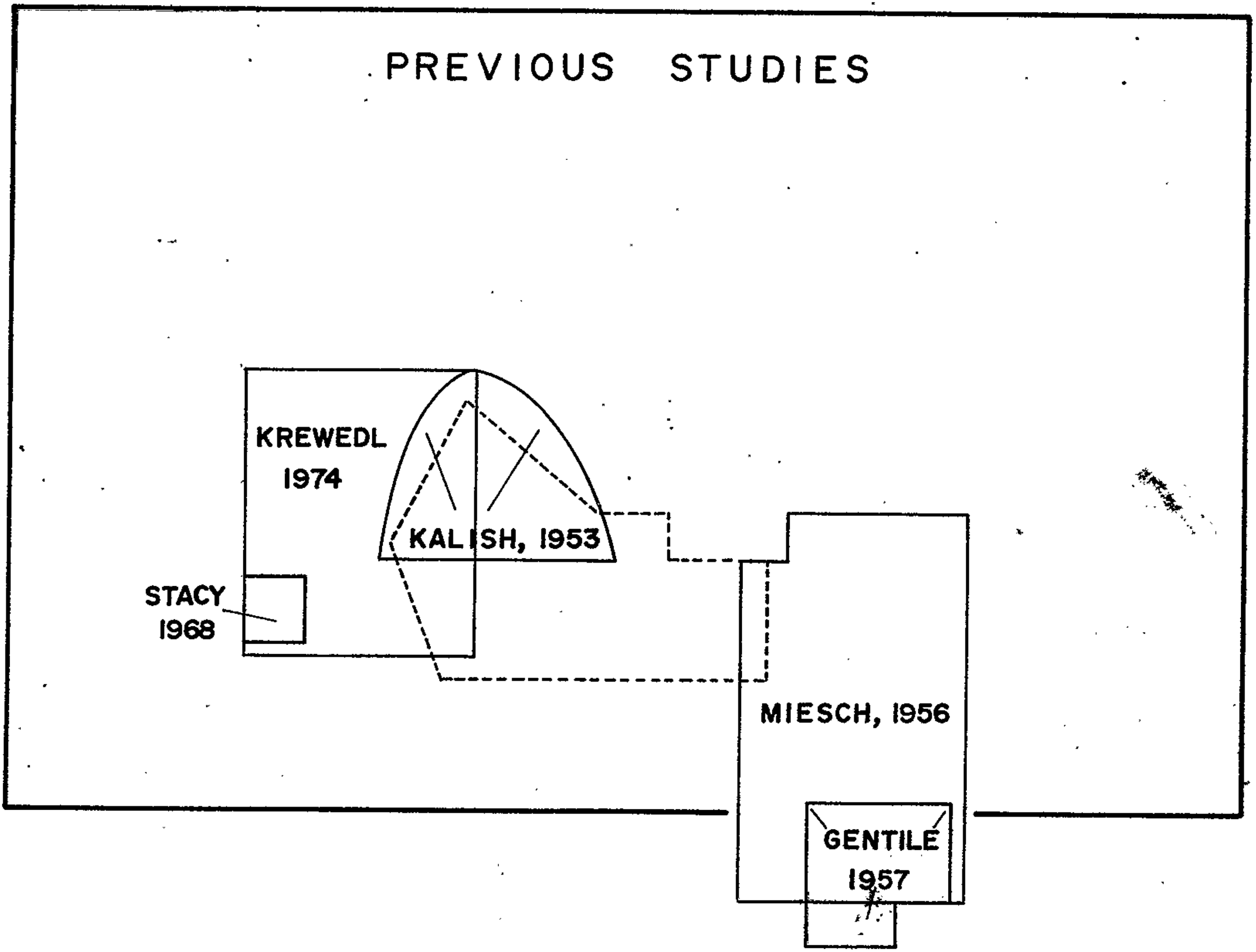


Figure 1: General location map showing relationship of the study area to major mountain ranges in Socorro County.


PREVIOUS STUDIES
KREWEDL
1974
KALISH, 1953
STACY
1968
MIESCH, 1956
GENTILE
1957

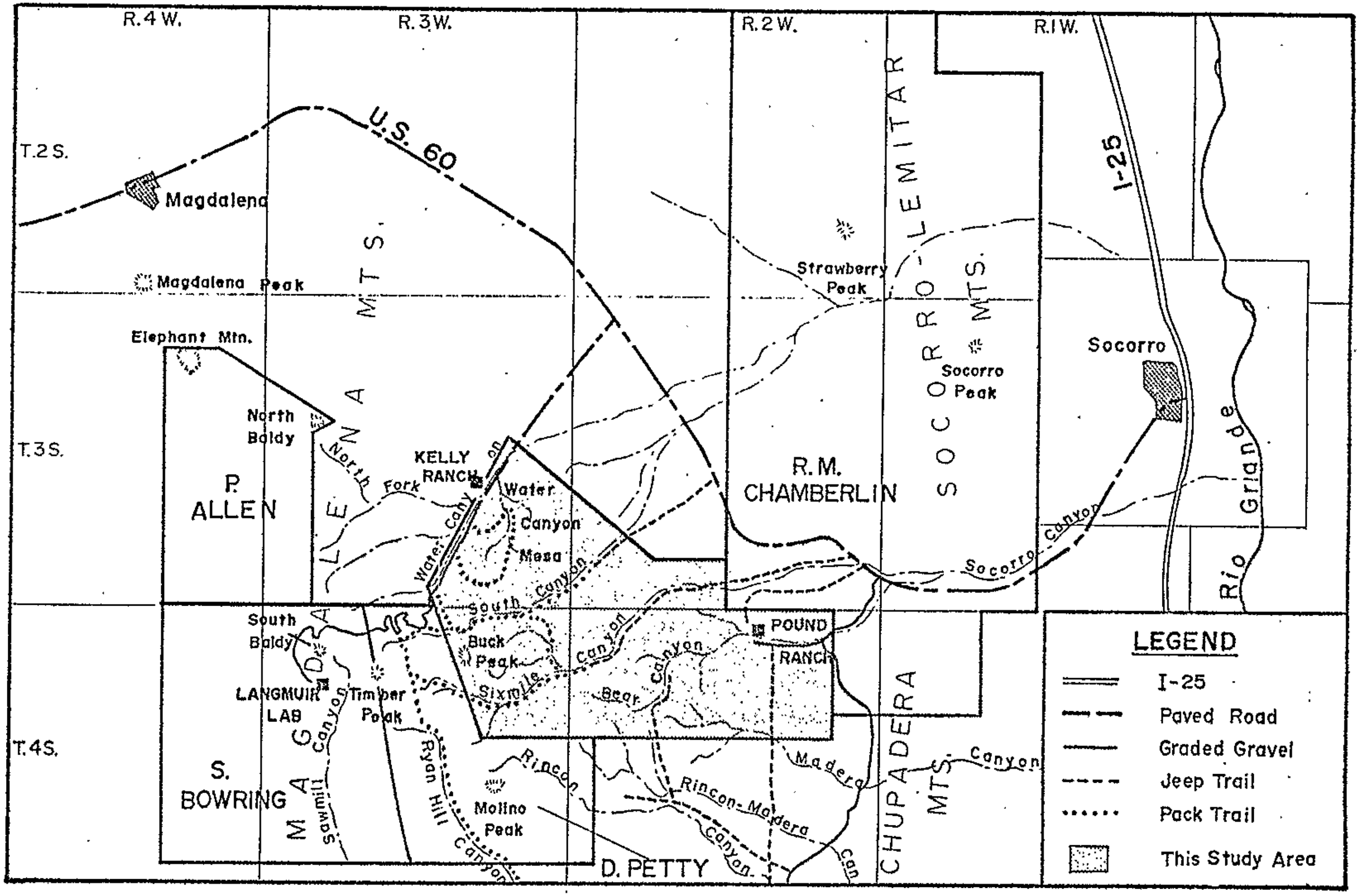


Figure 2: Relationships of the study area to geographic and physiographic features, surrounding studies, and routes of access.

Objectives.

The primary objectives of this study are: 1) to extend the regional stratigraphic framework developed in the Socorro-Magdalena area into the southeastern Magdalena Mountains, 2) to explain abnormal thicknesses, known from reconnaissance, of some Tertiary stratigraphic units in the southeastern Magdalena Mountains, 3) to provide a mapped link between the Magdalena and Chupadera mountains, and 4) to define the western margin of the Socorro cauldron.

Methods of Investigation.

Detailed geologic mapping was done at a scale of 1/24,000 on a base consisting of parts of the Molino Peak and South Baldy topographic quadrangles of the U.S. Geological Survey 7 1/2-minute series, and an enlargement of part of the Magdalena quadrangle of the U.S. Geological Survey 15-minute series. Aerial photographs of the GS-VMA series, 3-7-56, at a scale of 1/23,480 and U.S. Forest Service photographs, 4-13-71, at a scale of 1/12,000 were used to locate outcrops and facilitate structural interpretation. Mapping was done during the summer and fall of 1976 and the spring of 1977.

Fortyeight thinsections, prepared from samples collected throughout the study area, were used to describe and correlate rock units. An additional 21 thinsections from measured stratigraphic sections of Lemitar Tuff and tuff of South Canyon were modally analyzed. The modal analyses were done on a Zeiss binocular microscope using a Swift automatic point counter. At least 1750, and normally 2000 or more, points per thin section were counted on a rectangular grid measuring 1/3 by 2/3 mm. All thin-sections for modal analysis and some of the other thin-sections were stained for potassium with sodium cobaltinitrite using standard procedures (Deer, Howie and Zussman, 1966, p. 311). However, etching times were increased from 15 to 20 seconds to 60 to 90 seconds. Petrographic rock names are from Travis (1955) and colors reported are from the GSA Rock Color Chart.

Samples for radiometric dating were collected from three lava units within the area and several units were sampled for chemical analysis. At this time, all three of the dates and five partial analyses are available.

Previous Work.

The earliest mention of the area is by C. H. Gordon (1910) who briefly described mineral deposits west of Water Canyon. E. H. Wells (1918) reported on the occurrence of manganese in "chocolate-colored" rhyolite (tuff of South Canyon) on the east side of Water Canyon.

Several detailed geologic studies have been conducted in or near the eastern Magdalena Mountains. A. T. Miesch (1952) mapped the Luis Lopez manganese district in the northern Chupadera Mountains and A. L. Gentile (1953) studied rhyolite genesis in the central Chupadera Mountains. P. Kalish (1953) mapped and described the geology of the

Water Canyon area. All three of these studies were done before ash-flow tuffs and cauldrons were well known; consequently, most of their interpretations must be revised, although outcrop areas and contacts are generally accurate on their maps.

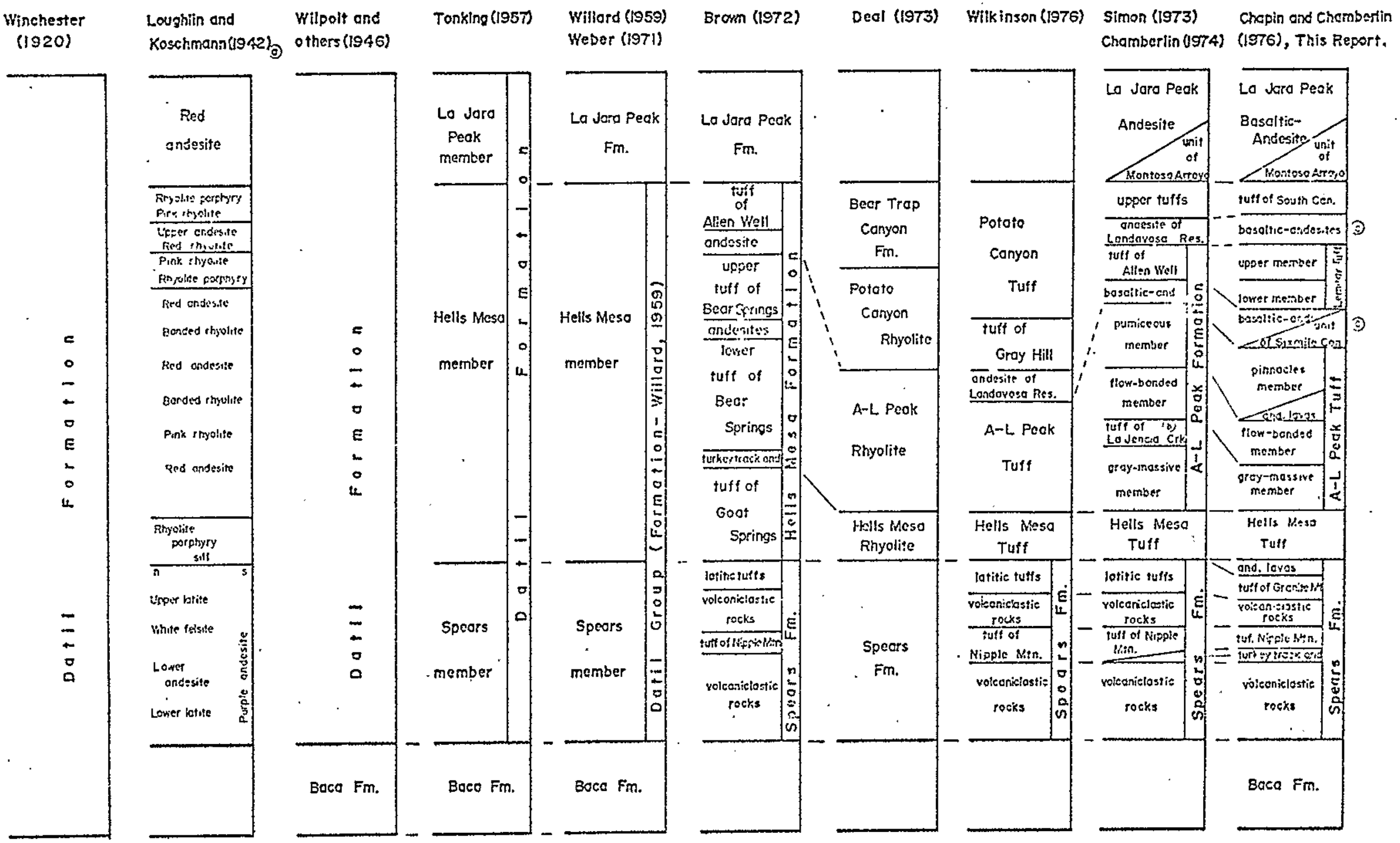
D. A. Krewedl (1973) mapped and described the geology of the central Magdalena Mountains, including the western edge of this study. R. M. Chamberlin (in progress) is mapping the central and southern Lemitar, Socorro, and northern Chupadera mountains; P. Allen, S. Bowring, and D. Petty are presently mapping areas west of this study in the central Magdalena Mountains.

In addition to studies adjacent to or overlapping this project, many workers have contributed to understanding the Tertiary stratigraphy in the Socorro-Magdalena area. The chronologic development of this stratigraphy is shown in figure 3. References to specific publications are given with unit descriptions in the text and with the graphic stratigraphic columns (Figs. 4, 5, and 19). Most of these studies have been carried out under the New Mexico Bureau of Mines and Mineral Resources "Magdalena Project" of which this study is also a part.

Acknowledgements.

I gratefully acknowledge the contributions of the many individuals who have helped in this study. Tom Kelly and Smokey Pound generously allowed access to their private ranch land. Richard Chamberlin supplied information and ideas during many informal discussions and critically read the manuscript. Dr. Kent Condie and Dr. Jacques R. Renault served on my thesis committee and critically read the manuscript.

A special thanks is extended to Dr. Charles Chapin for serving as my thesis advisor and generously supplying help and ideas during all stages of the study. The New Mexico Bureau of Mines and Mineral Resources provided financial support and the use of a field vehicle during the study.



a) no straight-forward correlation of present units with Loughlin and Koschmanns volcanic stratigraphy is possible. This column is after Blakestad, 1977 where the reader will find more detailed information.

b) The tuff of La Jencia Creek is now known to be Lemitar Tuff in a paleovalley.

c) These basaltic andesite intervals may be tongues of lower La Jara Peak basaltic andesite.

Figure 3: Correlation diagram showing the relationship of units defined in previous stratigraphic studies to the stratigraphic section of this study.

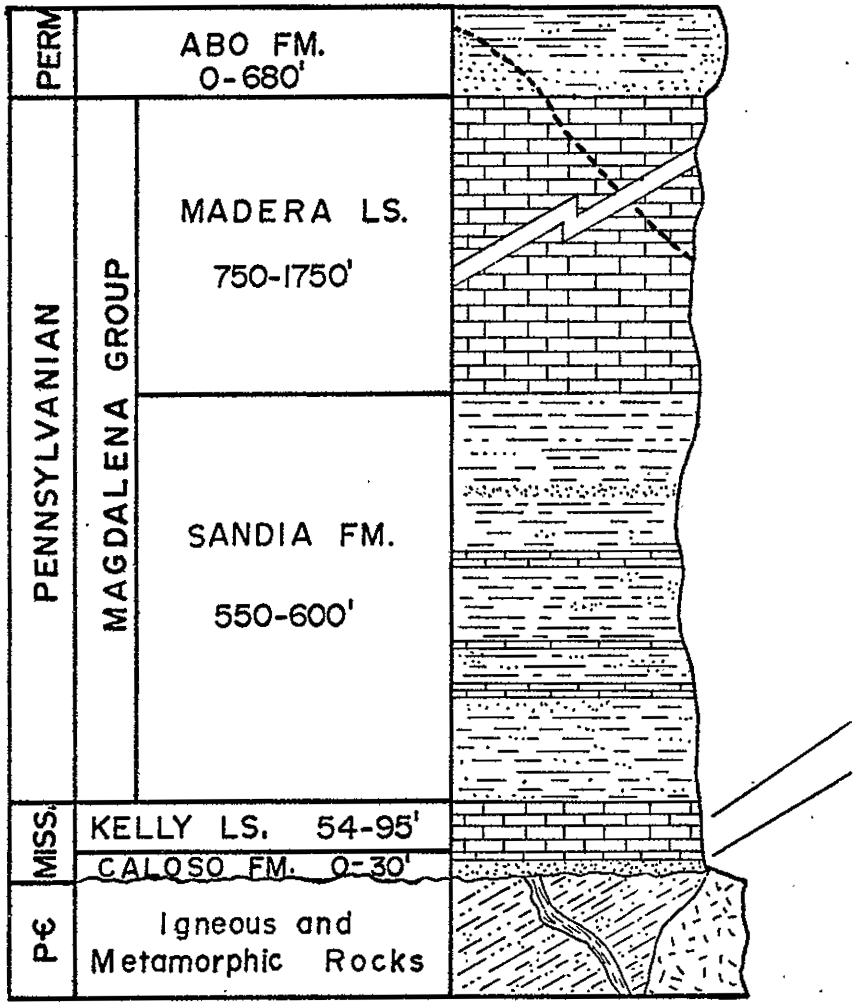
STRATIGRAPHY AND PETROGRAPHY

Pre-Tertiary Rocks.

Precambrian and Paleozoic rocks crop out along the west side of Water Canyon and extend a short distance into this study area. General lithologic descriptions and references to detailed works on these units are given in figure 4.

Small outcrops of thinly bedded, fine-grained, Precambrian metasedimentary rocks are found along and east of the stream bed in Water Canyon (SE/4, Section 27, T3S, R3W). These outcrops are bounded on the east by a fault which brings the Precambrian rocks into contact with the Tertiary Hells Mesa Tuff. At one location, immediately east of the Water Canyon stream and road, a short adit penetrates the Precambrian to a white rhyolite dike in the fault zone; no mineralization was seen on the dump or in the adit.

South and west of these Precambrian outcrops (NE/4, Section 34, and SE/4, Section 27, T3S, R3W), steeply west-dipping rocks of the Pennsylvanian system crop out but the Kelly Limestone (Mississippian) is not exposed. The interval between Precambrian and Pennsylvanian rocks is covered by alluvium, but it is probable that the Kelly Limestone was faulted out since it is normally resistant and forms good outcrops. Neither the upper or lower boundaries of the Pennsylvanian section are exposed. The lowest exposures



LIMESTONES: Thick, homogeneous sequence of lime muds (micrites) with a few thin beds of grn.-gry. to gry., med. to crs.-gnd. quartzite; upper 200-300 ft. consist of red, grn., and gry. micrites grading upward into arkosic strata of Abo Fm.; nodular micrites common throughout; micrites generally gray to blk. with strata becoming darker and more fossiliferous towards base.

REFERENCES: Laughlin and Koschmann, 1942; Kottlowski, 1960; Kottlowski, 1963; Siemers, 1974; Siemers, 1977.

SHALES, QUARTZITES, and LIMESTONES: gray to blk., sdy., carb., shales and siltstones with thin bds. of gry., med.-grd., micritic limestones and grn.-gry. to brn., med.-crs.-gnd. quartzites. Loughlin and Koschmann (1942) divided the Sandia into six members but lenticular bedding and rapid facies changes make this subdivision of limited value.

REFERENCES: Laughlin and Koschmann, 1942; Kottlowski, 1960; Kottlowski, 1963; Siemers, 1974; Siemers, 1977.

LIMESTONES: Lt.-gry., med.-crs. gnd., thk.-bdd., crinoidal sparrites; thn. bd. of dol. micrite near middle (Silver Pipe).

LIMESTONES and CONGLOMERATES: gry., pbly., sdy., mas., qtz., micrites and basal ark. cgls.

REFERENCES: Armstrong, 1958; Armstrong, 1963; Siemers, 1974; Iovenetti, 1977.

ARGILLITES, QUARTZITES, and GRANITES: thick sequence of meta-sedimentary rocks intruded by granites, gabbros, felsites, and diabase dikes.

REFERENCES: Loughlin and Koschmann, 1942; White, 1977; Condie and Budding, in press.

Figure 4: Precambrian and Paleozoic stratigraphic column. Column and descriptions after Chapin, Blakestad, and Siemers, 1974. Thicknesses: Sandia and Madera after Siemers, 1977; Caloso and Kelly after Chapin, 1974.

are in fault contact with Precambrian rocks and the upper Madera Limestone extends out of the study area. Krewedl (1974) reports the Spears Formation (Oligocene) to overlie the Madera Limestone immediately to the west on an erosional unconformity of Eocene age.

The Pennsylvanian rocks consist of a lower Sandia Formation and an upper Madera Limestone. The Sandia Formation is mainly dark, fissile shales with minor interbedded sandstone and limestone beds; the Madera Limestone is a thick sequence of gray, micritic limestones with subordinate shale and sandstone intervals. The Sandia-Madera contact was placed at the base of a thick limestone unit above which limestone becomes the dominant lithology.

Tertiary Extrusive and Sedimentary Rocks.

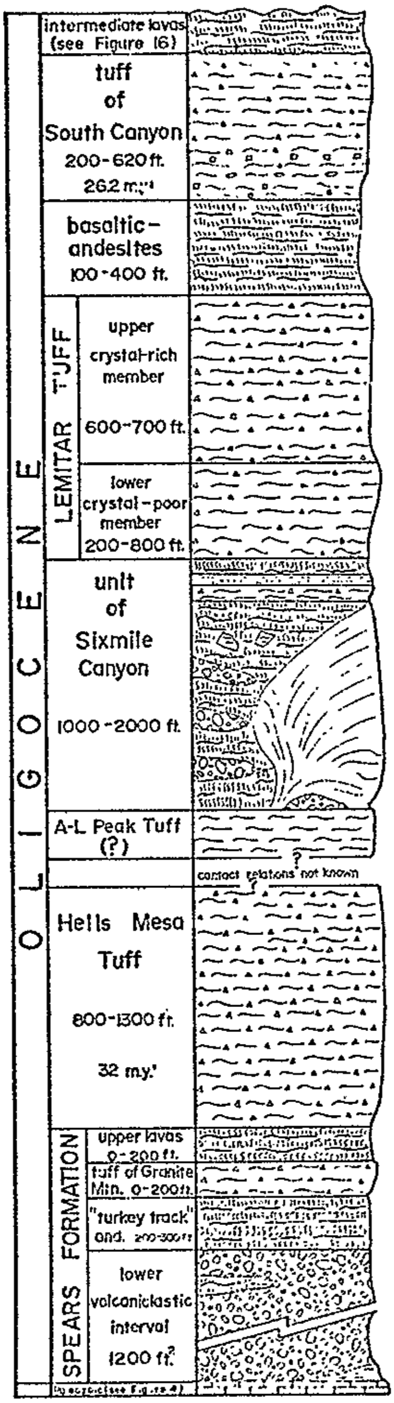
The Tertiary sequence in west-central Socorro County consists of both volcanic and sedimentary units. The earliest rocks are arkosic sandstones and conglomerates of the Baca Formation (Eocene), which are overlain by andesitic to latitic volcaniclastic sedimentary rocks of the Spears Formation (early Oligocene). These are in turn overlain by a sequence of ash-flow tuffs and basaltic andesite lavas (Oligocene to early Miocene) (Chapin and Chamberlin, 1976). Regional extension contemporaneous with the later stages of this volcanism created basins in which clastic sediments of the Santa Fe Group have accumulated.

The Tertiary rock units are the major emphasis of this study and cover almost all of the area mapped. Oligocene units are shown graphically on figure 5 and Miocene to Pliocene units are shown on figure 19. Many of these units have been described by previous workers. For these units only brief summaries of lithologic descriptions and references to the previous detailed work are given. More detailed stratigraphic descriptions are given for those units unique to this study area, or for those that vary significantly from occurrences in previously described areas.

Spears Formation

The Spears Formation is the oldest Tertiary unit exposed in the study area. The Baca Formation, of Eocene age, is absent since the Magdalena area was a highland during early Tertiary time and served as a source for Baca sediments deposited farther north (C. E. Chapin, oral communication, 1977). Several previous studies, including Brown (1972), Krewedl (1974), Chamberlin (1974), and Wilkenson (1976), have treated the Spears Formation in detail.

In general, the Spears Formation is a thick sequence of latitic to andesitic conglomerates, laharic breccias, and volcaniclastic sandstones with minor interbedded lavas and two or more interbedded ash-flow tuff units. The usual sequence of map units in the Magdalena area is a lower, mixed interval of conglomerates, laharic breccias, and lavas, overlain by a "turkey track" andesite-tuff of Nipple



ASH-FLOW TUFFS: rhyolite, multiple-flow, single cooling unit tuff; divided into lower, slightly welded "botryoidal pumice", intermediate lithophysal, and upper streaked zones; crystal-poor increasing to mod. crystal-rich within the lower streaked zone. All tuffs are qtz.-rich, 1-feldspar, pumiceous, and lithic rich. Unit correlative with upper "Potato Canyon Tuff", Spradlin, 1974; correlative in part with "upper tuffs", Simon, 1973; not correlative with "Potato Canyon Rhyolite", Deal, 1973. Dated in Joyita Hills (26.2 m.y., see Appendix A).

BASALTIC ANDESITES: Most are La Jara Peak like; gry., dense basaltic andesites with abun. small, red, hematized ferromag. phenocrysts and no feldspar phenocrysts. Some have abundant olivine and some feldspar phenocrysts.

ASH-FLOW TUFFS: rhyolite, multiple-flow, simple(?) cooling unit. Gry. to red, 1-feldspar, mod. crystal-poor lower member resembles A-L Peak but has more abun., med.-gnd., qtz. and more biotite. Dk.-red to pur.-gry., 2-feldspar, qtz.-rich, crystal-rich upper member strongly resembles Hells Mesa but has more biotite and fewer crystals. Lower member thick in Socorro cauldron, thin in Lemitar and Bear Mountains. Dated in Lemitar Mts. (26.3 m.y., see Appendix A).

ANDESITE TO BASALTIC-ANDESITE LAVAS, RHYOLITE LAVAS, ASH-FLOW TUFFS, LAHARIC BRECCIAS, and SANDSTONES: cauldron fill of Langmuir cauldron; dense, gry. to gry.-pur. andesite with no phenocrysts surrounds pale-red to pinkish-gray rhyolite lavas (dome?), and dark-gray to purple, heterolithic, laharic breccias. Crystal-poor, to mod. crystal-rich, rhyolite, ash-flow tuff interval and finely laminated, mod.-to well-sorted, qtz. and feldspar-rich sandstone occur near top of unit. "La Jara Peak like" basaltic-andesites overlie these and underlie Lemitar Tuff.

ASH-FLOW TUFFS: rhyolite, densely welded, 1-feldspar, pumiceous, tuffs; gry. to red-brn. with grayish-red pumice. Weathers to small platey talus; pumice lineated at some stratigraphic levels. Unit believed erupted from Langmuir cauldron; probably correlative in part with the A-L Peak Tuff. Base not known but unit minimally several thousand feet thick.

ASH-FLOW TUFFS: rhyolite, multiple-flow, simple cooling unit of densely welded, crystal-rich, qtz.-rich, 2-feldspar, massive tuffs. Pk. to rd.-brn. when fresh, gry. when propylitically altered. Weathers to blky. bldrs. Basal tuffs similar to tuff of Granite Mtn.; abrupt increase in qtz 10-25 ft. above base.

ANDESITE LAVAS: dense, andesite lavas with no phenocrysts. pur. to drk.-gry. in color. Possibly minor andesitic to latitic conglomerates included.
ASH-FLOW TUFFS: qtz. latite, multiple-flow, simple cooling unit of densely welded, crystal-rich, qtz.-poor, lithic-rich, massive tuffs; rd.-brn. when fresh, dark-grn.-gray when propylitically altered.
ANDESITE LAVAS: grysh.-rd. to purple porphyritic andesites with large, crudely flow-aligned plagioclase phenocrysts. Underlies tuff of Nipple Mtn. in northern Magdalena Mts.; tuff not recognized here.
CONGLOMERATES, LAHARIC BRECCIAS, SANDSTONES, BASALTIC-ANDESITE to LATITE LAVAS, and ASH-FLOW TUFFS: volcaniclastic apron of latite to andesite comp.; deposits coarser and contain more volcanic units upward and to south. Thin remnants of 2 ash-flow tuffs in Joyita Hills.

Figure 5: Oligocene stratigraphic section for rocks in the study area. Graphic section and descriptions modified after Chapin and Chamberlin, 1976.

Mountain interval. The tuff of Nipple Mountain is overlain by another interval of volcaniclastic sedimentary rocks and intermediate lavas and these, in turn, are overlain by an upper latitic, crystal rich, ash-flow tuff — the tuff of Granite Mountain (Chapin and Chamberlin, 1976). Krewedl (1974) mapped three units in the Spears Formation of the eastern Magdalena Mountains. These units were a lower interval of volcaniclastic sedimentary rocks and latitic lavas, an intermediate "turkey track" andesite, and an upper latitic, tuff of Granite Mountain. The tuff of Nipple Mountain was not recognized.

In the study area, the Spears Formation crops out in a strip along the floor of Water Canyon (Section 34, T3S, R3W). All three of the units separated by Krewedl were recognized in this study area. In most outcrops, however, the relationships between units is obscured by talus from the overlying Hells Mesa Tuff.

The lower unit is predominately conglomerates and laharic breccias with purple or gray, cobble-sized, latitic clasts in a sandy or muddy matrix. These beds are well exposed along the stream bed in Water Canyon.

The middle, "turkey "track" andesite crops out in a small outcrop beneath tuff of Granite Mountain east of Water Canyon in NE/4, Section 34 and along the Langmuir Laboratory access road on the western map boundary. At both locations the andesites are dark-grayish-red or grayish-purple and are deeply weathered. Tabular plagioclase phenocrysts as much as 8 mm in length occur in a crude, subparallel alignment. In thinsection, the plagioclase is largely altered to sericite and calcite. Many grains show relict "sieve texture" resorption features. The pilotaxitic groundmass consists of plagioclase microlites averaging 0.1 mm in length, magnetite, and pyroxenes. Most of the pyroxene and magnetite is altered to hematite.

The overlying tuff of Granite Mountain is highly altered and deeply weathered in outcrop. The rock is various shades of yellow, gray or brown and all feldspars are altered. The tuff weathers to small angular rubble and forms rounded slopes. It can be distinguished from Hells Mesa by its lack of quartz and the presence of abundant pumice and lithic fragments.

Dark-gray or purple, dense, aphanitic, andesitic lavas underlie Hells Mesa at stream level in Water Canyon along South Canyon trail #15 (SW/4, SE/4, Section 34). No tuff of Granite Mountain underlies this exposure and the contact with Hells Mesa could be a fault. Similar lavas, however, occur between tuff of Granite Mountain and Hells Mesa west of Water Canyon (D. Petty, oral communication, 1977).

In this study, due to limited outcrop areas, all sedimentary rocks and lava intervals were mapped as Spears undivided; the tuff of Granite Mountain was mapped separately.

Hells Mesa Tuff

Overlying the Spears Formation is the Hells Mesa Tuff which was named after a prominent land form in the southern Bear Mountains (Tonking, 1957). It is a multiple-flow, simple cooling unit of crystal-rich, densely welded, ash-flow tuff (Chapin and Chamberlin, 1976). The Hells Mesa is normally 600 feet, or less in thickness but may be as much as 3850 feet thick in the central Magdalena Mountains (Krewedl, 1974) where it fills the North Baldy cauldron (Chapin and Chamberlin, 1976). Unrecognized faulting may be partially responsible for the greater thickness. An exposed section east of Water Canyon (SE/4, Section 34) indicates the presence of as much as 1300 feet of Hells Mesa; however, a possible fault and an eroded top make this thickness very tentative.

Within the study area, the Hells Mesa crops out in a northeast-trending band along the east side of Water Canyon (Section 3, T4S, R3W, unsurveyed and Sections 34, 35, and 26, T3S, R3W). Here, the Hells Mesa is bleached to light-gray, buff or greenish colors, weathers to small blocky rubble, and forms steep slopes. Along fault zones, where it is silicified, the Hells Mesa stands as cliffs above surrounding topography. Particularly large cliffs occur along a steep north-trending ridge east of Water Canyon (Section 34). Within this ridge joints are closely spaced and extremely erratic in attitude; joint planes can be seen to curve from horizontal to vertical in a single outcrop.

The southern end of the Hells Mesa outcrop belt (Section

3) is truncated by a large northeast-trending structure across which Hells Mesa and the unit of Sixmile Canyon abutt. This structure is interpreted to be the topographic wall of the Sawmill Canyon cauldron (Chapin and Chamberlin, 1976) and the contact is believed to be a depositional unconformity. On the west, the Hells Mesa overlies the Spears Formation. To the east, the contact between Hells Mesa and the unit of Sixmile Canyon or Lemitar Tuff can be interpreted in different ways. The flat silicified top of the Hells Mesa outcrop (Section 34) dips eastward and apparently under the younger units to the east. The sinuous nature of this contact further suggests a stratigraphic contact. If this is the case, the unit of Sixmile Canyon is very thin and pinches out northward between the Hells Mesa and Lemitar Tuff. The A-L Peak Tuff is not present. Alternatively this contact may be the deeply eroded ring fracture zone of the Socorro cauldron or the topographic wall of a post-Hells Mesa, pre-Lemitar Tuff cauldron.

Brown (1972), Simon (1973), Chamberlin (1974), and Spradlin (1974) have all done detailed petrographic work on the Hells Mesa and the reader seeking more detailed petrographic information is referred to their work.

The Hells Mesa is normally crystal-rich, containing 45 to 55 per cent phenocrysts of quartz, sanidine, plagioclase, biotite, and magnetite; however, the basal few tens of feet may have as few as 30 percent phenocrysts and only traces of quartz. Sanidine, the most abundant mineral, is normally twice as abundant as quartz; plagioclase is intermediate in abundance. In the study area, both feldspars are partially to completely altered to clay minerals and sericite. Quartz occurs as large rounded grains that are often deeply embayed. Biotite and magnetite make up a few per cent of the rock. The biotite is in various stages of alteration to iron oxides, or chlorite and sericite.

A-L Peak Tuff (?)

The A-L Peak Tuff is a composite ash-flow sheet (Chapin and Deal, 1976). It is normally divided into at least three members, all of which are crystal-poor, densely welded, one-feldspar, rhyolite ash-flow tuffs with 4 to 8 per cent sanidine phenocrysts and 1 to 2 per cent small rounded quartz phenocrysts (Chapin and Chamberlin, 1976). Various shades of gray or reddish-brown are the predominant colors. The lower, light-gray, pumice-poor, gray-massive member grades upward into the gray or reddish-brown flow-banded member which has abundant, lineated pumice. These pumice give the flow-banded member a characteristic streaked appearance. The upper member contains abundant, usually non-lineated, pumice and has been called the pinnacles member after its characteristic outcrop patterns. In the Lemitar and Bear mountains, a few tens of feet of basaltic-andesite lavas sometimes separate the pinnacles member from the lower A-L Peak Tuff.

A tuff thought to be correlative with one of these members crops out in the head of Sixmile Canyon (Section 10, T4S, R3W, unsurveyed). Here the A-L Peak (?) is overlain by andesitic and rhyolitic lavas of the unit of Sixmile Canyon. Reconnaissance indicates extensive exposures of this unit to the southwest in Ryan Hill and Sawmill Canyons, but no basal contact is known to be exposed.

The rock is pumiceous, crystal-poor and is normally densely welded. It contains a few per cent sanidine, and scattered, small, rounded quartz phenocrysts. At the stratigraphic level exposed in the map area, the pumice are grayish-red and contrast strongly with the light-gray matrix. At lower stratigraphic levels (not exposed in the study area), the pumice are light-brown or gray, blend with the matrix, and are strongly lineated. This lineation suggests a correlation with the flow-banded member of the A-L Peak Tuff. In this report, however, due to limited outcrop area and lack of stratigraphic control, correlation is suggested only with the A-L Peak Tuff as a whole. Studies presently covering areas to the south and west (D. Petty, S. Bowring, and P. Allen, in progress) should clarify this correlation.

Unit of Sixmile Canyon

Overlying the A-L Peak Tuff(?) in the heads of Sixmile and South Canyons (Sections 2, 3, 10, and 11, T4S, R3W, unsurveyed) is a thick sequence of andesite lavas, with interbedded rhyolitic lavas, ash-flow tuffs, and volcaniclastic sedimentary rocks. Krewedl (1974) named this interval the Sixmile Canyon Andesite. The name is here changed to unit of Sixmile Canyon to relfect a heterolithic character and conform to U.S. Geological Survey convention for designation of informal units. The unit overlies Hells Mesa Tuff and underlies Lemitar Tuff, but its relationships to the A-L Peak are uncertain. Tuffs similar to the A-L Peak crop out beneath the unit of Sixmile Canyon near Sixmile Spring and possibly occur as scattered slide blocks within the unit of Sixmile Canyon along the west side of Buck Peak.

The unit covers a minimum topographic interval of 1000 feet and cross sections indicate that as much as 2500 feet may be present in areas around Buck Peak. Basaltic andesites in the Lemitar and Bear Mountains, at this stratigraphic level, have a thickness of as much as 500 feet (Chapin and Chamberlin, 1976). The increased thickness in the Buck Peak area is interpreted to be due to filling of the Sawmill Canyon cauldron by these units. This interpretation is supported by the heterogenous nature of these deposits. In addition to the basaltic andesites found elsewhere, there are coarse heterolithic breccias, which suggest the presence of significant topographic relief at the time of their deposition, and thick rhyolitic lava flows and thin local ash-flow tuffs that are typical of moat deposits.

The cauldron boundary trends approximately east-west where exposed in the study area, but its projection eastward is not known due to cover by the Lemitar Tuff. Small amounts of andesites and tuffs of the unit of Sixmile Canyon are found eastward in Sixmile Canyon (Sections 32, T3S, R3W and 7, T4S, R3W), and 210 feet of sandstones, conglomerates, and breccias beneath the Lemitar Tuff were cut by a diamond drill hole at the Tower Mine (Section 7, T4S, R1W), immediately east of the study area. In addition, as much as 1000 feet of andesitic lavas are exposed in Sixmile Canyon near the mountain front (Section 5, T4S, R2W). This thickness of the unit of Sixmile Canyon suggests that the Sawmill Canyon caldera may extend eastward past the mouth of Sixmile Canyon. No base is exposed at any of these exposures, except in the drill hole at the Tower Mine where strongly sheared A-L Peak-like tuffs underlie the sedimentary rocks.

A rhyolitic lava flow, a thin ash-flow tuff interval, and a distinctive sandstone within the unit of Sixmile Canyon were mapped separately; andesitic lavas and heterolithic breccias were mapped undivided.

rhyolitic lava flow.

In the upper reaches of Sixmile Canyon (Sections 10, 11, 14, and 15, T4S, R3W, unsurveyed), pale-red, grayish-pink, or pinkish-gray rhyolitic lavas crop out. In most places, these lavas appear to be stratigraphically above andesites of the unit of Sixmile Canyon or the A-L Peak Tuff (?), and are overlain by the tuff interval, andesitic lavas, or sandstone of the unit of Sixmile Canyon. However, at one location (W/2, Section 15), the Lemitar Tuff overlies the rhyolitic lava in a manner that suggests the rhyolite is intrusive. The Lemitar Tuff dips steeply into the top of the hill, yet the contact with the underlying rhyolite is nearly horizontal, and the lower exposures of Lemitar Tuff are silicified and brecciated. This contact is postulated to be a rotated normal fault and the lava to be a flow, or domal flow, since the majority of outcrops show conformable relationships and no unusual degree of alteration. Additional support is provided by the fact that rotated normal faults are the prevalent structural style in the area south of Buck Peak (see Plate 1). Also, the Lemitar Tuff is as extensively silicified on Buck Peak as it is where it overlies these lavas. The aphanitic groundmass of the rhyolitic lavas further suggests an extrusive origin, since an intrusion of this size should have a coarser texture.

The rhyolitic lavas crop out over a minimum topographic interval of 1000 feet and their maximum thickness, estimated from cross section (see Plate 1, cross section B-B') may be as much as 2500 feet. This thickness suggests proximity to the source; however, the sparse and erratic foliation was inadequate to locate the vent. The lavas pinch out to the north and west, but are extensive southwest of this area (D. Petty, oral communication, 1977). They disappear under younger units to the east. In outcrop, the rhyolitic lavas weather to small blocky talus and form steep rubbly slopes with occasional small cliffs. Petrographically, the rock is a rhyolite and contains 15 to 40 per cent phenocrysts of sanidine, quartz, and biotite. The aphanitic groundmass has devitrified to a mosaic of potassium feldspar and quartz; spherulites of the same material sometimes give the rock a mottled appearance.

Sanidine is the dominant phenocryst and occurs as equant or tabular crystals as much as 7 mm long. The sanidine is clear and may show light-blue or pearly-white chatoyancy when fresh. When altered, the sanidine tends to be white, pink, or light- to medium-brown and non-chatoyant. A few per cent rounded and embayed quartz phenocrysts averaging 1 mm in maximum dimension, are present along with as much as one per cent black or coppery biotite.

Brownish-gray, aphanitic, andesite lithic fragments normally make up from 3 to 5 per cent of the rock, but may be as abundant as 30 per cent at some locations. These lithics weather out and leave angular to rounded cavities in outcrop. Some of the lithic fragments are rounded and appear to have been embayed by the surrounding lava.

tuff interval.

Overlying the rhyolitic lavas or, locally, the andesitic lavas of the unit of Sixmile Canyon is a sequence of thin ash-flow tuffs which may be as much as 100 feet thick. At least two distinctive intervals are present. The lower is a crystal-poor, multiple-flow, poorly to moderately welded tuff; the upper is a moderately crystal-rich, densely welded tuff. Both intervals were mapped together due to their thin and discontinuous nature. A photograph of an outcrop of these tuffs and the overlying laminated sandstone is shown in figure 6.

The tuffs crop out discontinuously along both sides of Sixmile Canyon from Buck Peak to Box Spring (Sec. 7, T4S, R2W). Similar tuffs occur on Timber Peak and in Sawmill Canyon west of this study area (S. Bowering, oral communication, 1977) and a two-foot, crystal-rich interval in the drill hole at Tower Mine could be correlative with the upper part of this tuff interval. The extent or origin of these tuffs is not known.

The lower interval normally contains 6 to 8 per cent phenocrysts of sanidine, a few per cent small, rounded quartz grains and traces of coppery biotite. The tuff varies from light-gray to yellowish-gray where poorly welded to pale-red-purple where moderately welded. Sandy or tuffaceous sediments are locally present near the base.

The upper moderately crystal-rich interval is consistently dark-pinkish-gray on a fresh surface and weathers to shades of brownish-gray. It normally contains 20 to 25 per cent phenocrysts of sanidine, quartz and biotite. Sanidine, averaging 12 per cent of the rock, is about twice as abundant as quartz, and occurs as anhedral to subhedral crystals. Quartz occurs both as large, slightly rounded, dipyramidal crystals, as much as 4 mm across, and as smaller broken to rounded fragments averaging 0.3 mm in longest dimension.

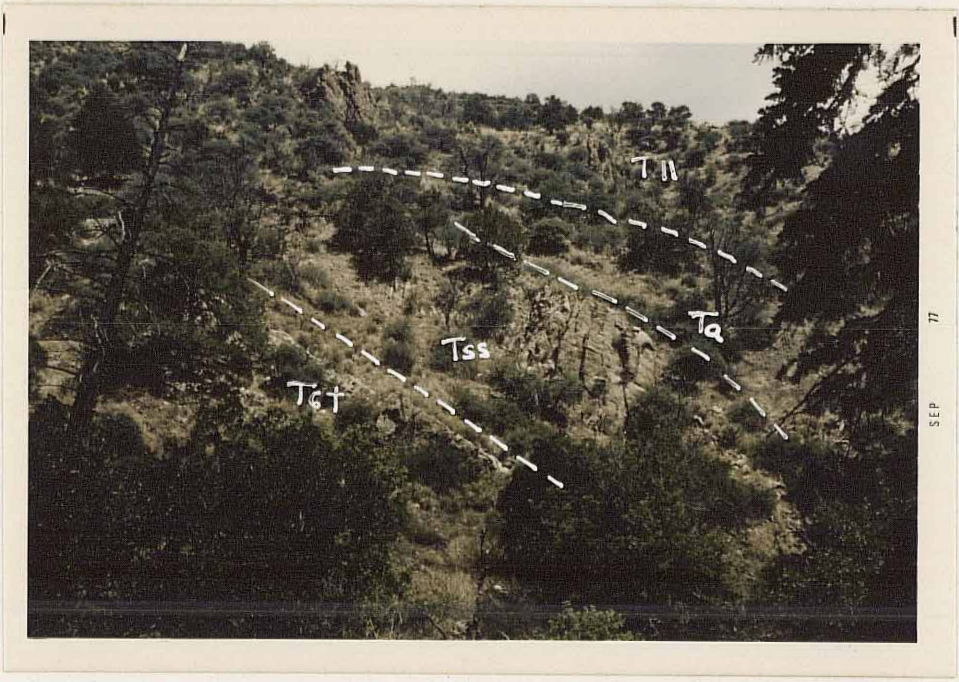


Figure 6: Photograph showing typical outcrops of several members in the unit of Sixmile Canyon. T6t-tuff interval, Tss-laminated sandstone interval, Ta- basaltic andesite lavas, and Tll-the overlying lower member of the Lemitar Tuff. View is toward the north wall of Sixmile Canyon, SW/4, Sec. 7, T4S, R3W.

One-half to one per cent coppery biotite and a trace of magnetite are also present.

sandstone.

Overlying the tuff interval and, locally, the underlying rhyolitic lavas is a distinctive 20- to 50-foot-thick interval of finely laminated sandstone. The sandstone crops out as ledgy slopes at scattered locations along Sixmile Canyon (Sections 12 and 14, T4S, R3W, unsurveyed, and Section 7, T4S, R2W). Similar sandstone intervals occur on Timber Peak and in Sawmill Canyon (Stacy, 1972; Bowring, oral communication, 1977) west of the study area. Approximately 80 feet of similar sandstone was logged at this stratigraphic level in the drill hole at the Tower Mine (Appendix A). About 150 feet of conglomerates, sandstones and breccias directly underlie the sandstones in the drill hole. The sandstone is pinkish-gray or gray on both fresh and weathered surfaces at most locations, but is pale- to moderate-red at the easternmost outcrop. The outcrops have even, thick bedding (0.1 to 1.0 m) and fine to very fine (1 to a few mm), planar, parallel laminations that are very continuous laterally. At one location, planar cross-laminations were noted. In general, the rock is composed of subequal amounts of poorly sorted, fine- to coarse-sand-size quartz and feldspar grains; alternation of coarse and fine layers causes the lamination. A few per cent dark, sand-size rock fragments and magnetite grains (?) give some beds a speckled appearance. Near the top of the unit a few thin conglomeratic lenses are found locally which contain pebbles of dark-red to brown aphanitic volcanic rocks. Local pumiceous and silty beds are also found in the easternmost outcrop (Section 7).

andesites and heterolithic breccias.

Much of the unit of Sixmile Canyon is a thick sequence of andesite lavas with local zones of mudflow deposits. At some locations, these andesites make up the entire unit while at others they surround other rock types. These relationships suggest that andesite lavas were accumulating over a relatively long period of time spanning the emplacement of rhyolitic lava, tuffs, and sandstone.

Based on mineralogy and texture, the andesite lavas may be subdivided into three types: 1) dense aphanitic, 2) pyroxene porphyritic (La Jara Peak-like) and 3) plagioclase prophyritic. Good outcrops occur locally but a colluvium of small angular blocks is the normal exposure.

Dense, aphanitic, dark-gray or purple andesites with no visible phenocrysts occur in the lower stratigraphic levels and is the most abundant andesite lithology in the unit of Sixmile Canyon. Good outcrops of these rocks are found along both sides of South Canyon north of Buck Peak (Sections 2 and 3, T4S, R3W, unsurveyed).

Second in abundance, and usually occurring at the top of the section directly under Lemitar Tuff and above the "tuff interval", are dense to vesicular rocks with an aphanitic groundmass containing small, red, oxidized pyroxene phenocrysts. These rocks closely resemble, both in hand specimen and thin section, the La Jara Peak Andesite (see Simon, 1973). Petrographically similar rocks are present in the interval above Lemitar Tuff. Good outcrops are found above the "tuff interval" in Sixmile Canyon (Section 12, T4S, R3W, unsurveyed).

Plagioclase-porphyritic andesites are found in minor amounts at various stratigraphic intervals and locations. The amount and size of plagioclase phenocrysts varies; most of the plagioclase is chalky and altered.

Coarse, heterolithic breccias with clasts as much as 3 feet in diameter crop out in a gully north of South Canyon along the Sawmill Canyon cauldron wall (?) (Section 3, T4S, R3W, unsurveyed). In these outcrops, coarse, angular-to-rounded clasts are found in a matrix of finely comminuted andesite; locally, the matrix appears to be a pumiceous tuff. Clast lithologies are diverse, with both rhyolitic and intermediate compositions present. Clasts believed to be Hells Mesa Tuff are common and usually rounded. They are reddish-brown and appear unaltered in contrast to the greenish or yellowish, altered Hells Mesa in nearby exposures. Other lithologies present as clasts include flow-banded rhyolites, latites similar to those found in the Spears Formation, and various other intermediate lavas. One distinctive lava with large (up to 4 cm) plagioclase phenocrysts occurs as clasts in these breccias but is seen in outcrop west of Timber Peak in the same apparent stratigraphic interval.

These breccias appear to dip to the southeast away from the Sawmill Canyon cauldron wall; however, the apparent bedding is very crude and may be misinterpreted. The heterolithic, unsorted, mud-supported clasts suggest a mud-flow origin. Their proximity to the Hells Mesa Tuff along the cauldron margin and their steep dips into the cauldron suggest that they were deposited by debris flows from the cauldron wall. An outcrop of these breccias is shown in figure 7; good exposures are indicated on plate 1 with a conglomeratic overlay pattern.

Near the breccia outcrops in South Canyon and at other scattered locations west of Buck Peak, large blocks of ash-flow tuffs as much as several hundred feet across are found. They are apparently surrounded by andesitic lavas and may be slide blocks from the cauldron wall. The presence of one block, resembling flow-banded A-L Peak Tuff, west of Buck Peak (SW/4, SE/4, Section 3) supports this interpretation. Other blocks are moderately crystal-rich, pumiceous, and weather to small slabby talus. These may be erosional remnants of the lower part of the "tuff interval" in the unit of Sixmile Canyon. Faults concealed by the poor outcrops of andesite lavas could account for the scattered distribution of the blocks.

Figure 7: Laharic breccias in the unit of Sixmile Canyon (NE/4, Section 3, T4S, R3W, unsurveyed). Unit is mud supported and heterolithic. Clast lithologies include Hells Mesa-like tuff (H), flow-banded rhyolite lavas (F), and various andesitic to latitic (L) lavas resembling those found in the volcaniclastic portions of the Spears Formation. The presence of rhyolitic clasts distinguishes these rocks from the Spears Formation. Matrix is finely comminuted latite to andesite fragments here but may be locally a pumiceous tuff. Hammer is approximately 12 inches long.

Lemitar Tuff

The Lemitar Tuff is a multiple-flow, simple cooling unit, rhyolite ash-flow tuff (Chapin and Chamberlin, 1976) and occurs in widespread, relatively continuous outcrops throughout a large part of the central study area (Plate 1). The outflow sheet can be divided into two members: 1) a crystal-rich upper member that is a few tens to two hundred feet thick and occurs throughout the Socorro-Magdalena area, and 2) a relatively crystal-poor lower member which occurs as a thin interval at scattered locations in the Lemitar Mountains and the Magdalena area. The Lemitar Tuff is believed to have been erupted from the Socorro cauldron (Chapin and Chamberlin, 1976; see also Fig. 26 this study).

The Lemitar Tuff, formerly tuff of Allen Well, has been described by several authors, but the most detailed petrography has been done by Simon (1973) on samples from the Crouch drill hole in the Silver Hill area (the unit was misidentified as tuff of La Jencia Creek due to its presence in a paleo-valley). R. M. Chamberlin has recently described a section in the Lemitar Mountains after which the tuff has been renamed. A sample from the Lemitar Mountains has been dated 26.3 m.y. using the K/Ar method on biotite.

Greater thicknesses of Lemitar Tuff are found in this study area. A stratigraphic section of the lower, moderately crystal-poor member was measured in Sixmile Canyon (Section

7, T4S, R2W); however, an adequate, unfaulted section of the upper, crystal-rich member was not found. Although control on thickness is poor due to extensive faulting and lack of exposures of the basal contact, reasonable thickness estimates may be made from cross sections in the central part of the study area. Several thickness estimates from the study area together with data from the Tower Mine drill hole, Crouch drill hole (Simon, 1973), estimates from Timber Peak and South Baldy (D. Petty and S. Bowring, oral communication, 1977), and the Lemitar and Chupadera mountains (R. M. Chamberlin, in progress) are presented in figure 8.

The Lemitar Tuff is consistently much thicker throughout the Chupadera and southeastern Magdalena Mountains than in other areas of exposure. The upper member is normally 600 to 700 feet thick in the study area and may be as thick as 2800 feet in the Chupadera Mountains. Miesch estimated a minimum of 1000 feet of Lemitar Tuff (massive rhyolite) in the Chupadera Mountains. Only 690 feet of Lemitar Tuff was cut by the drill hole at the Tower Mine, of which only 320 feet was upper member. R. M. Chamberlin has recently, however, estimated, from cross sections, thicknesses as great as 2900 feet for the upper Lemitar Tuff in the area just east of the Tower Mine area. Several hundred feet of upper member is also present on Timber Peak and South Baldy, west of this study area (D. Petty and S. Bowring, oral communication, 1977).

The lower member varies considerably in thickness

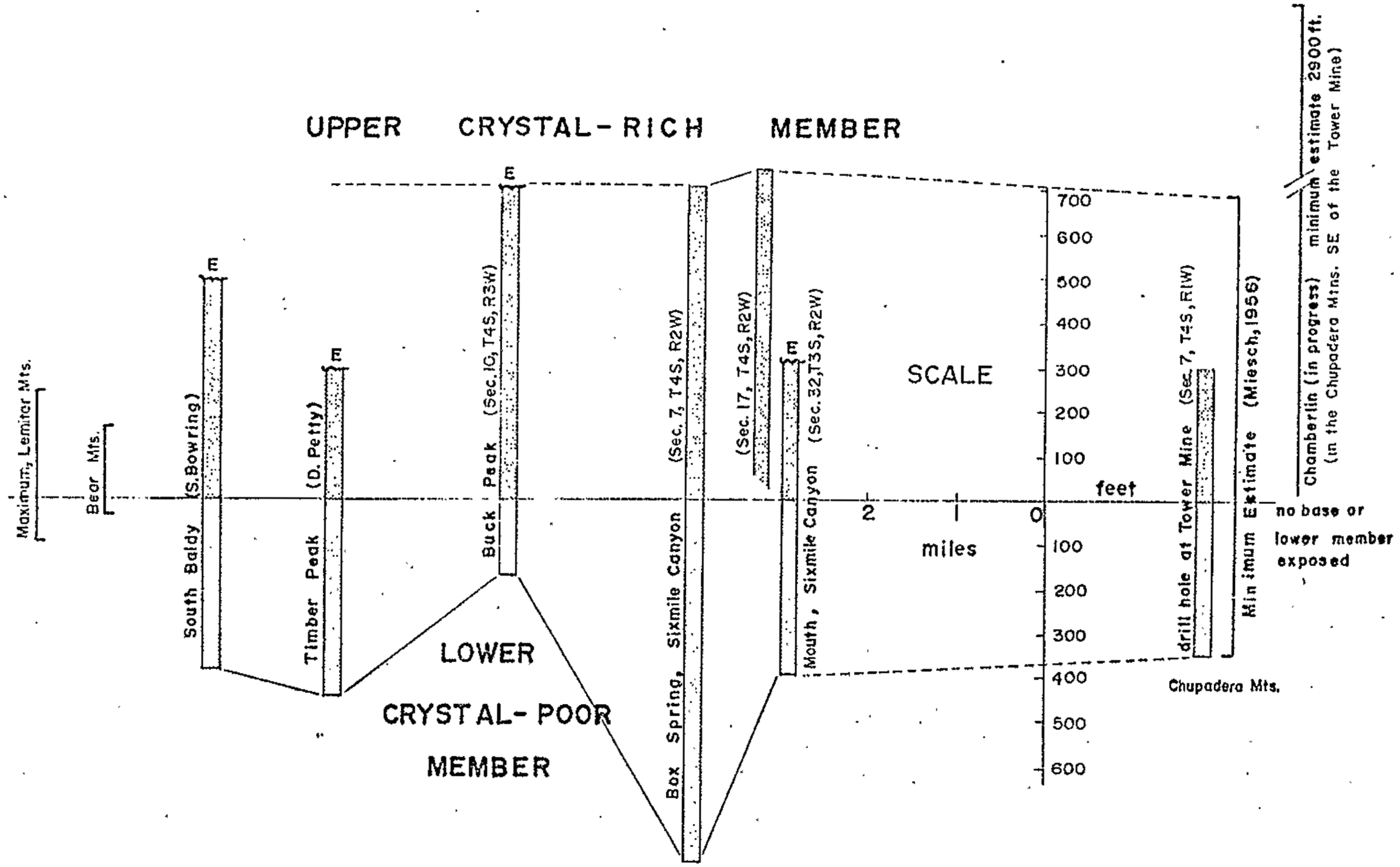


Figure 8: Fence diagram of Lemitar Tuff thicknesses from South Baldy to the Chupadera Mountains. Datum is the transition between upper and lower members. South Baldy and Timber Peak data are from S. Bowring and D. Petty, oral commun., 1977; Bear Mt. data is from the Crouch Drill hole, Simon, 1973; Lemitar and Chupadera Mts. data from Chamberlin, in progress.

where it is exposed. A stratigraphic thickness of 820 feet was measured in Sixmile Canyon (Section 7), but one mile northeast only 400 feet is found. In the drill hole at the Tower Mine, 367 feet of the lower member is present and to the west on Buck Peak only 150 to 200 feet is found. Thicknesses of 200 to 400 feet are estimated for the lower member on Timber Peak and South Baldy.

Two possible explanations could account for the thickness variations of the Lemitar Tuff in the study area. The first would have the Lemitar Tuff erupted from an unknown source and flow into a pre-existing depression consisting of the overlapping Langmuir and Socorro cauldrons. The lower member would have filled existing topographic lows and have become irregular in thickness while the upper would have flowed over the flat top of the lower member and have been relatively constant in thickness. Thick sections would have been deposited within the Socorro cauldron and westward along the moat of the Langmuir cauldron.

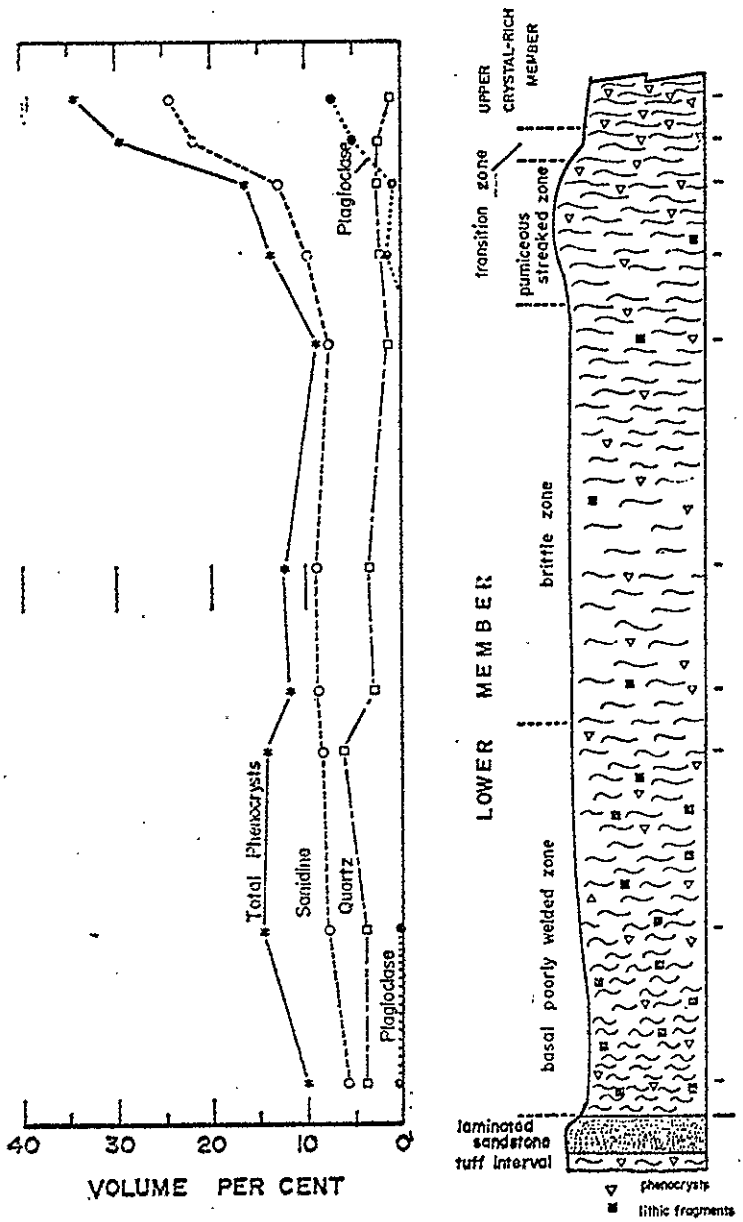
Alternatively, the Lemitar Tuff may have been erupted from the Socorro cauldron. Variations in thickness could be accounted for by differential subsidence and the Langmuir cauldron moat would still have provided a channel to be filled to the west. Evidence supporting this relationship, in addition to the thick sequence of Lemitar Tuff, includes moat deposits in the northern Chupadera Mountains overlying Lemitar Tuff (R. M. Chamberlin, in progress), and zones of large lithic fragments (probably mesobreccias in the terminology of Lipman, 1976) in the Chupadera Mountains (R. M. Chamberlin, in progress).

Insufficient evidence is available to decide between these two hypotheses; however, no structural offset or significant thickening of the Lemitar Tuff that could be interpreted as a cauldron margin was found within the study area. Interpretation of thickness variations within the proposed Socorro Cauldron may be further complicated by contemporaneous rifting.

lower Lemitar Tuff.

The modal data from samples collected from the measured section of lower Lemitar Tuff is reported in figure 9. The lower member can be divided into three zones on the basis of outcrop pattern, degree of welding, total phenocryst content, pumice and lithic content, and color. In general, phenocryst morphologies and sizes, and lithic fragment types are constant throughout the lower member and are therefore discussed before zonation. The entire member is moderately crystal-poor and averages 13 per cent phenocrysts of sanidine, quartz, and coppery biotite.

Sanidine is the most abundant mineral and occurs as untwinned, generally broken crystals averaging 0.9 mm in longest dimension. The sanidine occasionally shows perthitic exolution of albite (?). The exolved lamellae stained strongly for potassium, thus, the albite (?) has probably altered in a manner similar to the plagioclase phenocrysts



samp. loc.	Sample #	color fresh weathered	Total Phen.	sanidine	plag. (c)	quartz	biotite	opaques	points counted	lithics (a)	pumice (a)
843 255	6M-21	Moderate Pink (5R7/4) Pale-Red-Brown (10R5/4)	34.3	24.4	7.0	1.0	0.8	1.2	2063	5%	5-10%
810 245	6M-20	Grayish-red-pur. (5R4/2) Mod.-pink (5R7/4)	29.5	21.5	4.7	2.4	1.0	0.9	2528	2%	10
773 234	6M-19	Grayish-red (5R4/2) Pale-red (5R6/2)	16.4	12.6	0.9	2.4	tr	0.5	1871	2	20
713 215	6M-17	Grayish-red (5R4/2) Pale-red (5R6/2)	13.3	9.5	1.7	2.1	tr	tr	2854	5%	20
640 194	6M-16	Pale-red (5R6/2) Pale-red (5R6/2)	8.4	7.2	0	1.2	tr	tr	2523	5	10
460 140	6M-14	Grayish-red (10R4/2) Pale-reddish-brn. (10R5/4)	12.5	9.0	0	3.5	tr	0.4	2800	tr	5
358 110	6M-12	Grayish-red (10R4/2) Pale-reddish-brn. (10R5/4)	11.9	8.9	0	3.0	tr	tr	2736	tr	5
306 93	6M-10	Pale-red (5R6/2) Pale-red (5R6/2)	14.4	8.3	0	6.1	tr	tr	2425	5%	10-15% "botryoid
160 48	6M-7	Pale-red (10R6/2) Pale-yel.-brn. (10YR6/2)	14.6	7.7	0.4	3.9	tr	tr	2401	10	20
35 11	6M-4	Grayish-pink (5R8/2) Grayish-orng.-pink (5YR7/2)	10.0	8.7	0.5	3.8	tr	tr	3012	5	40

(a) estimated from hand specimen and outcrop.

(c) mineral counted as plagioclase is largely altered but resembles altered plagioclase in other units within the study area.

Figure 9: Modal data, graphic stratigraphic column and plot of relative phenocryst abundances for lower Lemitar Tuff. Samples for measured stratigraphic section in Section 7, T4S, R3W.

in the lower member and also in the upper member and the tuff of South Canyon. Subordinate quartz occurs as clear or dark-smokey-gray, anhedral to subhedral grains averaging 0.7 mm in diameter. Also present are trace amounts of reddish-brown, pleochroic biotite in varying stages of alteration to magnetite, and as much as 0.5 per cent magnetite as irregular rounded grains. Plagioclase, where present, is largely altered to clay minerals.

Several varieties of lithic fragments, averaging about 1 cm in diameter, are found throughout the member in varying amounts. The most common type is pink, dark-brown, or dark-gray, occasionally banded, aphanitic, silicic rock fragments. Andesites and various porphyritic crystal-poor to crystal-rich rhyolitic rock fragments (probably in part ash-flow tuffs) are also found in lesser amounts.

The groundmass is normally devitrified to a mosaic of quartz and potassium feldspar but locally may have domains of mosaic-texture quartz several millimeters across.

The basal zone in the lower member is light in color, poorly to moderately welded, pumiceous, and a slope-forming interval. It normally contains about 15 per cent phenocrysts and averages several per cent lithic fragments. Plagioclase occurs in trace amounts in this zone but was not recognized in the overlying interval. Pumice is abundant and has a "botryoidal" internal texture in the top of this basal zone and in the base of the overlying interval (Fig. 15).

Thickness varies from 300 feet at the measured section to a few tens of feet on Buck Peak; approximately 120 feet of this zone is found in the drill hole at the Tower Mine.

The overlying second zone is characteristically grayish-red, weathers to pale-reddish-brown and is brittle. It breaks into sharp, angular fragments and forms rough slopes and small cliffs; outcrops often appear brecciated. The contact with the lower zone is gradational over a few feet and has weathered to a notch in one location near the measured section. Phenocryst content is lower than in the rest of the lower member, averaging 8 to 12 per cent, and quartz has decreased in abundance to a maximum of three per cent. No plagioclase was seen in thin section; lithic fragments are scarce and pumice is not prominent. Shard structure is very well-preserved and the shards become more flattened upward. Figure 10 shows the well-preserved vitroclastic texture in thin section.

The gradation into the third and upper zone is marked by an increase in size and abundance of light-gray, highly compressed pumice and by darkening of the matrix. These features give the rock a streaked appearance which is shown in figure 11. Lithophysal cavities, filled with white silica or occasionally partially open, are present in this interval in South Canyon (Section 35, T3S, R3W). Phenocryst content gradually increases from 8 per cent to 15 per cent and parallels an increase in pumice content; altered plagioclase reappears and increases in abundance

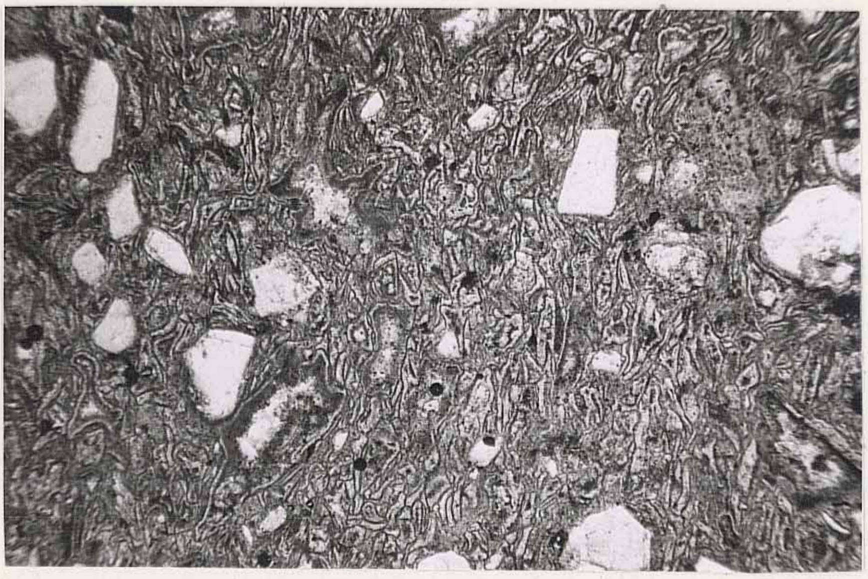


Figure 10: Photomicrograph (31.25x, uncrossed nichols) showing the well-preserved vitroclastic texture of the middle, brittle zone of the lower Lemitar Tuff. The distorted shapes are shards; the dark borders were probably dusty coatings on the shards. Quartz and sanidine phenocrysts are present but indistinguishable in this photograph. (Sample 6M-14, Fig. 9).

Figure 11: Specimens of the streaked zones of the tuff of South Canyon (left) and Lemitar Tuff (right). Both rocks have moderate phenocryst content, abundant quartz and sanidine, and streaky pumice foliation. Lower Lemitar Tuff (right) has slightly more biotite and plagioclase in the upper parts of the streaked zone. Individual specimens and outcrops may be virtually indistinguishable on petrographic criterion. The most reliable means of identifying these units is through the readily distinguished overlying and underlying intervals.

upward. Quartz remains scarce, averaging 2.5 per cent. This zone characteristically forms cliffs, often with the transition to upper Lemitar Tuff at the top.

Combined thickness of the two upper zones is 500 feet at the measured section and in the central study area, 240 feet in the drill hole at the Tower Mine, and 200 feet or less on Buck Peak in the west part of the area.

transition zone.

A gradational increase in crystal content to about 35 per cent, a parallel increase in the abundance of plagioclase and the appearance of "moderate-pink" blotches (5R7/4) define the 5- to 50-foot transition into upper Lemitar Tuff in the study area (Fig. 9). Pumice becomes crystal-rich and light-gray or grayish-purple with the increase in crystal content. Similar transitions are seen in the Lemitar Mountains (R. M. Chamberlin, oral communication, 1977) and in core from the drill hole at the Tower Mine (Appendix A). The content between upper and lower Lemitar Tuff was mapped at the increase in crystal content which corresponds approximately to the first occurrence of moderate-pink blotches, or, when silicification masks color and crystal content, at the point where prominent pumice streaking ended.

upper Lemitar Tuff.

In hand specimen, the upper Lemitar Tuff is consistently moderate- to light-red and crystal-rich; it contains 30 to

35 per cent phenocrysts of sanidine, plagioclase, quartz, and biotite. The upper member weathers to rounded blocks bounded by joint surfaces and crops out as steep, rounded, rubbly hills, or occasionally as ledges and small cliffs.

Sanidine is the most abundant mineral and occurs as fresh, untwinned, broken, tabular or equant crystals averaging 1.2 mm in longest dimension. Plagioclase is next in abundance but because of alteration, it is usually plucked from thinsections during their preparation. The resultant holes usually have a skeletal remnant of potassium feldspar (?) around the edges. In some cases this material has a fibrous texture and may be clay minerals. All of this remnant material stained strongly for potassium with sodium cobaltinitrite.

Quartz occurs as subhedral to anhedral rounded fragments as much as 4.0 mm in diameter and averaging 1.3 mm in size. It may be either clear or dark-smokey-gray. Quartz is scarce within the lower parts of the upper member but increases in abundance to several per cent throughout most of the member and may reach 15 per cent in abundance at the top.

One to a few per cent reddish-brown, pleochroic biotite occurs as euhedral, thin plates which exhibit varying stages of alteration to magnetite. As much as 0.5 per cent primary magnetite is also present as rounded grains averaging 0.4 mm in diameter. A few pyroxene grains, largely replaced with magnetite, and a trace of zircon (?) were seen in one thin section.

Pumice in the upper member is generally gray to reddish and blends with the matrix; however, in the upper third of the upper Lemitar Tuff, light-gray, crystal-rich clots become common. Stringers of light-grayish-red, quartz- and sanidine-poor, plagioclase- and biotite-rich pumice (?) are also common. The grayish-red pumice (?) is scarce in the northern part of the area and becomes more abundant southward. They are particularly large and abundant in the Rincon-Madera Canyon area immediately south of the study area (S/2, T4S, R2W). A photograph of the grayish-red pumice from this area is shown in figure 12. The white crystal-rich clots are scarce or absent in this area to the south but abundant in the Pound Ranch area. A photograph of white crystal-rich clots from the area west of Pound Ranch is shown in figure 13.

The upper few tens of feet of the Lemitar Tuff is sometimes light-gray to pinkish-gray and appears bleached. However, in thin section, all phenocrysts except plagioclase are fresh and this feature is considered to be zonation rather than alteration. In this upper zone, quartz and total phenocryst content are higher than normal with quartz content reaching 15 per cent and total phenocryst content nearing 50 per cent. Plagioclase is much less abundant than in lower zones and makes up only 1 to 2 per cent of the rock.

Figure 12: Reddish-gray, lenticular clots or pumice (?) in the upper Lemitar Tuff in Rincon-Madera Canyon, south of Pound Ranch. These clots are common throughout the southern part of the study area near the top of the unit. The clots are rich in plagioclase and biotite and have little or no quartz and sanidine. These clots, which are more mafic than the groundmass, contrast strongly with the crystal-rich, quartz-rich clots found in the Lemitar Tuff to the north, west of Pound Ranch (see Fig. 13).

Figure 13: White crystal-rich clots (c) in the upper part of the upper Lemitar Tuff. Clots are lighter in color, more crystal-rich, and more quartz-rich than the surrounding rock. These clots contrast strongly with both the normal upper Lemitar Tuff at this stratigraphic level and the reddish-gray clots found farther south (Fig. 12). West of Pound Ranch both types of clots are found together, to the south only reddish-gray mafic clots occur and to the north white crystal-rich clots predominate but a few mafic clots are also present.

A few feet of unwelded tuff is occasionally preserved at the top of the Lemitar Tuff. Thin, local lenses of medium- to fine-grained, moderately to well-sorted, red or light-brown rhyolitic sandstones commonly occur at the top of the Lemitar Tuff, or interbedded in the lower levels of the overlying basaltic andesites.

Basaltic Andesites

A thick sequence of porphyritic, pyroxene-bearing, basaltic andesite flows overlies Lemitar Tuff throughout the study area. As much as 1100 feet of similar lavas are present at this stratigraphic level in the Lemitar Mountains (R. M. Chamberlin, in progress) and Spradlin (1974) reports andesitic lavas at this level in the Joyita Hills.

The basaltic andesites crop out discontinuously over much of the central part of the study area. When well-exposed, as along the steep sides of South and Sixmile canyons (Section 36, T3S, R3W and Sections 5 and 7, T4S, R2W), individual flows with autobrecciated tops and bottoms can be seen and the lavas form steep slopes with small cliffs. Most exposures, however, consist of rounded hills covered with a colluvium of small angular fragments. Where both overlain and underlain by tuff intervals, the basaltic andesites weather to conspicuous benches.

At the mouth of South Canyon (SW/4, Section 30, T3S, R2W), 400 feet of these basaltic andesites were measured. Cross sections indicate a 400 to 600 foot thickness range for these lavas along South and Sixmile canyons. Farther southwest (Sections 13, T4S, R3W, unsurveyed) only a few feet of these lavas are found; to the east, west of Pound Ranch, the thickness ranges from 50 to 300 feet. In one area in Sixmile Canyon (E/2, Section 6, T4S, R2W), faults appear to cut Lemitar Tuff, but not tuff of South Canyon and control the thickness of these basaltic andesites. These variations in thickness of the basaltic andesites may be the result of post-eruption subsidence within the Socorro cauldron, rift faulting, or both. R. M. Chamberlin (in progress) has documented at least 300 feet of pre-Lemitar Tuff early-rift-fault relief in the Lemitar Mountains.

In hand specimen, most of these rocks are light-brownish-gray and weather to grayish-red or reddish-brown. They are prophyritic with several per cent small, reddish (iron-stained), altered pyroxene phenocrysts set in an aphanitic groundmass. A few lavas within these sections also have plagioclase and olivine phenocrysts. These rocks with plagioclase and olivine phenocrysts weather to ledges and larger colluvium blocks and are greenish-black when fresh. They weather to shades of brownish-gray.

In thin section, the aphanitic rocks with iron-stained pyroxene phenocrysts have a pilotaxitic groundmass of plagioclase microlites averaging 0.05 mm in length. About 70 per cent of the groundmass is plagioclase; small irregular clinopyroxene and magnetite grains fill interstices. In some specimens, which are reddish in hand specimen, all magnetite has been oxidized to hematite.

Two types of pyroxene phenocrysts make up the remainder of the rock. The largest and most abundant are orthopyroxenes which have been largely altered to hematite and magnetite, as is suggested by their red color in hand specimen. Where less altered, these crystals can be seen to have parallel extinction; however, the hematite staining prevented further optical tests. These orthopyroxenes are subhedral to euhedral, average 1.0 mm in maximum dimension, and make up as much as 3 per cent of the rock. Also present in amounts as great as 2 per cent, are smaller, relatively unaltered, clinopyroxene phenocrysts. These average 0.4 mm in length and are anhedral to subhedral. The clinopyroxene occurs as grains that may have low or high birefringence depending on the orientation of the crystal section. Optical properties are consistent with those of augite. In more altered samples, all mafic minerals are altered to magnetite and/or hematite.

In rocks that have plagioclase phenocrysts visible in hand specimen, olivine is present in addition to both types of pyroxenes found in the more aphanitic rocks. The olivine occurs as rounded grains as much as 2 mm in diameter and may make up as much as 0.5 per cent of the rock. Plagioclase occurs in varying amounts as phenocrysts up to several millimeters in length. The texture of these rocks tends to be seriate.

Locally, where the basal contact of the overlying tuff of South Canyon is well exposed, thin (0.1 m to a few m) layers of mudstones are found. Similar mudstones are found in scattered exposures from just west of Pound Ranch to South Canyon but it is not known if these are part of a continuous layer or are scattered deposits. The mudstones are brown or reddish-brown and may contain as much as 20 per cent pumice and several per cent rock fragments. These deposits were probably emplaced as mudflows. At one location in Sixmile Canyon (SE/4, Section 6, T4S, R2W), a few badly decomposed plant fragments were seen in this mudstone layer.

Also, in South Canyon (SW/4, Section 36, T3S, R3W), as much as 20 feet of volcaniclastic sedimentary rocks are found in a channel under the tuff of South Canyon. These vary from sandstones to coarse conglomerates and are overlain by the poorly welded basal zone of the tuff of South Canyon. Pebble imbrications indicate a northerly transport direction.

Tuff of South Canyon

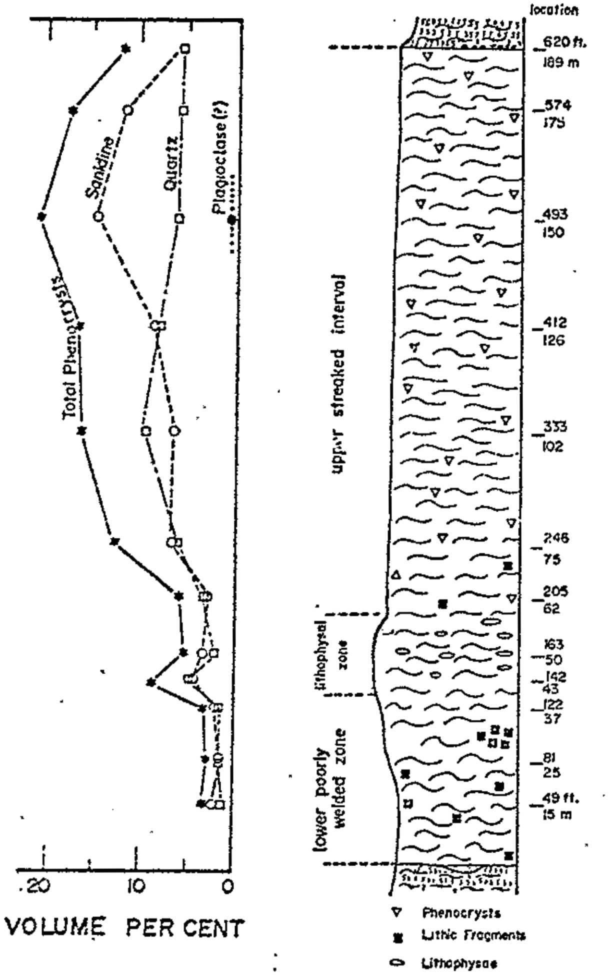
Recent works (Simon, 1973; and Chamberlin, 1974) have called all tuff units above Lemitar Tuff the upper tuffs. In this study, a multiple-flow, simple cooling unit of rhyolitic ash-flow tuff occurs above the basaltic andesites that overlie Lemitar Tuff. It is here called tuff of South Canyon, after a measured stratigraphic section at the mouth of South Canyon (SW/4, Section 30, T3S, R3W).

The tuff of South Canyon was dated at 26.2 ± 1.0 m.y. using the K/Ar method on biotite. It is correlative with the upper "Potato Canyon Rhyolite" as used by Spradlin

(1974) in the Joyita Hills, but is not correlative with the type locality "Potato Canyon Rhyolite" as used by Deal (1973) in the San Mateo Mountains. The tuff of South Canyon occurs in the Lemitar Mountains (R.M. Chamberlin, oral communication, 1977), but the relationship to the upper tuffs of Simon (1973) in the Silver Hill area is unknown.

The tuff of South Canyon crops out discontinuously over most of the north and central parts of the study area. It is as much as 620 feet thick along South Canyon and averages 200 to 400 feet in thickness in the area west of Pound Ranch (Sections 5, 6, 7, 8, and 17, T4S, R2W). Monolithic breccias of tuff of South Canyon (indurated colluvium with red, fine-grained, clastic matrix) overlie most sections and indicate erosion; thus, the original thickness is not known. A thin, lighter colored zone occurs at the top of the measured section in South Canyon and may represent zonation near the original top of the unit, or weathering. Petrographic data from specimens collected along the measured stratigraphic section is presented in figure 14.

The unit can be divided on phenocryst content into a crystal-poor lower member and a moderately crystal-rich upper member. Alternatively, the unit may be divided into a basal, poorly welded zone, which often contains pumice with a "botryoidal" internal texture; an intermediate densely welded zone, which often contains lithophysal



sample number	color: fresh weathered pumice	total phen.	Phenocrysts					points counted	lithics(a)	pumice(a)
			sanid.	quartz	plag.(c)	bio.	opaq.			
SC-11	grysh-orng-pink(5YR7/2) grysh-orng-pink(5YR7/2)	11.9	5.7	5.7	tr	tr	tr	2859	3%	15-20%
SC-10	pale-red (5R6/2) pale-red (5R6/2) pumice- grysh-pink (5R8/2)	17.5	11.6	5.9	tr	tr	tr	3366	tr	30-35%
SC-9	grysh-red (5R4/2) pale-red (5R6/2) pumice- light-gry (N7)	20.8	14.6	6.2	1.0	tr	tr	3291	tr	25%
SC-8	pale-red (5R6/2) pale-red (5R6/2 pumice- light-gry (N7)	16.6	8.6	8.0	tr	tr	tr	3060	tr	25%
SC-7	mod-grysh-red (5R5/2) pale-red (5R6/2) pumice- light-gry(N7)	16.1	6.4	9.7	0	tr	tr	2417	1%	25%
SC-6	pale-grysh-red (5R5/2 pale-red (5R6/2)	12.8	6.7	6.1	0	tr	tr	2332	4%	10-12%
SC-5	pale-red (5R6/2) med-gry (N5)	5.8	2.7	3.1	0	tr	tr	3492	tr	10-12%
SC-4	pale-red (10R6/2) pale-red (5R6/2)	5.3	3.1	2.0	0	tr	tr	3275	3%	10%
SC-3B	grysh-red (5R4/2) pale-grysh-red (5R6/2)	8.7	4.2	4.5	0	tr	tr	1794	8%	(?)
SC-3	light-brnsh-gry (5YR6/1) mod-brnsh-gry (5YR5/1)	3.1	1.7	1.4	0	tr	tr	2630	2%	10% "b"
SC-2	drk-pnksh-gry (5YR7/1) light-brnsh-gry (5YR6/1)	2.7	1.3	1.4	0	tr	tr	2333	3%	10% "b"
SC-1	pale-red (5R6/2) grysh-red (10R4/2)	3.1	1.9	1.2	0	tr	tr	2358	5%	10-15%

(a) estimated from hand specimen and outcrop.

"b" botryoidal internal texture in pumice.

(c) mineral counted as plagioclase is totally altered but resembles altered plagioclase in other units within the study area.

Figure 14: Modal data, graphic stratigraphic column and a plot of relative phenocryst abundances for the tuff of South Canyon from the measured stratigraphic section in South Canyon (SW/4, Section 30, T3S, R3W).

cavities; and an upper moderately to densely welded, streaked, pumiceous zone. The increase in phenocryst content from an average of 4 per cent to 15 to 20 per cent occurs gradationally a few tens of feet above the lithophysal zone within the upper streaked interval. Crystal-poor pumice occur throughout the unit; crystal-rich pumice become common above the increase in crystal content. The unit was mapped undivided in this study.

The basal layers of the tuff of South Canyon are very crystal-poor, often contain several per cent lithic fragments, and vary in weathering characteristics. Pumice are common and are crystal-poor. This basal interval varies in thickness, weathers to small soft fragments, and often forms notches beneath the denser overlying intervals. However, the top of the basal interval often is fairly dense, contains prominent "botryoidal" pumice, and weathers to large joint-bounded blocks and ledges or cliffs. The basal interval is usually brownish-gray to white but may be pale-red. The "botryoidal" internal texture of pumice in this zone is compared with that found in the lower Lemitar Tuff in figure 15.

The lithophysal zone, which occurs sporadically at the top of the crystal-poor interval, weathers to resistant ledges and cliffs where it is present. It is darker in color and mottled in shades of grayish-red or pale-red. Open to partially filled lithophysal cavities, as much as 6 inches long, are present in some outcrops.

Figure 15: "Botryoidal texture" of pumice in lower, moderately welded zones of Lemitar Tuff (left) and tuff of South Canyon (right). This texture is also known in the A-L Peak Tuff (R. M. Chamberlin, oral communication, 1977). These multiple occurrences limit the usefulness of this feature as a correlation tool. These zones in the two units shown are readily distinguishable since tuff of South Canyon is very crystal poor (1 to 3 per cent) while the lower Lemitar Tuff has 10 to 15 per cent phenocrysts. In addition, the "botryoidal texture" is much better developed in the tuff of South Canyon.

Above the lithophysal zone, the unit takes on a streaked appearance from abundant light-gray pumice in a darker, pale-red or grayish-red matrix (Fig. 11). These pumice may be several inches long and constitute 30 per cent or more of the rock. Both crystal-poor and crystal-rich varieties of pumice are present above the increase in crystal content. This interval characteristically breaks angularly, weathers to joint-bounded blocks and forms ledges or irregular, blocky cliffs. Talus from this zone and the underlying lithophysal zone often obscures the base of the tuff of South Canyon and the underlying basaltic andesites.

A mineralogic break is apparent in the streaked zone at about the 400 foot level of the measured section (Fig. 14). Above this level sanidine is considerably more abundant than quartz, and there are more phenocrysts. These mineralogic variations may be real or could be the result of sampling bias in selecting hand-specimens and areas within hand-specimens for thin sectioning. Striking similarities in appearance of the rocks above and below this apparent break strongly support the conclusion that the streaked zone is a single unit.

Despite its obvious zonation with respect to phenocryst content and textural characteristics, the tuff of South Canyon is very consistent in mineral proportions and species. The mineral suite characteristically consists of approximately equal amounts of quartz and sanidine and a trace of coppery

Figure 16: Potash feldspar phenocryst in tuff of South Canyon from the measured section in South Canyon. Light areas (s) are sanidine (anorthoclase) which stained lightly for potassium with sodium cobaltinitrite. The dark areas (a) are probably albite exolution lamellae which have been altered to clay minerals. Alteration has continued into some of the surrounding sanidine. These bands of altered material stained much more strongly for potassium than did the sanidine. Crossed nichols, 31.25x.

Figure 17: Quartz phenocrysts with rhombic outlines in the upper streaked zone of the tuff of South Canyon from the measured stratigraphic section in South Canyon. This shape is believed to result from sectioning a dipyramidal crystal along or at a small angle to the "c" crystallographic axis. Crossed nichols, 31.25x.

biotite. The quartz is usually clear; sanidine may be either clear or white and cloudy and often shows blue chatoyancy. Near the top of the unit sanidine is as much as twice as abundant as quartz. No unaltered plagioclase phenocrysts were seen in thin section; however, trace amounts of badly altered grains that resemble altered plagioclase phenocrysts in the Lemitar Tuff are seen in the upper levels of the streaked interval. These never exceed 1.0 per cent in abundance.

Sanidine occurs predominately as subhedral to euhedral, tabular or equant crystals averaging 1.0 mm in longest dimension or as glomerophric clumps as much as 3 mm across. Carlsbad twinning is common and much of the sanidine shows lamellar exolution of albite in thin section. This exolution is visible in hand specimen in white, cloudy grains. The exolved lamellae of albite (?) stained deeply with sodium cobaltinitrite. This staining probably indicates that the albite has been altered as has most of the plagioclase in the Water Canyon area. One of these sanidine phenocrysts with altered exolution lamellae is shown in figure 16.

Quartz occurs as subhedral to euhedral crystals averaging 1.0 mm in diameter and often shows internal conchoidal fracturing. Many of the euhedral phenocrysts have four-sided cross sections. An example of one of these is shown in figure 17. This shape is believed to result from sectioning a dipyramidal quartz crystal at a small angle to the "c" crystallographic axis.

Plagioclase may be present in trace amounts in the upper parts of the streaked zone. Here, badly altered grains which stain strongly with sodium cobaltinitrite are present. The appearance of these altered grains and their strong affinity for potassium stain suggest they are plagioclase altered in the same way as that in the upper Lemitar Tuff. No more than 1.0 per cent of these grains were seen in any section and most sections had none. Biotite occurs at all levels in trace amounts as small, euhedral, thin plates.

Lithic fragments are common, both as scattered individuals and in pods up to several feet thick; some pods may contain 50 per cent or more rock fragments. Lithic fragments are more common in the lower crystal-poor part of the tuff of South Canyon and decrease in abundance somewhat in the upper intervals. One of the lithic-rich pods from Bear Canyon, west of Pound Ranch (NE/4, Section 17, T4S, R2W), is shown in figure 18. Gray-to-red aphanitic silicic rock fragments, andesite, and crystal-poor to crystal-rich tuff (?) fragments are common lithologies. Fragments of both lower and upper Lemitar Tuff are frequently recognized.

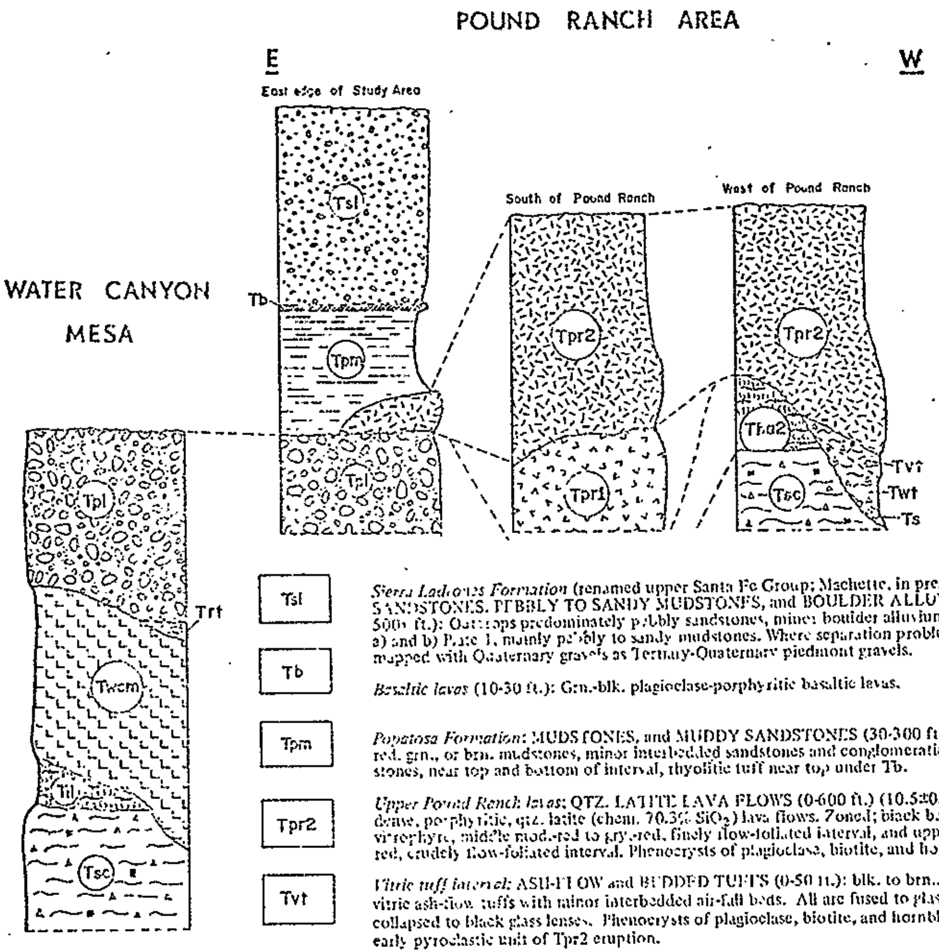
Intermediate to Silicic Lavas

Similar sequences of rocks, younger than tuff of South Canyon, crop out in two separate parts of the study area, the Water Canyon Mesa and Pound Ranch areas. These

Figure 18: Outlined area is a lithic-rich pod in the tuff of South Canyon from south of Pound Ranch. Lithic fragments make up as much as 60 per cent of the rock and in some areas may be as much as 12 inches in diameter. Lithic fragments in these zones are primarily basaltic andesites and Lemitar Tuff. Hammer is approximately 12 inches long.

outcrop areas are separated by a two mile strip with no correlative exposures. In both areas, intermediate or basic lavas overlie tuff of South Canyon. A later period of erosion has cut through these lavas and underlying units to the top of the Lemitar Tuff. Subsequently, silicic lavas containing plagioclase, biotite, and hornblende phenocrysts flowed over these erosion surfaces. Figure 19 compares the stratigraphic sequences of these two areas.

Despite the similarities of these two stratigraphic sequences, several factors suggest that they are of different ages: 1) the biotite-hornblende-bearing, upper Pound Ranch lava has been dated at 10.4 m.y. (Appendix B), whereas the similar lava from Water Canyon Mesa has been dated at 20.0 m.y. and underlies lower Popatosa laharic breccias believed to be early Miocene in age; 2) a sequence of local ash-flow tuffs, which underly the upper Pound Ranch lavas, are absent on Water Canyon Mesa; and 3) the lower "intermediate" lavas from the Pound Ranch area are basaltic andesites or basalts (chemical analysis of one sample yielded a silica content of 49.5 per cent (Appendix B), whereas the lower lavas from Water Canyon Mesa are more silicic and have scattered quartz phenocrysts and potassium feldspar overgrowths on plagioclase phenocrysts. Due to the above differences, the two sequences of rocks are separated and considered to be of two different ages.



Tsl	*Sierra Ladrones Formation* (renamed upper Santa Fe Group; Machette, in press): CONG. SANDSTONES, PEBBLY TO SANDY MUDSTONES, and BOULDER ALLUVIUM (300-500+ ft.): Outcrops predominately pebbly sandstones, minor boulder alluvium; drill holes a) and b) Plate 1, mainly pebbly to sandy mudstones. Where separation problematical, mapped with Quaternary gravels as Tertiary-Quaternary piedmont gravels.
Tb	*Basaltic lavas* (10-30 ft.): Grn.-blk. plagioclase-porphyritic basaltic lavas.
Tpm	*Popatosa Formation*: MUDSTONES, and MUDDY SANDSTONES (30-300 ft.): mainly red, grn., or brn. mudstones, minor interbedded sandstones and conglomeratic sandstones, near top and bottom of interval, rhyolitic tuff near top under Tb.
Tpr2	*Upper Pound Ranch lavas*: QTZ. LATITE LAVA FLOWS (0-600 ft.) (10.5±0.4 m.y.): dense, porphyritic, qtz. latite (chem. 70.3% SiO_2) lava flows. Zoned; black basal vitrophyre, middle mod.-red to gry.-red, finely flow-foliated interval, and upper pale-red, crudely flow-foliated interval. Phenocrysts of plagioclase, biotite, and hornblende.
Tvt	*Vitric tuff interval*: ASH-FLOW and BEDDED TUFFS (0-50 ft.): blk. to brn., qtz. latitic(?), vitric ash-flow tuffs with minor interbedded air-fall beds. All are fused to glass; pumice are collapsed to black glass lenses. Phenocrysts of plagioclase, biotite, and hornblende. Probable early pyroclastic unit of Tpr2 eruption.
Tpr1	*Lower Pound Ranch lavas*; RHYOLITIC LAVAS (0-400+ ft.) (11.8±0.5 m.y.): dense porphyritic, pale-red-brn., rhyolitic lavas. Phenocrysts of plagioclase, qtz., potash feldspar, biotite, and hornblende; crudely flow-foliated.
Twt	*Lower tuff interval*; ASH-FLOW and BEDDED TUFFS (0-300+ ft.): poorly welded, pumiceous, lithic-rich, rhyolitic ash-flow tuffs; minor interbedded air-fall beds with similar characteristics. Possible early deposit of Tpr1 eruption.
Ts	LAHARIC BRECCIAS, CONGLOMERATES, and SANDSTONES (0-150ft.): local deposits in paleovalleys; lower intervals are Popatosa-like laharic breccias. Conglomerates and sandstones dominate middle intervals and tuffaceous beds occur near top. Clasts are of underlying volcanic units.
Tpl	*Popatosa Formation*; LAHARIC BRECCIAS (0-150 ft.): dense red, well indurated laharic breccias with very minor interbedded pebble conglomerates. Basal sedimentary unit in most areas.
Trt	ASH-FLOW and BEDDED TUFFS (0-50 ft.): local thin, variable, poorly welded, rhyolitic ash-flow and bedded tuffs; buff to red. Probably deposited during emplacement of domes in Water Canyon area.
Twcm	*Water Canyon Mesa lavas*: QTZ. LATITE(?) LAVA FLOWS (0-600+ ft.): dense, mod.-gry.-pk. to gry.-red, porphyritic, rhyolitic or qtz. latitic lavas. Finely to crudely flow-foliated. Phenocrysts of plagioclase, biotite, hornblende, and magnetite.
Tba2	BASALTIC ANDESITE to BASALTIC LAVAS (0-300 ft.): some La Jara Peak-like, gry., dense basaltic andesites with abun., small, red, hematized ferromag. phenocrysts. Also minor grn.-blk., olivine-rich, plagioclase-porphyritic basalts with olivine clots to 2cm.
Til	*Intermediate lavas*: ANDESITIC TO LATITIC LAVAS (0-600 ft.): brn.-gry. to gry.-red mod. porphyritic lavas. Phenocrysts of plagioclase, biotite, pyroxenes, and quartz. K-spar(?) overgrowths common. Plagioclase commonly altered to K-spar, or potassium-rich clays, and occasionally replaced with calcite.
Tsc	*Tuff of South Canyon*: RHYOLITIC ASH-FLOW TUFFS: see figure 5.

Figure 19: Miocene and Pliocene stratigraphic correlation diagram for the southeastern Magdalena Mountains.

Water Canyon Mesa Area.

intermediate lavas

At scattered locations on Water Canyon Mesa, intermediate composition lavas crop out in the stratigraphic interval above tuff of South Canyon. These lavas average 100 to 200 feet in thickness, but may be as much as 600 feet thick along the mountain front north of South Canyon (NE/4, Section 25, T3S, R3W). When a base is exposed, the lavas overly tuff of South Canyon. They may be overlain by the Water Canyon Mesa lava, the lower Popatosa laharic breccias, or local (?), thin ash-flow tuffs.

These intermediate lavas normally crop out as rubbly slopes covered with small platey to angular colluvium. Near the mouth of Water Canyon (SE/4, Section 23, T3S, R3W), cliffs as much as 40 feet high are seen where the rocks are altered. The rocks vary in color from brownish-gray to grayish-red and usually weather to the same colors. These lavas are moderately porphyritic containing 5 to 15 per cent phenocrysts of plagioclase, quartz, biotite, and pyroxenes. The amount and size of phenocrysts appears to increase upward in the section.

Plagioclase is the dominant phenocryst in all of these rocks but in most specimens alteration has obliterated the albite twinning. In addition, most plagioclase grains have a thin potassium feldspar overgrowth (?). These overgrowths postdate fracturing of the phenocrysts and must have occurred very late in the crystallization history of these rocks. Plagioclase grains from these rocks in various stages of alteration are shown in figures 20 through 23. In some rocks, plagioclase is fairly fresh and shows only incipient alteration (Fig. 20), or occasionally almost complete alteration (Fig. 21). In other areas almost all the plagioclase has been badly altered and relict albite twinning is rarely seen. A typical grain from one of these badly altered rocks is shown in figure 22. In one area in Water Canyon (SE/4, Section 23), altered plagioclase has been replaced by calcite (Fig. 23). On the same grain the potassium feldspar overgrowths (?) are fresh.

Scattered quartz phenocrysts (?) are found in these lavas throughout the outcrop area. The quartz occurs as rounded grains as much as 5 mm across and average 1.0 mm in diameter. Most quartz grains have a brown or white glassy rim. A rimmed quartz grain, as well as an altered biotite phenocryst, is shown in figure 22.

Biotite and pyroxene (?) phenocrysts are scarce and highly altered. The biotite shows parallel extinction in some grains but no pyroxene fresh enough for optical tests was seen. Some of the postulated pyroxene may be hornblende.

The groundmass in some sections appears to be made up of flow-aligned plagioclase microlites (Fig. 20). On close examination many of the smaller microlites show no twinning and were stained strongly for potassium with sodium cobaltinitrite. In other rocks the groundmass is trachytic (Fig. 23).

Figure 20: Partially altered plagioclase crystal in the intermediate lavas on Water Canyon Mesa. Remnants of twin lamellae extend to the white line although most of the plagioclase along the edges of the crystal has been destroyed. Crossed nichols, 31.25x.

Figure 21: Altered plagioclase in the intermediate lavas of Water Canyon Mesa. A small remnant core of plagioclase is surrounded by a thick altered zone. The thinner light-colored rim surrounding the grain may be, or have been, a potassium feldspar overgrowth. This rim was formed after the crystal was broken and embayed. Crossed nichols, 31.25x.

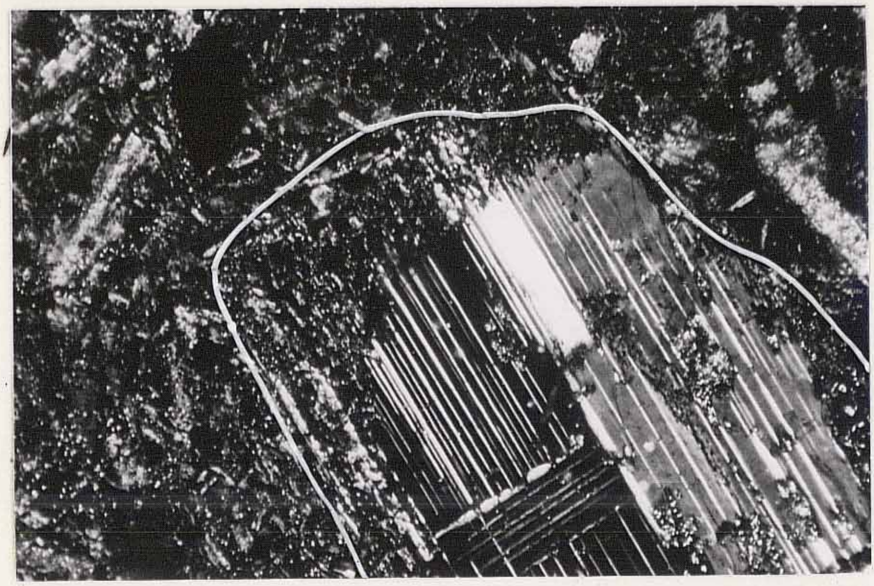
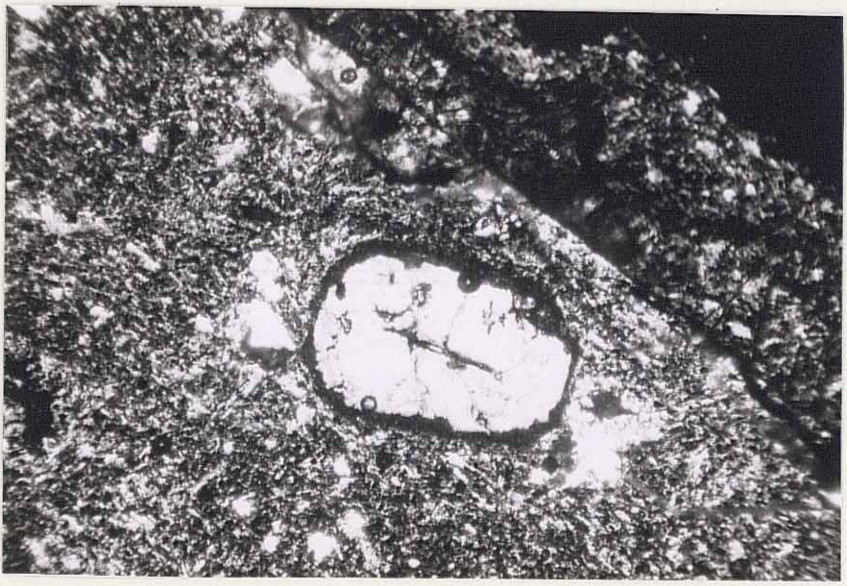


Figure 22: Plagioclase phenocrysts (light-colored) and quartz phenocryst (dark spot in upper left) in the intermediate lavas on Water Canyon Mesa. Many of the plagioclase grains appear optically continuous and resemble sanidine. However, they have wavy extinction, in part, and similar grains are found in the Water Canyon Mesa lava which does not contain sanidine phenocrysts. The quartz phenocryst is surrounded by a layer of tiny crystals that may be a devitrified glass rim. Crossed nichols, 31.25x.

Figure 23: Plagioclase phenocryst in intermediate lavas from Water Canyon (Section 23). The plagioclase has been completely replaced, except for the rim, by monocrystaline calcite (light). The outer rim (dark) is optically continuous and appears unaltered. This rim is probably potassium feldspar which was not affected by the fluids which altered and replaced the plagioclase grain. Crossed nichols, 31.25x.


Q



erosional unconformity

A period of erosion followed deposition of the intermediate lavas on Water Canyon Mesa. The stratigraphic interval affected by this erosion is well exposed along the north side of South Canyon and it is here that the erosion surface can best be seen. Over the eastern part of the exposure only the intermediate composition lavas and upper parts of the tuff of South Canyon were removed. Farther west, however, near the northeast corner of Buck Peak, all of the tuff of South Canyon and most of the underlying basaltic andesites were removed. Here the erosion apparently formed a valley of considerable depth since the overlying Water Canyon Mesa lavas are much thicker in this area. This valley is thought to have trended north-south through the area where a high ridge of Water Canyon Mesa lava now is found (W/2, Sections 25 and 36, T3S, R3W).

At several locations along both sides of South Canyon, a few feet to a few tens of feet of indurated colluvium is found on this erosion surface under the overlying Water Canyon Mesa lavas. These deposits are made up of poorly sorted, angular clasts, as much as several feet in diameter, surrounded by a dense, reddish-brown, fine-grained matrix. Some of the deposits are mud supported; in others the clasts are tightly packed. Clast lithologies include basaltic andesites, tuff of South Canyon, and Lemitar Tuff.

Thin layers of sand were seen interbedded with these breccias south of South Canyon (SW/4, NW/4, Section 1, T4S, R3W, unsurveyed).

Water Canyon Mesa Lavas

A thick lava flow, containing plagioclase, biotite, and hornblende as major mineral phases, occurs on Water Canyon Mesa (Sections 25, 35, and 36, T3S, R3W). These lavas lie on the previously described erosion surface and are overlain by laharic breccias believed to be lower Popotosa, or a younger poorly exposed interval of alluvium of unknown age (Sections 26 and 35). In a few areas, lithic-rich basal zones in the lava contain clasts of tuff of South Canyon, Lemitar Tuff, and basaltic andesites. Also present, locally, is a basal, black vitrophyre as much as 25 feet thick. The lava flow is as much as 500 feet thick on the north side of South Canyon but thins rapidly in all directions. Steep contacts on the south side of South Canyon show the presence of significant topographic relief at the time of eruption.

The unit weathers to large, joint-bounded blocks and forms steep, rugged slopes or cliffs where well-exposed. The rocks are moderate-grayish-pink to grayish-red in color when fresh and weather to lighter shades of these colors. The rock is coarsely porphyritic in hand specimen containing from 15 to 40 per cent phenocrysts of plagioclase, biotite, and hornblende. All of the hornblende and much of the biotite and plagioclase is altered where the rock is devitrified. In the vitrophyre, however, all minerals are unusually fresh.

Plagioclase dominates the mineral suite, making up 80 per cent or more of the phenocrysts. In fresh specimens, plagioclase occurs as complex, often broken, equant crystals that average 1 to 2 mm in length, but may be as much as 7 mm long. The plagioclase shows strong normal zoning and has oscillatory zonation on a smaller scale. Compositions were observed to vary from An_{33} to An_{52} (andesine) (Rittman zone method, 12 grains). In most specimens, however, the plagioclase is severely altered and many of the grains are plucked out during thin section preparation. In these thin sections, the remaining plagioclase grains are either skeletal remnants or grains with "feathery extinction" patterns. These usually show no remnant albite twinning and stain strongly for potassium. No sanidine is found in the fresher specimens, however, and these grains are probably the result of alteration and potassium enrichment. This plagioclase alteration resembles that seen in the underlying, intermediate-composition lavas and the Lemitar Tuff.

Thin plates of light-green, pleochroic biotite occur in amounts as great as 2 per cent and average 1.0 mm in diameter. In many specimens, the biotite is partially to completely altered to iron oxides. Hornblende occurs as laths as much as 4.0 mm in length and in amounts as great as 1.0 per cent. It is completely altered to iron oxides in most specimens and is fresh only in the vitrophyre. Magnetite occurs in trace amounts as rounded or euhedral grains as much as 1.0 mm in diameter. Rounded and embayed quartz phenocrysts as much as 3.0 mm in diameter also occur in trace amounts in some specimens.

Pound Ranch Area.

basalt and basaltic andesite lavas

In the area west of Pound Ranch, scattered outcrops of basaltic andesite and/or basalt flows occur above the tuff of South Canyon. These mafic flows post-date erosion of the tuff of South Canyon and are cut by a later period of erosion. The closest constraint on the minimum age of these lavas is the overlying 10 m.y. old Pound Ranch lavas. The mafic interval is as thick as 200 feet at several places and a much greater thickness may be present immediately west of Pound Ranch (SE/4, Section 4, T4S, R2W). The top of the unit is everywhere eroded and thicknesses change abruptly.

These lavas closely resemble the interval of basaltic andesites below tuff of South Canyon. Some of the rocks have reddish altered pyroxene phenocrysts and these could not be distinguished from the similar rocks in the lower interval of basaltic andesites. These aphantic rocks have a pilotaxitic groundmass and contain a few per cent orthopyroxene plus clinopyroxenes. In some of these rocks, scattered olivine phenocrysts are also present.

In several areas, the rocks also contained plagioclase and abundant olivine phenocrysts and at one location, in Bear Canyon west of Pound Ranch (NW/4, Sec. 9, T4S, R2W), olivine clots as much as 2.0 cm in diameter are found. Chemical analysis of this olivine-rich rock revealed a SiO_2 content of 49.5 per cent (appendix B). This same rock in thin section resembled the plagioclase and olivine bearing basaltic andesites from the interval below tuff of South Canyon but contained more pyroxene and olivine. These rocks which contain olivine clots are coarsely porphyritic and may contain as much as 25 per cent phenocrysts of plagioclase, olivine and pyroxenes; their texture is seriate.

Plagioclase dominates both the phenocrysts and the groundmass in these olivine rich basalts. As phenocrysts, it occurs as blocky or tabular, anhedral to subhedral crystals that sometimes show pronounced reverse zonation. Normal zonation was also observed. The zonation is sharp in some grains and suggests two generations of plagioclase growth. "Sieve structure" resorption features are common; the holes in the plagioclase often contain small pyroxene grains. Plagioclase compositions vary from An_{49} to An_{70} (labradorite) (Rittmann zone method, 6 grains).

Olivine occurs as rounded grains as much as 3 mm in diameter and in amounts as great as 3 per cent. Most such grains show alteration rims of iddingsite (?). Most of the pyroxene phenocrysts are badly altered in thin section and were not specifically identified.

The groundmass is composed of a framework of plagioclase microlites which make up about 50 per cent of the fine-grained portions of the rock. Pyroxene microlites and euhedral to rounded magnetite grains make up the remainder.

erosional unconformity

A period of faulting and erosion produced a surface with significant topographic relief by the time the Pound Ranch lavas were erupted. This erosion surface is easily seen in several areas west of Pound Ranch where the basaltic andesite interval above tuff of South Canyon abruptly thins or is truncated. In most areas, only the mafic lavas are eroded; however, farther west (NW/4, Section 18, T4S, R2W), erosion cut entirely through the tuff of South Canyon and the underlying basaltic andesites to the top of the Lemitar Tuff. The combined thickness of these eroded units is 800 to 1000 feet at this location. Attitudes of the tuffs that underly the Pound Ranch lavas suggest dips were in the same direction as today but 10 to 15 degrees gentler at the time of Pound Ranch lava emplacement. The erosion surface cited above is perpendicular to strike; therefore, since we go down section as much as 1000 feet traveling in a direction nearly parallel to strike (see Plate 1) at least several hundred feet of topographic relief are indicated on the pre-Pound Ranch lava topographic surface.

pre-Pound Ranch lava sediments

A 50- to 100-foot-thick sequence of variable, conglomeratic sedimentary rocks overlies the upper Lemitar Tuff on the erosion surface described above in the extreme south-central part of the study area (SW/4, NE/4, Section 18, T4S, R2W). The lower sedimentary layers are coarse, heterolithic breccias cemented with a dense, reddish-brown, siliceous material. The clasts are mainly Lemitar Tuff, tuff of South Canyon and basalts to basaltic andesites. Upward in the sequence, sandy, conglomeratic beds predominate and toward the top of the sedimentary interval tuffaceous beds are present. The contact with the overlying, pre-lava ash-flow tuffs is concealed by colluvium. The lower beds resemble lower Popotosa laharic breccias, but the stratigraphic limits do not allow correlation.

Sedimentary rocks also crop out approximately one mile northeast of these last sedimentary outcrops (SW/4, SE/4, Section 8, T4S, R2W). These latter rocks are locally sandy, well-indurated, red or reddish-brown, heterolithic conglomerates. The stratigraphic position of these rocks is not clearly exposed and only a few tens of feet of outcrops are present. These rocks lie above tuff of South Canyon and at least part of the overlying basaltic andesites and appear to underly the pre-Pound-Ranch-lava tuffs. In the easternmost outcrop at this location, the sedimentary rocks lie in an arroyo bottom south of a ridge of tuff of

South Canyon. This reversed stratigraphic relationship is thought to be due to pre-sediment, erosional topography but could be the result of undiscovered faulting.

The two areas of sedimentary rocks just described both underly upper Pound Ranch lavas and appear to be deposited on the same erosion surface; however, the stratigraphic evidence does not permit conclusive correlation of these two outcrops.

pre-Pound Ranch lava ash-flow tuffs

Overlying the erosional unconformity and the scattered outcrops of sedimentary rocks in the Pound Ranch area are local ash-flow tuffs. Two petrographically and texturally distinctive intervals were separated in this study. They are a lower, poorly welded, light-colored interval, and an upper, dark, densely welded, vitric interval. The contact between these two intervals is sharp or sharply gradational over a few feet. Both tuff intervals occur in scattered outcrops in an area of three square miles south of Sixmile Canyon (Sections 7, 8, 17, and 18, T4S, R2W); the vitric upper interval is found alone to the east near Pound Ranch (Sections 9 and 10, T4S, R2W). Thicknesses often vary abruptly and in some cases the tuffs are overlain at high angles by the overlying upper Pound Ranch lavas (Plate 1, NW/4, Section 8). These tuffs are thought to be pre-lava pyroclastic deposits; therefore, it seems probable that this angular relationship was caused by erosion of the surface over which the lava flowed. In one area south of Sixmile Canyon (N/2, Section 18), the lower light-colored tuffs thicken against major faults (Fig. 27). This is interpreted to indicate pre-tuff movement on these faults; subsequent offset is also evident. The total thickness of the two units is normally less than 50 feet but thicker sections are found locally. The maximum thickness known is 300 feet in N/2, Section 18; the section there is entirely the lower light-colored tuff.

<u>lower tuff interval</u>. The lower tuff interval is made up of poorly welded, ash-flow tuffs but may contain local bedded air-fall tuffs and sediment intervals near the base. The rock is normally buff to light-brown in color and usually contains several per cent reddish-brown or dark-brown lithic fragments. In thin section, these lithic fragments can be seen to be mainly basaltic andesites or reddish glass, sometimes with preserved shard structures. The rocks weather to small, platey fragments but form steep slopes and may stand as prominent, rounded light-colored cliffs.

In hand specimen, lithic fragments and pumice are numerous and prominent, but phenocrysts appear scarce. Thin sections reveal, however, as many as 20 per cent phenocrysts of plagioclase, sanidine, quartz, biotite, and hornblende. The mineral species and relative abundances closely match those of the lower Pound Ranch lava. Based on this mineralogical data, it is probable that the lower tuffs and lower Pound Ranch lavas are related units but no other supportive data is available.

Plagioclase, the most abundant mineral, occurs as broken, tabular or equant crystal fragments averaging 0.4 mm in longest dimension. Plagioclase averages one-half to two-thirds of the phenocryst content and may reach 12 per cent of the rock. The plagioclase is strongly zoned (normal) and most is fresh; although some grains show "sieve structure" resorption. Plagioclase compositions vary from An_{27} to An_{53} (andesine) (Rittmann zone method, 10 grains).

Sanidine occurs as angular to slightly rounded, equant crystal fragments and makes up as much as 3 per cent of the rock. The sanidine phenocrysts are usually untwinned and average 0.4 mm in longest dimension. Quartz is present in amounts as great as 2 per cent as large rounded grains as much as 1.5 mm in diameter or as small, broken fragments averaging 0.3 mm in length. Light-green, pleochroic biotite may make up as much as 0.5 per cent of the rock and trace amounts of hornblende and magnetite are present.

<u>upper vitric tuff interval</u>. An interval of tuffs made up of several thin ash-flows with thin, interbedded air-fall layers overlies the lower light-colored tuff interval in most areas. This vitric-tuff interval, as much as 50 feet thick, weathers to angular blocks and forms ledges and small cliffs in outcrop. Both the ash-flow tuffs and interbedded air-fall tuffs are usually fused to a black

or dusky-red glass and pumice have collapsed to black glass lenses. The black vitrophyre of the upper Pound Ranch lavas normally overlies the vitric tuffs and the occurrence of these two black, glassy units together obscures the contact. Clasts of the underlying vitric tuffs are often incorporated into the basal layers of the lava vitrophyre.

These vitric tuffs may have been hot enough to fuse themselves and the interbedded air-fall beds as the individual units were emplaced. Alternatively, the ash-flows and air-fall tuffs both may have been fused by contact with large amounts of hot, upper Pound Ranch lavas. A photograph showing one of the fused air-fall tuff beds in an outcrop of ash-flow units is shown in figure 24.

The vitric tuffs are porphyritic containing 10 to 20 per cent phenocrysts of plagioclase, biotite, and hornblende. Small rounded quartz phenocrysts and rounded magnetite grains occur in trace amounts. Mineralogically these tuffs closely resemble the upper Pound Ranch lavas and the tuffs are always closely associated with the lavas in outcrop. It seems probable, therefore, that the tuffs are a pyroclastic unit associated with eruption of the upper Pound Ranch lava.

Plagioclase is the dominant mineral and normally comprises 80 per cent of the phenocryst content. It occurs as broken, equant to tabular, subhedral crystals as much as 3 mm in length, but averaging 0.8 mm in longest dimension. Most samples are fresh and many show "sieve structure" resorption features. The plagioclase shows strong normal zoning and

Figure 24: Photograph of an interval of the vitric tuff near Pound Ranch (SE/4, Section 4, T4S, R2W). These tuffs are normally 10 to 40 feet thick and consist of a sequence of ash-flow tuffs and bedded tuffs, all of which have been fused to glass. Pumice have collapsed to lenses of black glass. In this photograph, the lower and upper darker beds (af) are ash-flow tuffs. The center lighter-colored bands (b) are fused bedded tuffs. Brown to reddish-brown lithic fragments (L), which resemble the overlying lavas, are also glassy. Black numerals on scale are in tenths of feet.

some oscillatory zonation on a smaller scale. Plagioclase compositions vary from An_{33} to An_{57} (andesine to labradorite) (Rittmann zone method, 15 grains). Light-green or reddish-brown, strongly pleochroic biotite occurs as hexagonal plates that average 0.6 mm in diameter. Biotite may reach 1.0 per cent in abundance. Pleochroic hornblende occurs in amounts as great as 1.0 per cent as laths as much as 2.0 mm in length and 0.5 mm across.

lower Pound Ranch Lavas

A quartz-rich lava flow crops out in two relatively small areas south of Pound Ranch (S/2, Section 3, and N/2, Section 10, T4S, R2W and NW/4, Section 13, T4S, R2W). No basal contact is known for this flow; however, it is the age equivalent of upper Popatosa Formation. These lavas have no exposed contact with the tuff intervals that are normally present under the upper Pound Ranch lavas; however, mineralogical similarities suggest these lavas may be related to the lower, poorly welded tuff interval. Lavas similar in lithology and age to the Pound Ranch lavas are interbedded with the Popatosa Formation in the Socorro Peak area (Chamberlin, 1978).

A minimum of 400 feet of lava is indicated by topographic expression, but the dip of foliation planes is steep and the maximum thickness may be much greater. These lavas stand topographically higher than some of the surrounding upper Pound Ranch lavas. At the southern outcrop area, the upper lavas dip away from the contact with these lower lavas, in some cases in opposition to regional dip. These factors suggest the lower lavas stood as a topographic high (probably as a dome or domes) at the time of upper Pound Ranch lava emplacement.

The lower Pound Ranch lava is coarsely porphyritic and contains phenocrysts of plagioclase, sanidine, quartz, biotite and hornblende. A chemical analysis indicates 73.0 per cent SiO_2 (Appendix C); the rock is a rhyolite chemically but a quartz latite mineralogically. A sample collected from NE/4, NW/4, Section 15, T4S, R2W gave a date of 11.8 ± 0.5 m.y. using the K/Ar method on biotite (Appendix B).

The rock is typically pale-reddish-brown, dense and stony, and weathers to rounded boulders or ledges in outcrop. A vitric phase is present at both outcrop areas and may be various shades of gray, yellow or light brown.

In thin section, the rock contains about 10 per cent quartz and plagioclase and one to a few per cent sanidine and biotite. Trace amounts of hornblende are also present. Quartz occurs as anhedral, rounded and often embayed grains, as much as 3 mm in diameter, but averaging 1.0 mm in size. Internal fracturing, in some cases closely spaced, regular, and resembling cleavage, is prevalent in the quartz. Plagioclase occurs both as single, simple crystals and as large glomerophyric groups. The plagioclase varies in size from 0.5 mm to 4.0 mm and averages 1.5 mm in longest dimension.

Plagioclase compositions vary from An_{24} to An_{43} (oligoclase to andesine) (Rittmann zone method, 10 grains). The plagioclase has strong oscillatory zoning but overall normal zonation is characteristic.

Sanidine is found as subhedral to anhedral untwinned crystals averaging 1.5 mm in longest dimension. Some of the sanidine surrounds plagioclase crystals. Most sanidine is broken in thin section; however, euhedral, often carlsbad twinned, tabular sanidine crystals as long as 2 cm weather out of some outcrops. Light-green, pleochroic biotite, as blocky or thin plates, makes up as much as 2 per cent of the rock and average 0.3 mm in diameter. Trace amounts of magnetite as rounded grains and hornblende as elongate, euhedral laths also occur.

The groundmass of the non-vitric rocks has devitrified to spherulites of radiating quartz and potassium feldspar. These spherulites average 5 mm in diameter and, in some areas, have partially recrystallized in irregular patches to a mosaic texture.

upper Pound Ranch Lavas

An extensive, porphyritic lava flow containing phenocrysts of plagioclase, biotite, and hornblende crops out over a large part of the eastern study area (Plate 1). Thick, relatively continuous outcrops are found in a two-mile-wide strip trending south from Pound Ranch (Sections 3, 4, 9, 10, 16, and 17, T4S, R2W). Discontinuous scattered outcrops occur to the west of this strip (Sections 5, 7, 8, 13, and 18, T4S, R2W), and one small, but stratigraphically important, outcrop is found two miles southeast of Pound Ranch (Section 12, T4S, R2W).

The lava unconformably overlies all older units above Lemitar Tuff. No rock units overlie the lava except at the eastern isolated outcrop (Section 12). Here, a few tens of feet of Popotosa mudstones and a thin basalt flow overlie these lavas.

In the eastern part of the exposure area, where outcrops are fairly continuous, at least 600 feet of upper Pound Ranch lava is exposed (NE/4, Section 16). The true maximum thickness may be much greater, but in most areas 400 feet, or less, of the lavas are found. The unit pinches out to the north and west and is downfaulted and covered to the east. These same lavas are exposed for at least another mile south of the study area but relationships there are not known. Original thickness of the unit appears to have been partially controlled by pre-existing topography.

A probable vent is located about one mile southwest of Pound Ranch (NW/4, Section 10). It is defined by a linear zone of vertical foliation away from which foliation attitudes flatten in both directions. A cross-section-like exposure of this vent zone is found on the northwest slope of the prominent, north-trending ridge in Section 10. This vent location is supported by the rough convergence of flow directions taken on tension cracks and flow fluting within

1.5 to 2.0 miles of the vent. Measurements taken farther away, particularly to the west, tend to be erratic in direction.

A sample collected from 2 miles south of Pound Ranch (NW/4, Section 15) gave a date of 10.5 ± 0.4 m.y. using the K/Ar method on biotite; chemical analysis of the same sample yielded 72.3 per cent SiO_2 (Appendix C). A rock with plagioclase, biotite and hornblende, but no quartz or potassium feldspar is an andesite in the terminology of Travis, 1955. However, the high silica content, viscous flow structures, and light color of these rocks indicates that they are rhyolites or quartz latites.

The flow is zoned texturally but not mineralogically. In a complete exposure, a black, basal vitrophyre, a few feet to 100 feet thick, is overlain by a thick section of reddish-brown lava. This lava is finely flow-foliated at the base (scale of a few mm) and gradually becomes more massive upward. The foliated lower lava closely resembles a flow-banded, ash-flow tuff. Within this lower interval, foliation attitudes are consistent and roughly conformable with regional attitudes. Higher in the unit, the flow-banding becomes erratic and attitudes are unrelated to regional dips. The lower, finely flow-foliated interval is absent in areas more distant from the vent. The gradation in textural features and the upward increase in phenocryst content from 10 to 25 per cent suggest the lava was initially hotter and cooled during the eruption. Changes in volatile content may have also affected the change in fluidity. A photograph showing a complete section of upper Pound Ranch lavas and part of the underlying, vitric tuff interval is shown in figure 25.

The lower parts of the upper Pound Ranch lava are normally moderate-red to grayish-red in color and darker than the upper intervals of the flow which are pale-red when fresh. Both intervals weather to lighter shades and pick up brownish or grayish color tints. Manganese staining is common on joints and weathering surfaces. In outcrop, the lower lavas form blocky ledges with a slabby surface and the upper intervals weather to slightly more rounded blocks and ledges. Both intervals may form cliffs on steep slopes.

In thin section, plagioclase is the dominant mineral and averages 70 to 90 per cent of the phenocrysts. It occurs as broken, tabular to equant, single crystals or in glomerophyric aggregates. The plagioclase is strongly zoned and "sieve structure" resorption features are common in some sections. Compositions vary from An_{32} to An_{55} (oligoclase to labradorite) and much of this range can be seen within a single crystal (Rittmann zone method, 20 grains).

Biotite, as pleochroic light-green or reddish-brown thin plates, averaging 0.7 mm in diameter, makes up as much as 2.0 per cent of the rock. Pleochroic, euhedral to subhedral hornblende phenocrysts average 1.0 mm in

Figure 25: Outcrop of upper Pound Ranch lavas and the underlying vitric tuff interval. The upper dense parts of the lava flow (U) at the top of the hill are crudely flow-foliated. The lower cliffy interval (L) is the finely laminated basal lava. A thin black vitrophyre (v) usually underlies the lavas and overlies the vitric tuff interval (vt). The hill is about 320 feet high.

cross section and may be as long as 4 mm. The hornblende, about as abundant as biotite, make up as much as 1.5 per cent of the rock. Both biotite and hornblende are usually partially altered to magnetite.

Popotosa Formation

The Popotosa Formation is the name given to the lower Santa Fe Group in the Socorro-Magdalena area (Denny, 1940). These sedimentary rocks are diverse in lithology; the formation contains mudstones, fanglomerates, and laharic breccias (Bruning, 1973). In this study area, the Popotosa Formation consists of a lower interval of laharic breccias and an upper mudstone interval. The laharic breccias are a part of Bruning's "fanglomerate facies" and the mudstones are probably correlative with part of his "playa facies".

lower laharic breccias.

A thick sequence of laharic breccias crops out over much of the northern half of Water Canyon Mesa (Sections 23, 24, 25, and 26, T3S, R3W). Similar rocks are also found in the extreme southeast corner of this study area (Section 13, T4S, R2W). Similar laharic deposits also occur in this interval in the Socorro-Lemitar Mountains (R. M. Chamberlin, oral communication, 1977).

On Water Canyon Mesa, the laharic breccias overlie "intermediate lavas", Water Canyon Mesa lavas, thin quartz-rich ash-flow tuffs, or bedded tuffs. Thin lenses of sandstones are also found under the laharic breccias at several locations on Water Canyon Mesa and may represent deposits in small channels. No rock units except an aluvial unit of uncertain age overlie the laharic breccias on Water Canyon Mesa. Southeast of Pound Ranch, the basal relationships of the lower Popotosa laharic breccias is not exposed, but the upper surface appears to be an erosional unconformity with considerable topographic relief. This unconformity is overlain by mudstones believed to be middle to late Popotosa in age.

The lower Popotosa laharic breccias crop out as cliffs and steep ledgy slopes and form the steep scarp along the east side of Water Canyon in the northern extent of the canyon. The rocks are well indurated with a matrix as resistant as the clasts so that the rock fractures across clasts rather than around them. The unit weathers to large boulders and produces profuse talus which often obscures basal contact relationships. Cross sections indicate a maximum thickness of 400 to 500 feet in the Water Canyon area. These rocks generally are reddish in color but lighter or darker clasts may locally impart other colors to the rock.

mudstones.

A few small outcrops of mudstones are found along the eastern map boundary. Larger surrounding areas are mapped as alluvium both east and west of the graben containing down-faulted upper Santa Fe gravels. The alluvium is probably underlain by these same mudstones. On the east side of this graben, the mudstones apparently overlie the Popotosa laharic breccias on an erosional unconformity. Along both sides of the graben, these mudstones have eroded more rapidly than the down-faulted upper Santa Fe gravels creating reversed topography along the graben-bounding faults. Upper Pound Ranch lavas apparently overlie the erosional unconformity and are buried by mudstones along the eastern map boundary. Cross sections indicate these mudstones to be as much as 300 feet thick; however, outcrops are scarce and undiscovered faults may be present.

Where exposed the mudstones are massive or crudely bedded and may be shades of maroon, green or brown. In many outcrops, they are relatively pure clay but a short distance east of the study area, conglomeratic sands are interbedded in the mudstones. The mudstones are overlain by a thin basalt flow.

Basaltic Lava Flow

A basaltic lava flow crops out in a small part of the eastern study area. The flow overlies Popotosa mudstones and is overlain by sands and conglomerates believed to be upper Santa Fe gravels. Another small deeply weathered outcrop occurs in an arroyo bottom immediately south of the stock tank in Section 11. Here, the basalt underlies a thick sequence of upper Santa Fe gravels. The presence of sand and tuff layers in the mudstones directly beneath this basalt suggest it may be correlative with the basalt of Black Mesa under which similar sequences of rocks are found (R. M. Chamberlin, oral communication, 1977). Alternatively, the flow may be correlative with basalts interbedded in the Popotosa mudstones. They would then be unconformably overlain by the upper Santa Fe gravels.

Where well exposed this flow forms ledges and caps small ridges within the poorly consolidated sedimentary rocks. It varies from 0 to 30 feet in thickness and the rocks are greenish-black when fresh and weather to yellowish or brownish colors. The rock contains sparse plagioclase phenocrysts and has a sugary texture, sub-vitreous luster and has a white, speckled appearance on a broken surface. These textural features suggest that the rock is silicified.

Tertiary Intrusive Rocks.

Intrusive rocks are restricted to the western part of the study area. The majority of the intrusives present are "white rhyolite" dikes and domes; mafic, monzonite and rhyolite dikes occur in lesser numbers. Age control on these intrusives is poor. The rocks are clearly younger than the rocks they intrude (Oligocene); a few intrude Lemitar Tuff (26.3 m.y.). Lower age limits are not available for any intrusive except the northernmost white-rhyolite dome which is overlain by Popotosa laharic breccias.

White Rhyolite Domes

Two white rhyolite domes are thought to be the youngest volcanic rocks on Water Canyon Mesa. These domes apparently intrude Water Canyon Mesa lava and the northern dome is overlain by Popotosa laharic breccias. Both domes are apparently cut by later faulting (Plate 1). Veins in the northern dome parallel the cliff face of the overlying Popotosa laharic breccias and probably lie along a continuation of the large fault present to the south (Plate 1, Section 29). Calcite, quartz, barite, and occasionally limonite or hematite pseudomorphs after pyrite occur in these veins. Little alteration is found along intrusive contacts of these domes. At the southern dome, a thin intrusive breccia is found along the northern contact with Lemitar Tuff and, in a few areas, rocks are silicified near the contacts with these domes.

The two rhyolite domes are similar lithologically. Both are flow-banded (Scale of 1 to a few mm), break into small platey colluvium, and weather to rounded topography with few outcrops. Both are relatively crystal-poor containing a few per cent quartz and sanidine phenocrysts. The northern dome contains one to a few per cent phenocrysts and the southern dome contains 8 to 15 per cent phenocrysts. In thin section, the southern dome (Section 35) averages 12 per cent quartz, sanidine and biotite phenocrysts. Quartz and sanidine dominate the mineralogy and occur in approximately equal amounts. The quartz is subhedral to anhedral and may be slightly rounded or embayed; it averages 0.7 mm in diameter. Sanidine is fresh, commonly carlsbad-twinned, and averages 0.7 mm in length. As much as 2 per cent badly altered plagioclase (?) (grains resembling the altered plagioclase in other units in the Water Canyon Mesa area) are found in one thin section. Trace amounts of biotite are also present.

White Rhyolite Dikes

Dikes lumped under this heading are quite variable in total phenocryst content, weathering characteristics and type and degree of alteration. Phenocryst content varies from almost zero to as much as 30 per cent. Some of the dikes are resistant and weather to walls that stand above surrounding topography; others weather to platy rubble and low relief. Many are silicified, have overgrowths on quartz phenocrysts, and show alteration of biotite to chlorite and sericite. Gold has been mined from one such silicified white rhyolite dike in South Canyon, west of this study area, and prospect pits are commonly found around these dikes within the study area. However, no economic mineralization is known to be associated with these dikes in the study area.

The white rhyolite dikes tend to occur along local structures. Many trend approximately north-south but other trends are common. Most are elongate and vary from a few feet to 150 feet in thickness, but a few are relatively equant in shape. No systematic variations were noted in these dikes. Their relative ages are unknown; however, it is considered probable by this writer that more than one intrusive episode is represented due to the diversity of characteristics present.

All of the white rhyolite dikes have quartz as the dominant phenocryst and are light in color. Most contain only quartz, sanidine, and traces of biotite, but a few of the more crystal-rich dikes contain appreciable plagioclase and a few have limonite pseudomorphs after pyrite. Colors vary from white to yellowish-gray in most areas; however, one dike which intrudes Lemitar Tuff in Sixmile Canyon is grayish-red.

Rhyolite Intrusions

In the south-central part of the study area, along the upper reaches of Rincon-Madera Canyon, at least three rhyolitic intrusions are found (Section 18, T4S, R2W). These rocks closely resemble the rhyolitic lavas in the unit of Sixmile Canyon but are thought to be considerably younger since they intrude Lemitar Tuff and tuff of South Canyon. The eastern two intrusions are small and elongate but the western intrusion is larger and can be considered a small dome. Both areas are situated along major fault zones and the magmas may have intruded along these structures.

In outcrop, these rocks weather to small angular talus and form areas of low relief except where silicified along fracture zones. Colors vary from pale-red to pinkish-gray and the rocks are often mottled. Flow-banding is scarce, but steep where present. Andesite lithic fragments are common in some areas and appear to have been embayed by the lava in some specimens. These andesites contain reddish or brown altered pyroxene phenocrysts and resemble the basaltic andesites that occur above Lemitar Tuff.

The rocks are moderately porphyritic in hand specimen and contain 10 to 20 per cent sanidine and quartz phenocrysts. Almost all the phenocrysts are sanidine which is usually tabular and averages 1.5 mm in length but may reach lengths of 4.0 mm. When fresh, the sanidine may exhibit blue or pearly white "chatoyancy". Quartz is present in trace amounts as small rounded grains and coppery biotite is also present in trace amounts.

Monzonite Dikes

Several monzonite dikes are found along Water Canyon intruding rocks as young as the Spears Formation. The overlying units have been eroded from this area. D. Krewedl (1974) suggested that there is a genetic relationship between these dikes and the Water Canyon Stock (30.5 m.y.; Section 16, T3S, R4W). The dikes trend in a northerly direction, parallel to local structure.

In outcrop, these dikes stand above surrounding terrain as walls sometimes as much as 20 feet high and weather with a rounded irregular surface. They are bordered by a thin bleached zone along intrusive contacts. The monzonite varies from moderately porphyritic along contacts to coarsely porphyritic in the interiors of dikes. Phenocrysts are sanidine, plagioclase, quartz, and mafic minerals. Sanidine is the most abundant and largest of the phenocrysts and sometimes weathers out of outcrops in euhedral cyrstals as much as 5 cm in length. Plagioclase occurs in smaller phenocrysts as does quartz which is usually rounded and embayed. Krewedl (1974) reports considerable variation in feldspar ratios and the amount of mafic minerals between dikes. He also attributes the green color common in hand specimens to chloritization of mafic minerals.

Mafic Dikes

A few small, fine-grained mafic dikes occur along the western border of the study area; two small mafic intrusions are also seen in the basaltic andesites above Lemitar Tuff in Sixmile Canyon (NW/4, Section 5, T4S, R2W) and a few other small mafic dikes intrude fault zones in the Lemitar Tuff at scattered locations in the central study area (Plate 1). These dikes are generally small, greenish in color, fine-grained and deeply weathered. They often intrude the same fault zones as white rhyolite dikes and one was seen within a larger white rhyolite dike just southwest of Buck Peak. These dikes were not studied in detail. One thin section from Sixmile Canyon had a pilotaxitic groundmass of plagioclase, pyroxenes and magnetite. Most of the plagioclase and pyroxene were altered.

Tertiary-Quaternary Sedimentary Rocks.

A Quaternary fault scarp trends northeast from the mountain front just south of South Canyon. South of this down-to-the-north fault, an old piedmont slope, whose surface now stands 60 to 100 feet above the bottoms of actively down cutting arroyos, descends eastward from the mountain front. The surface of this piedmont slope is largely covered with rounded pebble to cobble sized clasts of volcanic rocks. The lithologies of these clasts are diverse but restricted to Tertiary volcanic rocks which crop out along the nearby mountain front or along canyons that penetrate the mountains. Near the mountain front, the slope is a bench cut on the east-dipping Tertiary volcanic units. Outcrops along Sixmile Canyon (Sections 32 and 33) show this relationship well. Here, the volcanic bedrock is overlain by a few feet to as much as 100 feet of heterolithic fanglomerates. Farther to the east and north (Plate 1, drill hole data a and b), the underlying rocks are upper Santa Fe sedimentary rocks. These are largely gravelly sandstones or gravelly mudstones. Clasts within these older deposits are lithologically the same as those in the overlying Quaternary gravels since they were shed from the same sources. These upper Santa Fe deposits are mapped as the Sierra Ladrones Formation (Machette, in press) where well exposed or where their outcrop area can be reasonably inferred.

Along the eastern border of the study area, Popotosa mudstones can be inferred to underly this piedmont slope. Here, Popotosa mudstones or talus/colluvium is mapped on the lower slopes of arroyo walls. Otherwise, all of the area covered by the piedmont slope is mapped undivided as Tertiary-Quaternary piedmont gravels.

Sierra Ladrones Formation

East of Pound Ranch (Sections 11 and 14, T4S, R2W), a group of large rounded hills are mapped as the Sierra Ladrones Formation (upper Santa Fe deposits). These outcrops have been downfaulted into a graben between outcrops of Popotosa mudstones and upper Pound Ranch lavas. The upper Santa Fe deposits stand as topographic highs, even though they are within a graben, because the surrounding mudstones eroded much more rapidly. The Sierra Ladrones deposits overlie a basalt flow and their upper surface is cut by an old deeply disected erosion surface.

Where outcrops are found these deposits vary from gravelly sandstones to boulder alluvium with clasts as much as 1 foot in diameter. Clast lithologies include Lemitar Tuff, tuff of South Canyon, basaltic andesites and Pound Ranch lavas. Beds dip gently (10 to 15 degrees) in various directions except at the northwestern outcrop where fault drag has steepened the dips to 40 to 50 degrees toward the southeast. A minimum thickness of 300 feet is indicated by the topographic relief. A topographically similar hill east of these deposits (SW/4, Section 2, T4S, R2W) is believed to consist of a remnant of these deposits overlying a basalt flow.

A second small outcrop area of the Sierra Ladrones Formation is inferred along the first arroyo north of Sixmile Canyon (N/2, Section 33). A drill hole just north of this outcrop area (NW corner, Section 33) cut 70 feet of gravels (T-Qg) and 230 feet of sandy and gravelly (?) mudstones (probably Sierra Ladrones deposits). R. M. Chamberlin (in progress) has mapped outcrops of upper Santa Fe deposits farther down this same arroyo system.

Alluvium of unknown age

A large part of the highest surface of western Water Canyon Mesa (Sections 35 and 26) is covered with alluvium. No outcrops occur within this area, yet, the unit covers a minimum topographic interval of 200 feet and may be as thick as 400 feet. The alluvium overlies the Popotosa laharic breccias in a north-trending graben (see Plate 1). Clast lithologies are diverse and include all local Tertiary rock units, vein quartz, and a distinctive porphyritic andesite which only crops out west of this study area. These sediments could be of any age younger than lower Popotosa laharic breccias.

Quaternary Units.

Alluvium

Stream sediments in active drainages, stream terraces, and relatively undissected alluvial surfaces were mapped as Quaternary alluvium. Terraces are separated where obvious and are labeled on the geologic map (Plate 1). Two large areas of Quaternary alluvium were mapped in this study. The first of these is east of Pound Ranch where Popotosa mudstones (?) are covered by an alluvial surface. The second is along the mountain front north of South Canyon. Just south of the mouth of South Canyon, a northeast-trending fault drops the older piedmont surface down to the north where it is covered by more recent alluvium. A large alluvial fan extends from the mouth of South Canyon and several coalescing fans descend from the mountain front to the north. These relatively undisected fans, clearly younger than the higher piedmont surface to the south, were mapped as Quaternary alluvium.

Talus/Colluvium

Active talus slopes and stabilized colluvium cover large areas throughout the study area. In general, talus/colluvium was mapped only where important geologic contacts or faults were obscured.

STRUCTURE

Regional Structure.

The present tectonic patterns of the Socorro-Magdalena area largely reflect the influence of three partially overlapping tectonic periods. During Laramide time, compressional forces formed fold belts and thrusts in west-central New Mexico (Kelley and Wood, 1946; Tonking, 1957; Kelley and Clinton, 1960). In the Magdalena area, Loughlin and Koschmann (1942) found evidence for an elongate anticlinal structure of Laramide age which had been beveled by erosion prior to deposition of Oligocene volcanic rocks. Sediments from this erosion surface were shed northward into the Baca basin and formed the Baca Formation of Eocene age (C. E. Chapin, oral communication, 1977). During Oligocene time, intense volcanism buried the Socorro-Magdalena area under a thick plateau of volcaniclastic sediments, ash-flow tuffs, and lavas. During this volcanism, several cauldrons formed in the Magdalena area (Chapin and Chamberlin, 1976). Since late-Oligocene or early-Miocene time, block faulting related to Rio Grande rifting has formed the mountain ranges and basins of the present topography.

Local Structure.

The Magdalena Mountains can be geologically divided into northern and southern parts. The northern Magdalena

Mountains are a complex west-tilted fault block containing Precambrian, Paleozoic, and Tertiary rocks. The Magdalena cauldron forms the western boundary of this northern block (C. E. Chapin and P. Allen, oral communication, 1977). This part of the range has been relatively intensively studied due to the mineralization in the Kelly Mining District. (Laughlin and Koschmann, 1942; Titley, 1959; Park, 1971; Siemers, 1974; Iovenitti, 1977; Blakestad, 1977). The southern Magdalena Mountains are dominantly volcanic rocks and are less well understood. Four cauldrons, the Magdalena, North Baldy, Sawmill Canyon and Socorro cauldrons, are known in west, south, and eastern Magdalena Mountains (Chapin and Chamberlin, 1976). The relationships of these cauldrons to local physiographic features and the study area are shown in figure 26. This study overlaps parts of the Sawmill Canyon and Socorro cauldrons.

Sawmill Canyon Cauldron

The Sawmill Canyon cauldron forms much of the southern Magdalena Mountains. Its northern wall is well exposed just south of the Langmuir Laboratory access road and can be traced west from just northwest of Buck Peak to north of South Baldy (Krewedl, 1973; Chapin and Chamberlin, 1976; D. Petty and S. Bowring, oral communication, 1977). A short segment of this cauldron margin is exposed in this study area northwest of Buck Peak (Section 3, T4S, R3W, unsurveyed). This cauldron wall is a near-vertical contact

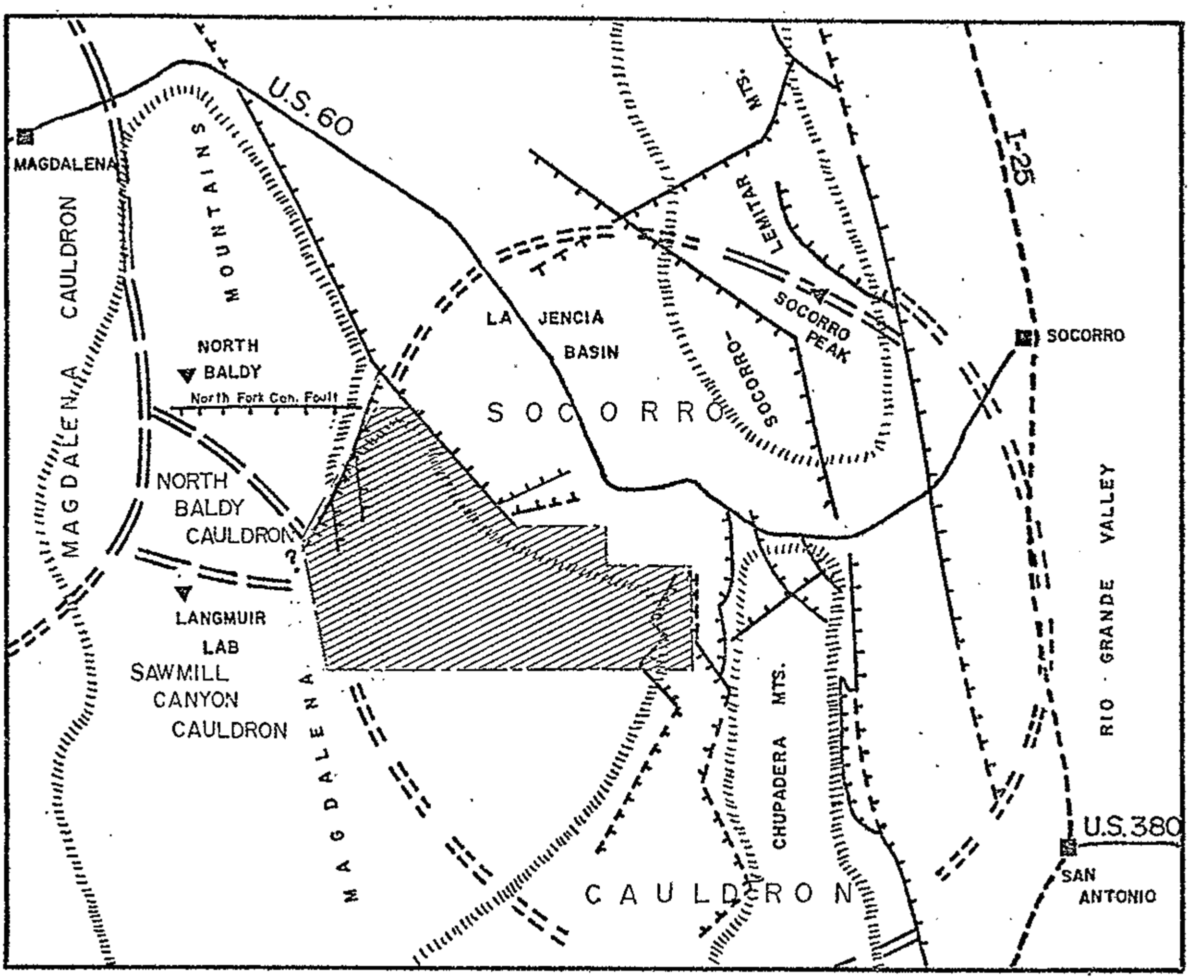


Figure 26: Relationship of Study Area (striped) to cauldrons, major faults, and selected geographic features. Shaded area, west part of Study Area, is an anomalous structural zone through which the western Socorro cauldron margin may run.

between Hells Mesa Tuff on the north and andesites, tuffs, and sedimentary rocks of the unit of Sixmile Canyon on the south.

This contact is clearly visible in the field due to differing weathering characteristics of the two units; however, the contact usually has little or no topographic expression. The lavas, tuffs, and sedimentary rocks of the unit of Sixmile Canyon are considered to be cauldron fill. Laharic breccias of the unit of Sixmile Canyon are found in a scallop (?) in this cauldron wall (S/2, NE/4, Section 3) and appear to dip away from the wall.

The regional extent and size of the Sawmill Canyon cauldron are not known. The presence of as much as 1000 feet of andesites under the Lemitar Tuff at the mouth of Sixmile Canyon suggest the margin may extend that far east. An alternative explanation, however, for these thick andesites at the mouth of Sixmile Canyon is that they are fill of a different pre-Lemitar Tuff cauldron in the eastern Magdalena Mountains.

Socorro Cauldron

The northern margin of the Socorro cauldron has been delineated on Socorro Peak where moat deposits apparently overlie Madera Limestone on the eroded lip of the cauldron and underlie tuff of South Canyon (R. M. Chamberlin, in progress). These same moat deposits overly the Lemitar Tuff in the northern Chupadera Mountains. These relationships suggest that the Lemitar Tuff was erupted from the Socorro cauldron. Supportive evidence includes large zones of lithic-rich Lemitar Tuff (massive rhyolite of Miesch, 1956) in the Chupadera Mountains (R. M. Chamberlin, in progress) that are interpreted as cauldron-collapse breccias (mesobreccias in the terminology of Lipman (1977)). The thickness of the Lemitar Tuff (700 to 2800 feet) in the Chupadera and southeastern Magdalena mountains further suggests a cauldron environment (Fig. 8) but similar thicknesses of Lemitar Tuff (750 to 800 feet with eroded tops) are found to the west on Timber Peak and South Baldy, respectively. These thick sections suggest that the Lemitar Tuff also partially filled the moat of the Langmuir cauldron. The similar or thicker sections to the east in the study area may have accumulated in the depression of a pre-Lemitar Tuff cauldron or in the Socorro cauldron as it subsided. The lack of abrupt thickness changes of the Lemitar Tuff in the western part of this study area suggests that, if cauldron subsidence did occur there contemporaneously with eruption of Lemitar Tuff, that it was probably a trapdoor subsidence hinged on the west.

The projection of the proposed Socorro cauldron margin on Socorro Peak should intersect the Magdalena Mountains in the vicinity of Water Canyon. The Water Canyon area is structurally complex but no feature or features that can be clearly interpreted as the Socorro cauldron margin are seen. Consequently, the western margin of the Socorro cauldron is shown as a wide zone on the regional structural map (Fig. 26) and not shown on the geologic map (plate 1).

Within the zone indicated in figure 26, a change in structural style, more intense intrusive activity and more intense alteration are seen. These features suggest the presence of the Socorro cauldron margin. In most of the study area, west-dipping normal faults (55 to 75 degrees) cut east-dipping strata (20 to 45 degrees). In the west part of the study area, dips in the Lemitar Tuff steepen (60 degrees to slightly overturned) and fault planes are more rotated (as low as 30 degrees). The shaded zone in figure 26 also contains the greatest concentration of intrusives in the study area. These intrusives, most of which are younger than Lemitar Tuff, include white rhyolite domes, and white rhyolite, monzonite, and mafic dikes. The Lemitar Tuff is silicified and brecciated within this zone to a greater degree than elsewhere. Some calcite and silica veining is present; one large black calcite vein (100 x 200 feet) is found north of South Canyon (SE/4, SW/4, Section 35). In this same area, numerous prospect pits and short adits are found where calcite veining is intense. The Hells Mesa Tuff is also altered in the western part of the study area; however, it is generally bleached and altered throughout the central Magdalena Mountains.

A key feature relative to interpreting this proposed structural zone is the Hells Mesa outcrop belt along the east side of Water Canyon. The Hells Mesa crops out as a sinuous band along most of the length of Water Canyon. It is overlain by Lemitar Tuff for most of that length; A-L Peak Tuff and the unit of Sixmile Canyon are absent except at the southern end where a few tens of feet of andesite are found.

To the south (NE/4, Section 34), the silicified top of the Hells Mesa dips toward the east at moderate angles (30 to 35 degrees) apparently under the overlying andesites and Lemitar Tuff. The foliation in the Hells Mesa, however, dips only 18 to 20 degrees to the east where it can be measured. Farther north (Section 26), the top of the Hells Mesa can be followed as a prominant topographic bench below the cliffs that rim Water Canyon Mesa. This bench is largely covered with talus from overlying units; the Hells Mesa crops out just below the edge of the bench in scattered, small outcrops. At least two large faults (500 or more feet of displacement) apparently cut this bench (SW/4, Section 26); yet, no offset of the surface is seen. Remnant terrace levels, present at several places at this level in Water Canyon, suggest that erosion has beveled this surface since the last movement on these faults. The Hells Mesa is downfaulted and not exposed farther north in section 23.

The Hells Mesa outcrop belt is truncated on the south by the Sawmill Canyon cauldron wall; however, at the northwest corner of Buck Peak, this wall bends north (a scallop) or intersects a north-south trending structure. Thick andesites and laharic breccias abutt the Hells Mesa along this north-trending contact for a short distance. Farther north, the Lemitar Tuff covers the andesites and only a thin exposure is found between Hells Mesa and Lemitar Tuff.

These anomalous features can be explained by a pre-Lemitar Tuff depression (Cauldron (?)) partially filled with andesites and covered by the Lemitar Tuff. The Hells Mesa contact could be a relatively steep eroded scarp and the thin exposures of andesites could be only the upper levels of a thick sequence. Available data is also compatible with a stratigraphic contact between Hells Mesa and Lemitar Tuff (Plate 1, cross section B-B'). In this interpretation the andesites are thin flows, the A-L Peak is absent, and the thick section of andesites north of South Canyon would lie in a scallop in the Sawmill Canyon cauldron wall. In both situations, the Socorro cauldron margin with a hinged or collapsed western margin may still be present. A hinged western margin is considered more likely since no certain significant stratigraphic offset was seen in this study.

collapse in the Water Canyon area.

The stratigraphic sequence above Lemitar Tuff in the Water Canyon Mesa area differs considerably from the rocks found at the same stratigraphic levels in the northern

Chupadera Mountains to the east and on South Baldy to the west. These stratigraphic variations imply differences in the post-Lemitar Tuff tectonic histories of the three areas. Exposures of this stratigraphic level are not present elsewhere in this study area. The present erosion level is below this interval in the central study area and these units are missing under the upper Pound Ranch lavas to the east.

In the northern Chupadera Mountains, R. M. Chamberlin (oral communication, 1977) has found a thick sequence of tuffs, lavas, and minor sedimentary rocks directly above the Lemitar Tuff. These units are locally overlain by the tuff of South Canyon and the entire sequence is unconformably overlain by laharic breccias of the basal Popotosa Formation. In the Water Canyon Mesa area, basaltic andesites overlie Lemitar Tuff directly and are overlain by tuff of South Canyon. The Lemitar Tuff and tuff of South Canyon are generally conformable in attitude. Above tuff of South Canyon, a sequence of intermediate to silicic lavas, rhyolite domes, and minor tuffs and sedimentary rocks are found. These units are overlain by Popotosa laharic breccias. On South Baldy similar laharic breccias overlie eroded tuff of South Canyon or basaltic andesites. Here, the basaltic andesites also directly overlie Lemitar Tuff (Stacy, 1968; S. Bowring, oral communication, 1977).

These stratigraphic differences suggest the following sequence of events:

1) Cauldron collapse in the northern Chupadera Mountains concurrent with eruption of Lemitar Tuff.

2) Emplacement of moat tuffs, lavas, domes and minor volcaniclastic sedimentary rocks in the northern Chupadera Mountains. The Water Canyon Mesa area must have stood high during this period as it received no moat deposits.

3) Emplacement of the basaltic andesite interval followed by the tuff of South Canyon in all three areas; thicknesses are variable.

4) Structural subsidence and erosion in the Water Canyon Mesa area followed by emplacement of intermediate to silicic lavas, domes, tuffs and sediments (see Plate 1, cross section B-B').

5) Deposition of the Popotosa laharic breccias in all three areas.

These events suggest that: 1) significant cauldron subsidence occurred in the northern Chupadera Mountains during and after Lemitar Tuff eruption but little if any occurred in the Water Canyon Mesa area; 2) a later period of subsidence occurred in the Water Canyon Mesa area after emplacement of the tuff of South Canyon; and 3) the South Baldy area was a relative highland during these periods of subsidence but was buried by later Popotosa sedimentation. Rifting contemporaneous with Socorro cauldron subsidence may partially have controlled these differences.

Block Faulting

Block faulting, partly contemporaneous with late-Oligocene volcanism and continuing until the present, has extensively broken the study area. Throughout most of the area, rock units dip to the east and west-dipping faults repeat the stratigraphic section (Plate 1, cross section A-A'). In addition to these down-to-the-west faults, several grabens penetrate the mountain front along the northeast part of the study area and a few transverse faults are found in the same area.

age of faulting.

Block faulting began north of Magdalena in the Riley area, about 28 m.y. ago (Chapin, 1971). R. M. Chamberlin (in progress) has documented significant fault displacements in the Lemitar Mountains before the deposition of Lemitar Tuff (26.3 m.y.). In this study area, most faults postdate major ash-flow tuff volcanism which ended approximately 26 m.y.b.p. However, the basaltic andesite interval between Lemitar Tuff and the tuff of South Canyon varies considerably in thickness (0 to 400 feet) and a few faults are seen in the Sixmile Canyon area (NE/4, Section 7 and Section 5, T4S, R2W) that appear to cut Lemitar Tuff but not the overlying tuff of South Canyon. Thus, it appears that block faulting began in the study area at least 26 m.y. ago. However, it is difficult to determine whether these early block faults are related to rifting, to cauldron subsidence, or both.

In the southern part of the study area, several hundred feet of down-to-the-west displacement can be demonstrated on major faults prior to deposition of upper Pound Ranch lavas and the underlying, associated ash-flow tuffs (10.5 m.y.).

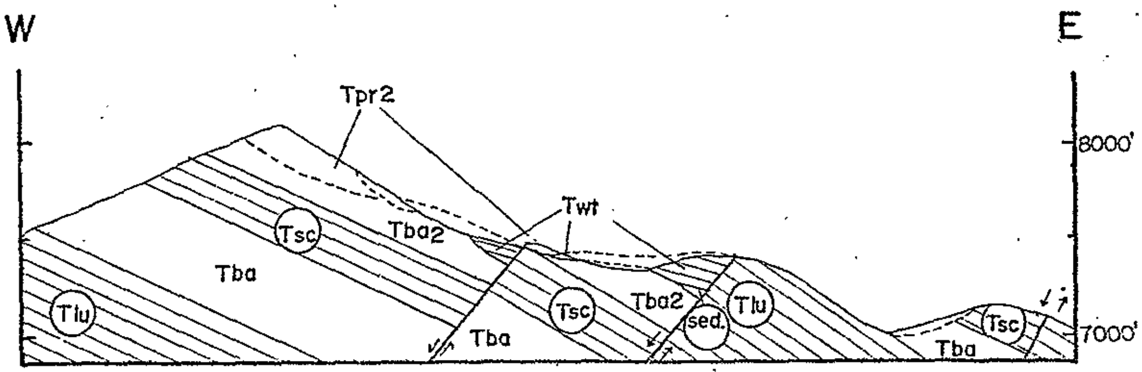
Here, the pre-lava ash-flow tuffs thicken markedly against fault scarps and in one case, underlying sedimentary rocks are seen near the old fault scarp. An enlarged structural cross section of this area is shown in figure 27. Subsequent displacement offsets these tuffs and the overlying Pound Ranch lavas throughout the eastern part of the study area. In the remainder of the study area, where there are no Pound Ranch lavas, faults cut all volcanic units.

Faulting has continued until recent times in some parts of the area. East of Pound Ranch, upper Santa Fe gravels (upper Miocene) are downfaulted into a graben; in the northern part of the study area, Quaternary fault scarps cut alluvial fans along the mountain front.

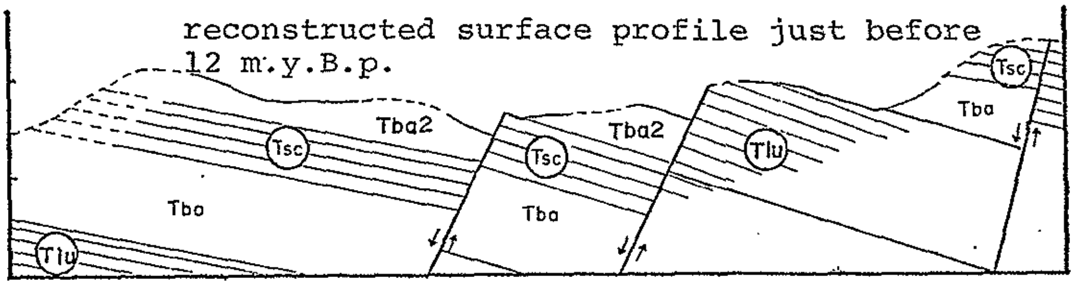
Down-to-the-west faults.

Major down-to-the-west faults in the study area are shown in figure 28. South of South Canyon and east of Buck Peak, the rocks dip generally to the east and faults dip to the west in a nearly orthogonal relationship to the bedding. These faults are thought to have formed as steep west-dipping fractures (75 to 90 degrees) with both fault planes and bedding planes rotating simultaneously as a number of parallel fault blocks tilted toward the basin to the east.

In the area diagrammed in figure 27, beds now dip to the east at 30 to 35 degrees and faults dip to the west at angles of 45 to 60 degrees. If the tuffs at the base of the Pound Ranch lavas are rotated to a horizontal position



a) Structural cross section showing present surface (solid line) and probable pre-erosion base of upper Pound Ranch lavas (dashed).



b) Same cross section as a) above with 10 to 12 m.y. lavas and tuffs removed. In addition, unit dips have been reduced to pre-12 m.y. attitudes assuming the tuffs under the Pound Ranch lavas were deposited horizontally. Solid lines where surface is preserved under tuffs or lavas, dashed lines where inferred.

Figure 27: Cross section and paleo-surface reconstruction for east-west profile through Section 18, T4S, R2W, southwest of Pound Ranch. These cross sections document fault movement before deposition of 10-12 m.y. Pound Ranch lavas and associated ash-flow tuffs. Scale approximately 1/12000, no vertical exageration.

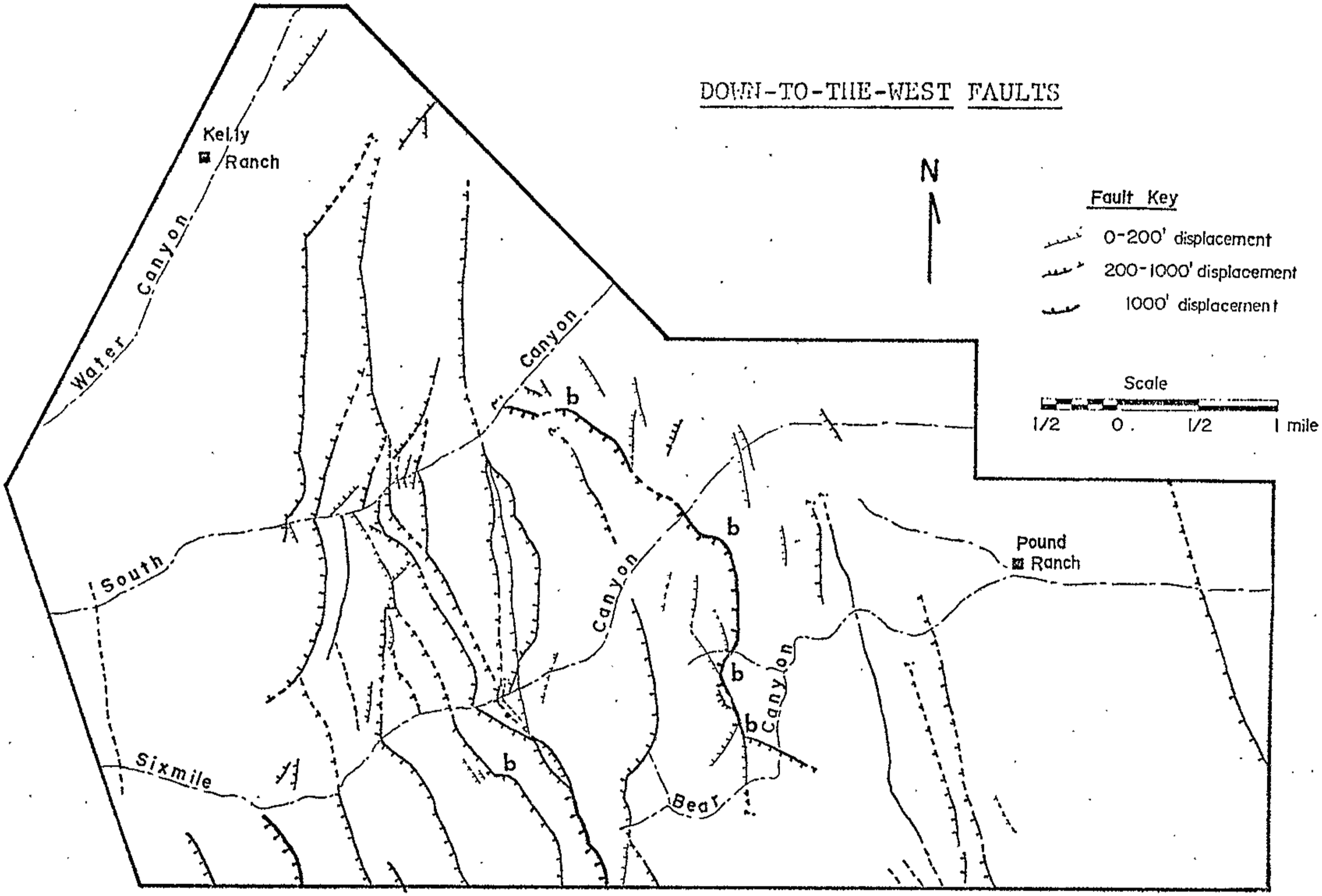


Figure 28: Down-to-the-west faults in the study area, including those faults shown paired with down-to-the-east graben faults in figure 28. Several bends in fault traces or shifts in the trend of major fault displacements are marked (b). Most other bends in fault traces are the result of low angle faults intersecting steep canyon walls.

(Fig. 27b), the underlying Lemitar Tuff and tuff of South Canyon dip gently to the east (10 to 15 degrees) and the major faults dip to the west at 65 to 80 degrees. Farther west, south of Buck Peak, beds dip as steep as 60 degrees to the east and fault planes dip to the west at angles of 25 to 35 degrees. R. M. Chamberlin (in progress) has documented similar, but more severely rotated, low-angle normal faults in the Lemitar Mountains north of this study area.

Individual faults can be traced as breccia zones a few inches to several feet in width. The breccia in these zones characteristically consists of rounded clasts of the surrounding rock in a reddish matrix of finely comminuted rock fragments. These zones are often intensely silicified. Where tuffs are faulted against andesites, these silicified fault zones stand as topographic walls and served as the most accurate source of data on the dip of fault planes. One such fault is shown in figure 29. Other breccias, not obviously associated with faults, are also found in the study area and may or may not be silicified.

The fault pattern (Fig. 28) reflects a subparallel series of north- to north-west trending fault blocks (cross section B-B', Plate 1) that have been rotated to the east from 20 to 40 degrees. Individual faults tend to bifurcate and rejoin, and some faults abruptly change direction. In most cases where major displacements change direction, small faults or shear zones can be seen to

Figure 29: Photograph of a rotated normal fault within the study area. View is toward the north. The scarp on the right is silicified Lemitar Tuff that is brecciated along the fault surface. The overlying basaltic andesite interval erodes to the low topography on the left. This fault plane has been only moderately rotated (15 to 20 degrees) and now dips to the west at about 60 degrees. Other such faults in the study area dip at angles as low as 30 degrees to the west. Displacement is about 200 feet and is down-to-the-west (left).

continue on the original trend. Several such turns are marked on figure 28. Other apparent bends in fault traces are illusions caused by moderate- to low-angle faults intersecting steep topography.

The reasons for the step down of faults to the west away from the Rio Grande valley and for the rotation accompanying faulting is uncertain. This "field of tilted blocks" continues westward across the Magdalena Range and into the eastern San Mateo Mountains (D. Petty and S. Bowring, oral communication, 1977; Deal, 1973). To the north, the field of tilted blocks interfingers with a plunging graben system on Water Canyon Mesa. West of Water Canyon, the Langmuir cauldron margin marks a fairly abrupt transition from east-tilted fault blocks to the west-tilted block of the central and northern Magdalena Mountains. This northern block has been rotated as much as 25 degrees to the west since Oligocene time; however, parts of the Hells Mesa Tuff are near horizontal and indicate little if any rotation since deposition.

One possible explanation is that this field of tilted blocks may have formed in conjunction with the development of a marginal graben in the eastern San Mateo Mountains. Morton and Black (1975, Fig. 8) have published a model for fields of tilted blocks in the Afar depression which may apply to this portion of the Rio Grande rift. Figure 30 is a reproduction of this model from their paper. In their model, a marginal graben forms above the transition at depth

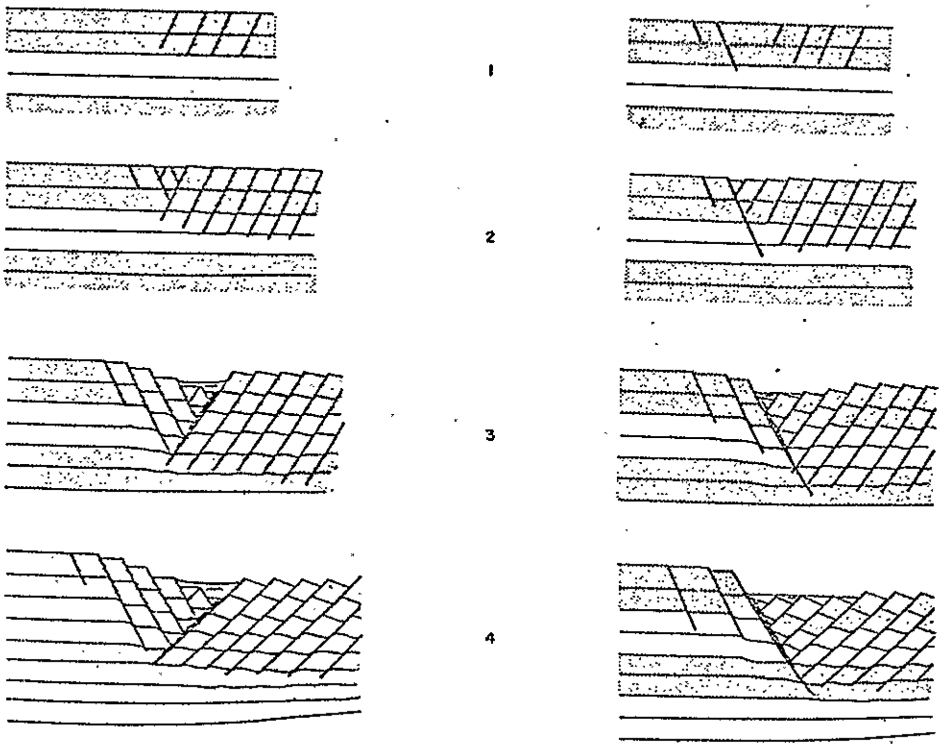


Figure 30: Two possible modes of development of a marginal graben, following the hypotheses of crustal attenuation. Reproduced from Morton and Black, 1975, figure 8. The model on the right diagrams a situation similar to that found in the eastern Magdalena Mountains.

from rigid crust to crust that is deforming plastically. A field of parallel faults forms opposite the stable block parallel to and dipping toward this graben. Continuing extension along the axis of this marginal graben would produce a complex graben system with faults down toward the graben. However, if extension was widespread, or if the axis of spreading moved away from the graben axis, block rotation would continue along already established fractures in response to the continuing extension. The initial marginal graben may no longer remain the low point structurally or topographically. Morton and Black (Fig. 3, p. 57) show cross sections from the Afar depression in which the lowest area topographically is under the field of tilted blocks rather than along the marginal graben. Cross section A-A' (Plate 1) also shows a field of rotated blocks with the lowest areas remote from the hypothetical marginal graben.

In the Socorro-Magdalena area, it is postulated that initial extension formed a graben system centered in the San Mateo Mountains (see Deal, 1973, Plate 1). An associated field of west-dipping faults developed east of this graben, perhaps extending as far as the Chupadera Mountains. Further extension, either to the east along the present axis of the Rio Grande rift or spread equally over a relatively broad area, caused rotation of fault blocks and concurrent fault movement. The plutons underlying 26 m.y. old cauldrons in the southern Magdalena Mountains could have still been hot and have deformed plastically at relatively shallow depths.

This early period of faulting caused moderate fault and bedding plane rotation (10-20 degrees) by 12 m.y. ago when the tuffs under the Pound Ranch lavas were deposited. Significant topography was present at this time (see Fig. 27) but the hills were apparently of fairly equal elevation.

Continuing down-to-the-west faulting has offset Pound Ranch lavas and further rotated beds in the area. In addition, a "sag" has developed in the eastern part of the study area. A given stratigraphic level crops out at progressively lower elevations toward the east, despite predominantly up-to-the-east faulting. This "sag" may have developed in response to the development of a center of extension to the east, along the present Rio Grande valley. Given this situation, down-to-the-west faulting would have continued along existing fracture planes initially. Eventually grabens could and apparently did form over the new centers of extension.

The prevalent north to northwest trend of major faults in the southern part of the study area apparently changes to north to northeast, north of South Canyon. South Canyon coincides with the eastward projection of the Sawmill Canyon cauldron margin; this change in fault trend may be a surface manifestation of the cauldron margin at depth.

Down-to-the-east faults, grabens, and transverse faults.

Down-to-the-east faults, graben structures and transverse faults are shown on figure 31. The major structures of these types are restricted to the Water Canyon-Water Canyon Mesa area and the area east of Pound Ranch. Only minor transverse and down-to-the-east faults occur in the remainder of the study area.

Water Canyon-Water Canyon Mesa area

A complex system of down-to-the-east faults is found in Water Canyon and on Water Canyon Mesa. For the purpose of this discussion and on figure 31 these are paired with opposing down-to-the-west faults in grabens; concurrent movement is indicated on at least one of the pairs of graben faults prior to emplacement of the Water Canyon Mesa lavas (Plate 1, Cross Section B-B', easternmost graben).

At the mouth of Water Canyon, the Water Canyon fault has been estimated to have as much as 3000 feet of displacement (Kalish, 1954; Krewedl, 1974). Based on current stratigraphic knowledge, 3000 to 4000 feet is considered to be a reasonable estimate of displacement along the northern parts of Water Canyon. South along Water Canyon, faults split from the main Water Canyon fault into Water Canyon Mesa. This decreases displacement on the main fault to the south, until at the last exposure in the study area the displacement is estimated to be between

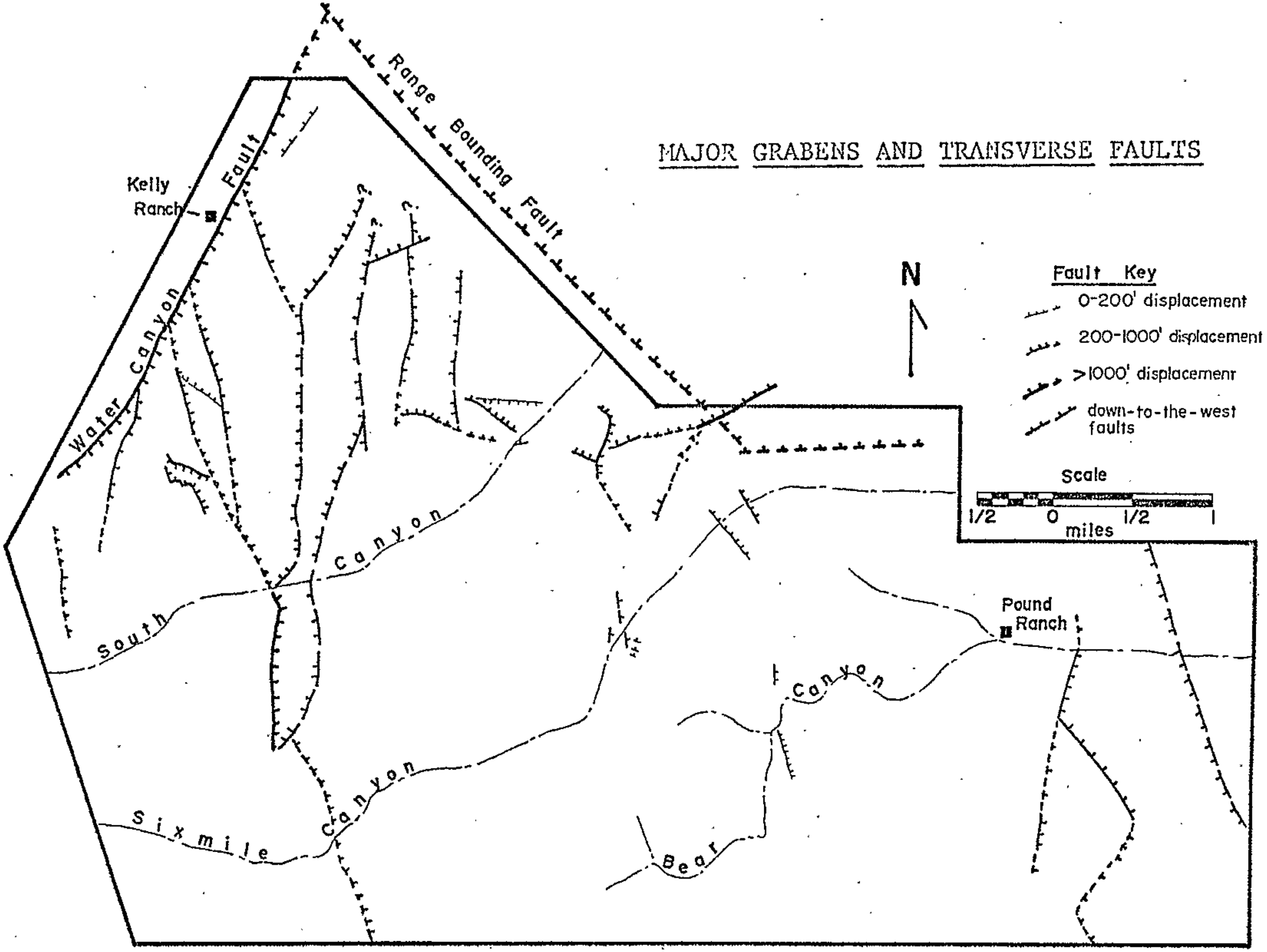


Figure 31: Location of major grabens, down-to-the-east faults, and transverse faults in the study area. Range bounding fault is approximately located along a Quaternary fault scarp a few feet high.

1000 and 1500 feet. The down-to-the-east displacement that splits off into Water Canyon Mesa can be traced southward along the east side of Buck Peak (Plate 1). There, the down-to-the-east faults apparently intersect down-to-the-west faults that form the eastern margin of the graben system. South of this intersection, one small graben can be traced south of Sixmile Canyon, but displacements are less than on the main graben.

A minor graben, trending N70W and apparently intersecting the major graben system described above is found in the southwestern part of Water Canyon Mesa (NW/4, Section 35). This small graben is intimately associated with a white rhyolite dome, or domes, and drops the tuff of South Canyon and younger unit down between outcrops of Lemitar Tuff. This structure may be related to rifting or may be a collapse structure related to dome emplacement.

Another north-trending graben is seen on the eastern corner of Water Canyon Mesa. This graben downfaults Popotosa laharic breccias between tuff of South Canyon exposures and is apparently truncated on the south by an east-trending transverse fault. Other east-trending faults are found along this trend toward the mountain front and one of these continues into La Jencia basin as a Quaternary fault scarp. The graben on the eastern corner of Water Canyon Mesa was apparently active before eruption of the Water Canyon Mesa lava since the underlying intermediate lavas are considerably thicker within the graben (Plate 1, Cross Section B-B').

Rock units on Water Canyon Mesa do not have the prevalent northerly strike and east dip found in most of the study area. Here, strikes and dips are quite variable between individual fault blocks. Rocks along the mountain front on the east tend to dip to the north or northwest, the Popotosa laharic breccias along Water Canyon, generally strike northeast and dip to the northwest. Rock units farther south along Water Canyon are variable in strike and dip. These variations are attributed to the complex interfingering of the field of down-to-the-west tilted blocks prevalent south of South Canyon and the northward plunging grabens of Water Canyon Mesa. The buried Langmuir cauldron margin beneath South Canyon may control the change in structural style.

Pound Ranch Area

East of Pound Ranch, upper Santa Fe gravels (Sierra Ladrones Formation) are down-faulted into a north-trending graben. Pound Ranch lavas and Popotosa mudstones border this graben on both sides. The inter-graben gravels stand high topographically (reversed topography) above the more rapidly eroded mudstones (Plate 1, Cross Section A-A'). Border faults are obvious but poorly exposed due to the semi-consolidated units involved. A remnant of the upper Santa Fe gravels is found east of the eastern graben fault as a small conical hill overlying a basalt flow; colluvium from the Santa Fe gravels covers parts of the area underlain by mudstones to the south. The gravels in the colluvium could have been deposited contemporaneously with the inter-graben deposits; however, this writer considers that origin unlikely since deposits much less resistant than the Santa Fe sandy-gravels must have been present in this area to allow the development of the prominent reversed topography.

Recent Fault Scarps

A northwest-trending fault scarp, a few feet high, can be seen on aerial photographs cutting Quaternary fan surfaces basinward from Water and South canyons along the northwestern border of the study area. This scarp, the youngest expression of the Magdalena Range bounding fault, ends just south of the mouth of South Canyon where it intersects a northeast-trending Quaternary fault scarp. This N65E-trending, down-to-the-north fault is expressed as a 20- to 30-foot-high scarp in the basin sediments. Tertiary-Quaternary gravels exposed to the south are downfaulted to the north and covered by Quaternary fan gravels. A subparallel transverse fault with approximately 300 feet of down-to-the-north displacement continues into the mountain front to the west (fig. 31).

ALTERATION AND MINERALIZATION

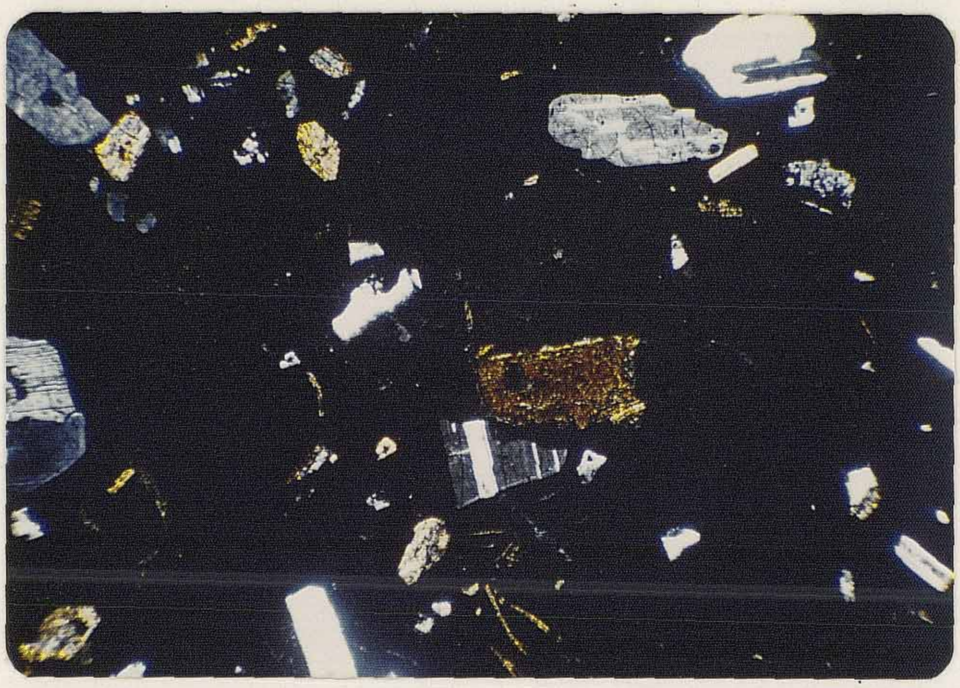
Plagioclase Alteration (Potassium Metasomatism (?)).

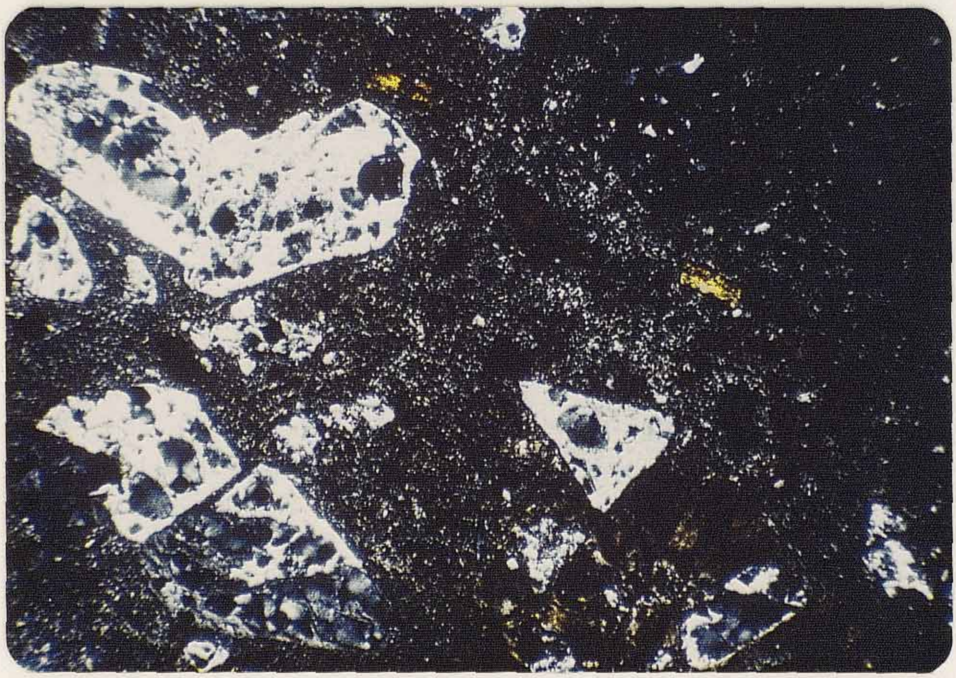
Within this study area, most plagioclase phenocrysts have been replaced by potassium-rich minerals in the Lemitar Tuff, tuff of South Canyon, intermediate lavas of Water Canyon Mesa, Water Canyon Mesa lavas, and some of the intrusives in the Water Canyon area. Plagioclase in the Hells Mesa Tuff and the older Spears Formation are altered but not in this manner and the 10 to 12 m.y. old Pound Ranch lavas have unaltered plagioclase phenocrysts. The lack of alteration in the young Pound Ranch lavas suggests the potassium enrichment occurred before their emplacement. The lack of potassium enrichment in the Hells Mesa and older units along Water Canyon may indicate that this area was outside the area affected by potassium metasomatism. Similar plagioclase alteration was not noted in the mafic lavas within the area.

A striking example of the affect of this type of plagioclase alteration can be seen in the Water Canyon Mesa lavas (Fig. 19). These lavas are fresh only in the small exposures of vitrophyre along South Canyon. The fresh rock contains plagioclase, biotite, and hornblende phenocrysts (Fig. 32). The unit is altered to various degrees where it is devitrified. Figure 33 shows a specimen from these lavas where they are badly altered; all plagioclase

Figure 32: Photomicrograph of the unaltered vitrophyre of the Water Canyon Mesa lavas. The plagioclase (white to gray grains) is fractured but unaltered and strongly zoned in a normal manner (An_{33} to An_{52}). This same sample was dated at 20.0 m.y. using the K/Ar method on biotite. Highly birofringent minerals are biotite and hornblende. Sample from NE/4, NE/4, Section 2, T4S, R3W, unsurveyed. Crossed nichols approximately 30x.

Figure 33: Photomicrograph of badly altered plagioclase from devitrified portion of the Water Canyon Mesa lavas. White cellular phenocrysts were plagioclase but are now probably orthoclase (framework) and clay minerals (centers) which were plucked out during thin section preparation. This unit has no potassium feldspar in fresh specimens. Biotite and hornblende are partially altered to hematite but are still recognizable. Crossed nichols, approximately 80x.





is replaced by potassium-rich minerals. These minerals were not specifically identified but are believed to be potash feldspar where the material is optically continuous, as in the skeletal remains of phenocrysts shown in figure 33, and clay minerals where the material is amorphous or microcrystalline. The centers of phenocrysts in figure 33 were probably clay minerals which were plucked out during thin section preparation.

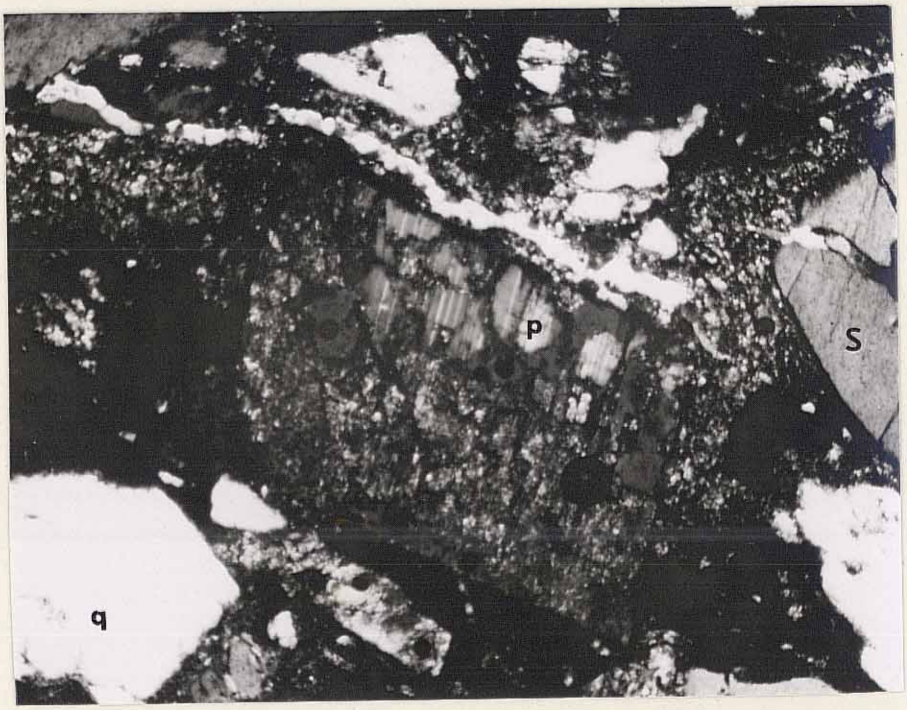
Plagioclase replacement has also apparently occurred in exolution lamellae within sanidine phenocrysts. A typical perthitic sanidine with altered lamellae is shown in figure 16, p. 54. In the Lemitar Tuff, sanidine is largely unaltered while plagioclase is almost completely destroyed. Figures 34 and 35 show relict plagioclase in the Lemitar Tuff from the measured section in Sixmile Canyon and the Lemitar Mountains, respectively.

The textures described above are thought to represent replacement of plagioclase by potassium-rich minerals, probably K-feldspar and clays. These textures closely resemble those found in replaced plagioclase phenocrysts in keratophyres (silicic lavas that have undergone alkali metasomatism and inversion to low-temperature mineral phases) in New Zealand (Battey, 1955, Plate VI, p. 104).

Support for the occurrence of alkali metasomatism in a volcanically active area is provided by P. M. Orville (1963) who experimentally investigated the system -- K-feldspar-Albite- NaCl-KCl-H_2O -- and concluded:

Figure 34: Partially altered plagioclase phenocryst from the Lemitar Tuff (sample 6M-21, measured section, Fig. 9). Dark gray areas ajoining plagioclase are probably potassium feldspar while the speckled areas in the upper part of the phenocryst are probably clay minerals, but could be finely crystalline K-feldspar. Brilliant white phenocrysts are quartz (q), medium-gray phenocryst at left is sanidine (S). Nichols crossed but rotated approximately 5 degrees from orthogonal to reduce contrast in photograph.

Figure 35: Comparison of sanidine (s, left) to altered plagioclase (p, right). Sanidine stained lightly and in a mottled pattern with sodium cobaltinitrite, while the materials which have replaced plagioclase stained much more strongly. Uncrossed nichols, white areas around altered plagioclase are holes where parts of the replacing minerals were plucked out during thin section preparation. Sample from the measured stratigraphic section (R. M. Chamberlin, in progress) in the Lemitar Mountains after which the unit was renamed.


p
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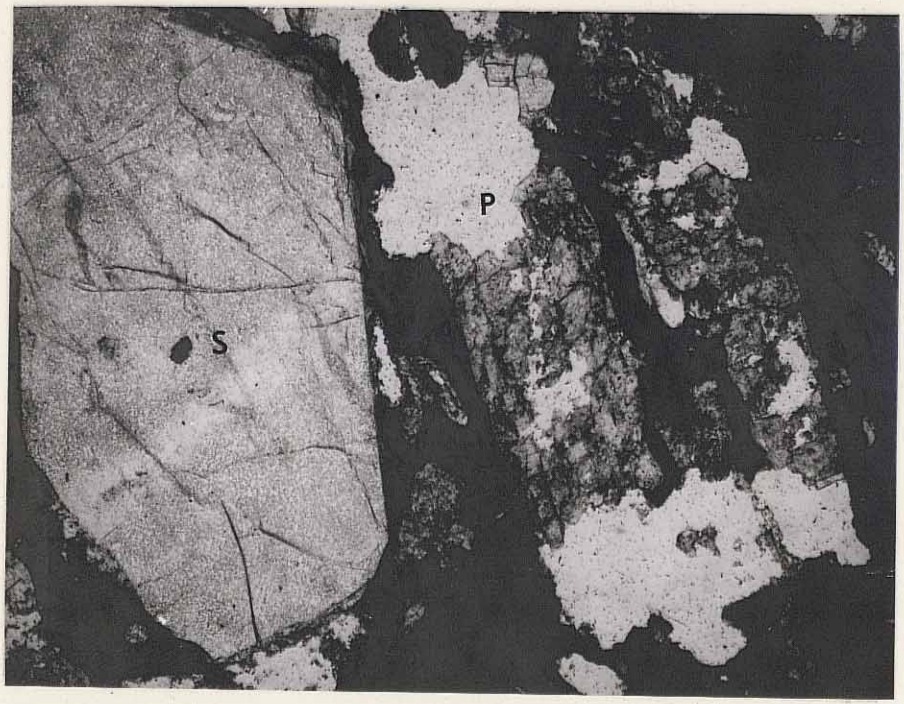

P
S

> "the presence of a thermal gradient in a two-feldspar rock requires the presence of compositional gradients with respect to the alkalies in the vapor phase. Alkali ions will tend to diffuse through the vapor in response to these gradients and alkali metasomatism ... will take place. In general, the cooler rocks will be enriched and the warmer rocks depleted in K-feldspar." (abs., p. 201)

Orville further suggests a reason why the plagioclase in siliceous rocks is altered while that in nearby basaltic andesites is fresh.

> "At constant temperatures an increase in the Ca-content of the feldspar phases will result in higher K/Na ratios in the vapor phase. ... Rocks originally rich in Ca will tend to be depleted in K-feldspar, and rocks originally poor in Ca will tend to be enriched in K-feldspar." (abs., p. 201)

Thus, Orville has suggested that, in an area with high thermal gradient and a pervasive vapor phase, deeper (hotter) rocks will be enriched in sodium while near-surface, cooler rocks will be enriched in potassium. C. N. Fenner (1946) described near surface alkali enrichment at about 200 degrees C. from cores in Yellowstone National Park where such a system is presently active.

> "The most notable effect found in the cores has been the addition of silica and the molar replacement of soda and lime of the feldspars by potash." (abs., p. 225)

Therefore it is postulated that silicic rocks in at least part of this study area have undergone potassium metasomatism for the following reasons:

1) Replacement features and staining indicate that plagioclase has been replaced by potassium-rich minerals. These replacement textures are strikingly similar to replacement textures in rocks that have undergone alkali metasomatism (Battey, 1955).

2) Preliminary chemical data indicates alkali enrichment in at least some of the units with replaced feldspar textures. (Appendix C).

3) It has been demonstrated theoretically and experimentally that, if a temperature gradient exists in the presence of a pervasive vapor phase, alkali exchange will take place. Fenner (1936) has described potassium enrichment in a hydrothermal system that is active today.

4) The complex volcanic history of the Socorro-Magdalena area suggest that at least one and perhaps several such geothermal systems could have existed in the past 26 million years. The hot springs at the base of Socorro Peak show the existence of one such system today.

Manganese Mineralization.

A detailed study of the Luis Lopez manganese district was largely completed by M. E. Willard by the time of his death in 1972. Willard's preliminary manuscript is on file at the New Mexico Bureau of Mines and Mineral Resources and may be published in the future. This manuscript was consulted during this study and in general observations made during this study agree with his data.

Manganese oxide minerals occur throughout this study area as thin coatings on joint surfaces and locally as the cementing material in breccia zones. A few of the cemented-breccia deposits have been mined commercially and small prospect pits are numerous throughout the study area, except in the area south of Buck Peak. The minerals noted in these prospects are largely manganese oxides. The major mineral is probably pyrolusite with various cation substitutions; Hewett (1964) reported hollandite, coronadite, and cryptomelane (containing Ba, Pb, and K, respectively). Calcite, jasperoid, quartz, and barite were seen as accessory minerals in various prospects and pyrolusite pseudomorphs after manganite were seen in one location in Sixmile Canyon. The prospects on Water Canyon Mesa tended to have more accessory minerals, such as jasperoid, calcite, and barite, and less manganese minerals. Limonite and hematite pseudomorphs after pyrite were seen in prospects along the mountain front on Water Canyon Mesa. Significant amounts of manganese ore have been shipped from two localities in the area and minor amounts have probably been shipped from a third.

The earliest manganese production noted was from a mine on the east slope of Water Canyon (SW/4, NE/4, Section 26) which produced, at most, a few thousand tons of concentrated manganese ores in 1917 and 1918 (Wells, 1918). Wells reports this manganese to occur in "a chocolate-colored rhyolite found throughout the manganese district." The workings of this mine were not entered but an inspection of the dump materials shows the mineralization to be largely botryoidal coatings of manganese oxides on breccia fragments and within fractures. The host rock is tuff of South Canyon which is bleached and brecciated throughout the outcrop area surrounding the mine. Locally, the rock is silicified and minor silica and calcite occur with the ore minerals.

The second area to have produced ore is at the mouth of Sixmile Canyon (Sections 33, T3S, R3W) where the Tertiary volcanic rocks have been beveled by a pediment slope. The manganese here occurs as fracture fillings within zones of brecciated upper Lemitar Tuff. The Lemitar Tuff has been slightly bleached and some feldspars have been altered to clay minerals. The workings at this location are open cuts along breccia zones with no provable offset: one exploration adit followed a breccia zone for a few tens of feet along strike from one of these cuts. Much material was moved, but large dumps with little manganese mineralization indicate that the ore bodies were of low grade and that the ore was sorted before shipment. Piles of dumped ore along the access road suggest that even the shipped ore was of low grade, as does the mineralization remaining in the open cuts.

Numerous prospect pits for manganese are found throughout the eastern parts of the study area in most silicic rock units. Upper Pound Ranch lavas, as well as tuff of South Canyon and Lemitar Tuff, host mineralization. West of Pound Ranch and south of the mines in Sixmile Canyon, two exploration pits occur in the upper Pound Ranch lavas. These are relatively large (more than 100 feet across) and remnants of a loading chute and other equipment near one of them suggests that some ore may have been shipped from this location; little indication of minable ore remains in the pits now. Mineralization in these younger rocks occurs as thin veins and cement in breccia zones, as in the older units.

Although manganese mineralization was not a major emphasis of this study, available geologic data suggests several conclusions. First, mineralization occurs in silicic units as old as Lemitar Tuff and as young as upper Pound Ranch lavas; therefore, at least some of the mineralization must be younger than 10.5 m.y. Second, it is suggested that mineralization may be restricted to silicic units due to their greater tendency to brecciate and hold open fractures. Also, breccia fragments in mineralized zones tend to be bleached and feldspars altered to clay minerals. Similar feldspar alteration occurs throughout the study area and is postulated to have been caused by pervasive potassium metasomatism. If alteration is more intense in the mineralized zones, as it appears to be, these breccia zones may have served as channels for the metasomatic fluids which may have also deposited the manganese minerals.

Calcite Veining.

Black and white calcite occurs as cement in breccia zones and along faults throughout the study area. In two areas, however, these calcite veins are large enough to be mapped as separate geologic features. North of Buck Peak, on the north side of South Canyon (S/2, Section 35), a large black calcite vein occurs within basaltic andesites. The vein is at least 100 feet across but may be larger since one side is covered by the overlying alluvial unit. This vein is largely moderately to coarsely crystalline, banded, black calcite with minor interlayered white calcite.

In some areas, the calcite has been brecciated and recemented by later stages of black calcite. Several small prospect pits penetrate this vein but revealed only more black calcite.

South of this large black-calcite vein along the north slope of South Canyon, numerous prospect pits and adits follow breccia zones cemented with stringers and small veins of black to dusky-gray calcite. In addition, another adit penetrates a similar breccia zone, farther to the east, near the mouth of Sixmile Canyon (SW/4, Section 32), and continues for at least 200 feet in andesitic lavas. No mineralization, except minor silica veining and the calcite, were noted in these workings. The object of these explorations is not known; however, the writer considers it probable that the prospecting was for precious metals since the exposed amounts of manganese minerals could not have been economic and no sulfide mineralization was seen.

Several large white, or black and white, banded calcite veins are also found within the upper Pound Ranch lavas south of Pound Ranch (Plate 1). The banding is irregular but generally vertical. The veins appear to have been deposited in open fractures along fault zones and may represent deposits of a hydrothermal system related to the cooling Pound-Ranch-lava pluton. No other minerals were seen in these veins and only one small prospect pit was found along the veins.

CONCLUSIONS

Several contributions to the geology of the Socorro-Magdalena area have resulted from this investigation of the eastern Magdalena Mountains. These conclusions are divided into stratigraphic, structural, and alteration-mineralization sections and are detailed below.

Stratigraphy.

The rocks in the study area are dominantly Tertiary volcanic units and consist mainly of rhyolitic ash-flow tuffs, separated by andesitic to basaltic andesite lavas. In addition, voluminous felsic lava flows occur at three separate stratigraphic intervals. The volcanic rocks in this study area, in general, fit the previously developed Tertiary volcanic stratigraphy as presented by Chapin and Chamberlin, 1976. Several units, however, vary significantly from occurrences in other parts of the Socorro-Magdalena area and others are unique to the eastern Magdalena Mountains. These variations from the regional framework are listed below in order from oldest to youngest:

1) A thick interval (as much as 2000 feet) of andesitic lavas with interbedded rhyolitic lavas, local ash-flow tuffs, laharic breccias, and sandstones occurs in the southwestern part of the study area within the confines of the Sawmill Canyon caldera. This interval is here called the unit of Sixmile Canyon and is considered

fill of the Sawmill Canyon caldera. This unit lies above the A-L Peak Tuff (?) and is overlain by the Lemitar Tuff. In other parts of the Socorro-Magdalena area, 0 to 600 feet of basaltic andesite lava flows are present in this interval.

2) The Lemitar Tuff is thicker (800 to 1500 feet) in the eastern Magdalena Mountains than is normal in other parts of the Socorro-Magdalena area. The upper crystal-rich member of the Lemitar Tuff, which is normally about 100 to 200 feet thick in the Magdalena area, averages 600 feet in thickness in this study area and the lower moderately crystal-rich member, which is sporadically present regionally, is a thick and variable unit (200 to 800 feet) in this study area. A reference stratigraphic section of the lower Lemitar Tuff was measured and described from Sixmile Canyon (NW/4, Section 7, T4S, R2W) in the study area.

3) Moat deposits which directly overlie the Lemitar Tuff in the northern Chupadera and southern Socorro mountains (R. M. Chamberlin, in preparation) are absent in the eastern Magdalena Mountains. The absence of these units probably indicates that the floor of the Socorro cauldron was structurally complex and that the eastern Magdalena Mountains stood high during emplacement of these moat deposits.

4) A moderately to densely welded, multiple-flow, simple cooling unit of crystal-poor (basal) to moderately

crystal-rich (upper), rhyolitic ash-flow tuffs, is informally termed the tuff of South Canyon. This unit overlies the basaltic andesite interval above the Lemitar Tuff and varies from 0 (southwest) to 600 feet (mouth of South Canyon) in thickness within this study area. A reference stratigraphic section of the tuff of South Canyon was measured and described at the mouth of South Canyon (SW/4, Section 30, T3S, R2W). This unit has been dated at 26.2 m.y. in the Joyita Hills and occurs in the Lemitar Mountains; correlation with units to the west is problematical.

5) Intermediate to silicic lavas, local ash-flow tuffs, and domes were emplaced in the northern part of the study area (Water Canyon Mesa) following emplacement of tuff of South Canyon. Emplacement of the lower intermediate lavas was followed by a period of erosion and faulting. Subsequently, felsic lavas and rhyolitic domes and associated pyroclastics were emplaced. The felsic lavas have been called the Water Canyon Mesa lavas and have yielded a date of 20.0 m.y. This sequence of units is overlain by lower Popotosa laharic breccias.

6) A sequence of mafic and rhyolitic lavas overlies lower Popotosa laharic breccias in the eastern part of this study area (Pound Ranch area). Here, basalt to basaltic andesite lavas overly tuff of South Canyon and are cut by an erosion surface that developed several hundred feet of topographic relief. Two rhyolitic

lavas, designated the Pound Ranch lavas, and associated pyroclastic units flowed over and partially buried this erosion surface. The Pound Ranch lavas have been dated at 11.8 and 10.5 m.y. respectively. Lavas of equivalent age and similar composition overlie upper Popotosa mudstones in the Socorro Peak area indicating the Magdalena Mountains were a highland 12 m.y. ago.

Structure.

Structurally, the eastern Magdalena Mountains are complex. Oligocene ash-flow tuff cauldrons dominate the structure of the eastern Magdalena Mountains. Two major features in this map area can be related to this period of cauldron formation:

1) The Sawmill Canyon cauldron margin is well exposed along the Langmuir Laboratory access road in the extreme western part of the study area. The unit of Sixmile Canyon represents fill of this cauldron.

2) A complex zone in the western study area may represent the Socorro cauldron margin. This zone is defined by more severe bedding-plane and fault rotation, more intense silicification and brecciation, and a greater concentration of intrusives than found in the rest of the study area.

Extensive block faulting, related to rifting, is superimposed on all volcanic features. This study area can be divided into two major structural domains and the northwestern border (Water Canyon) represents the contact with a third domain:

1) The southern part of the study area consists of a "field of tilted blocks" with east-dipping beds and west-dipping fault planes. The faults are thought to have developed as steep normal faults, with subsequent offset and rotation developing concurrently. This "field of tilted blocks" may have developed in conjunction with a marginal graben in the San Mateo Mountains in a manner similar to that described by Morton and Black (1975).

2) The northern part of the study area (Water Canyon Mesa) consists of a set of north-plunging grabens. These grabens interfinger with the "field of tilted blocks" along a line approximately coincident with South Canyon which lies above the projection of the buried Sawmill Canyon cauldron margin. Movement on these graben faults began before 20.0 m.y.

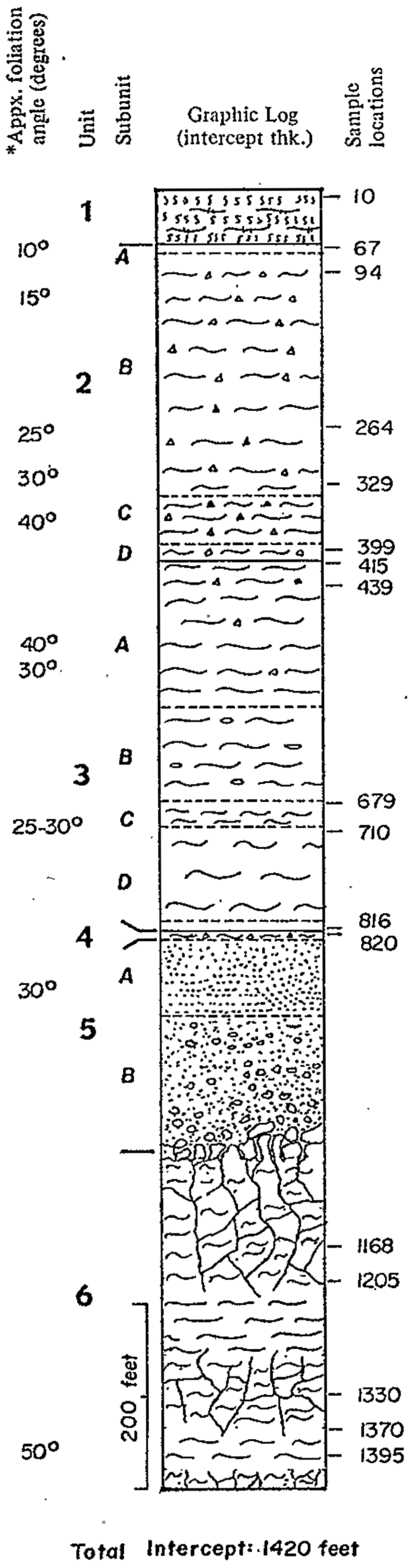
3) The Water Canyon fault zone separates the east- or north-dipping eastern Magdalena Mountains from the west-dipping central Magdalena Mountain block.

Alteration-mineralization.

Plagioclase has been altered to potassium-rich minerals in silicic rock units older than the Pound Ranch lavas throughout the study area except along Water Canyon. This potassium enrichment is thought to have resulted from one or more hydrothermal systems existing in the area between 26 and 12 m.y. ago.

Manganese mineralization occurs in silicic units from Lemitar Tuff (26.3 m.y.) to upper Pound Ranch lavas (10.5 m.y.). This indicates that some manganese mineralization postdates 10.5 m.y. The association of this mineralization with rocks showing intense feldspar alteration suggests that the mineralized breccias may have served as conduits for the potassium carrying fluids. These same fluids, at some stage in the hydrothermal systems, may have deposited the manganese oxides.

APPENDIX A



Appx. true thickness — Unit Descriptions

63' BASALTIC ANDESITE LAVAS: red and gry. basaltic andesites (La Jara Peak-like) with abundant red hematized pyroxene phenocrysts. Equivalent to similar stratigraphic interval in figure 5.

323' *LEMITAR TUFF;* CRYSTAL-RICH ASH-FLOW TUFFS (Upper Member, 25-45% Phen.):

A. Upper gray, crystal-rich, mod. welded zone (12').
B. Red, densely welded zone with large qtz. phen. (265').
C. Red, densely welded, pumiceous (vapor phase minerals in pumice) (55').
D. Red and gray, mottled, densely welded, pumiceous transition zone (15').

NOTE: – 2' breccia zone with Mn veinlets at 120';
– sheared upper Lemitar Tuff cemented by red jasperoid at 320' depth.

367' *LEMITAR TUFF;* CRYSTAL-POOR ASH-FLOW TUFFS (lower Member, 5-15% Phen.):

A. Mottled red and gray, pumiceous, mod. crystal content (160').
B. Mottled red and gray, massive, lithophysal zone (105').
C. Pur.-gry. pumice in a reddish matrix, mod. welded, mottled small-pumice zone (13').
D. Lt.-gry., crystal-poor, mod. to poorly welded zone, with dark-gray botryoidal pumice (120').
E. Chalky, white, basal unwelded zone (7').

NOTE: – Biotite and sanidine of the Lemitar Tuff are fresh and there is little alteration except in brecciated zones with manganese films on joint surfaces. Abundant silicified shear zones with finely comminuted matrix in conjugate sets at 70 to 90 degrees.

215' *UNIT OF SIXMILE CANYON:* ASH-FLOW TUFF (?): Lithic-rich, qtz-rich, crystal-rich tuff that may be a boulder of Hells Mesa or may be equivalent to the tuff interval in the unit of Sixmile Canyon (2'). TUFFACEOUS SANDSTONES AND HETEROLITHIC CONGLOMERATES: Possibly correlative with parts of the unit of Sixmile Canyon.

A. Massive, red, med.-grained, tuffaceous sandstone which grades downward into red and gray laminated and cross-laminated sandstones with minor conglomeratic beds (84').
B. Red, conglomeratic sandstones and conglomerates with clasts as much as 6" across. Grades downward into brecciated beds of the underlying tuffs (158').

NOTE: – Sediments are immature with angular clasts and sand grains which are not noticably altered.
– Drusy cavity filled with barite crystals at 834' (Willard, unpublished report).

305' *A-L PEAK TUFF(?);* CRYSTAL-POOR ASH-FLOW TUFFS: Gray and massive to pur.-gray and pumiceous, crystal-poor ash-flow tuffs. Rocks are extensively brecciated (fragments a few mm to few cm in length) to an extent not seen in the overlying Lemitar Tuff. Feldspars, altered to clays (5%); small qtz. phen. (1%), andesite lithics (1%). Some quartz veinlets reported for this interval (Willard, unpublished report).

* maximum angle between foliation and a plane normal to core axis.

Log of the Tower Mine Drill Hole (NW/4, NW/4, Sec. 7, T4S, R1W)
(hole inclined 60° to S70W)

APPENDIX B: Data For Radiometric Ages

Rock Unit/ Location	Age m.y.	Method	Ave Ar^{40*}ppm	K^{40}ppm	%K$_2$O
Lemitar Tuff, Lemitar Mountains	26.3±1.0	K/Ar-biotite	0.01185	7.644	6.266
tuff of South Canyon, Joyita Hills	23.9±0.9	K/Ar-sanidine	0.01069	7.582	6.215
"	26.2±1.0	K/Ar-biotite	0.01199	7.755	6.357
Water Canyon Mesa lavas, north side South Canyon	20.0±0.8	K/Ar-biotite	0.008240	7.020	5.754
lower Pound Ranch lavas, Pound Ranch area	11.8±0.5	K/Ar-biotite	0.006001	8.674	7.110
upper Pound Ranch lavas Pound Ranch area	10.5±0.4	K/Ar-biotite	0.004616	7.465	6.119

Dates are unpublished data of C. E. Chapin, New Mexico Bur. Min. and Mineral Res. Dates were performed by Geochron Laboratories.

APPENDIX C: Chemical Data

Sample/ Location	SiO_2	Al_2O_3	ΣFe	CaO	Na_2O	K_2O	TiO_2	MnO
Light-colored, crystal-rich clot from Lemitar Tuff west of Pound Ranch	76.51	12.75		0.53	3.63	5.97		0.05
Red Matrix surrounding above sample	66.73	18.10		0.84	3.65	8.45		0.04
Basalt with large olivine clots overlying tuff of South Canyon in Bear Canyon west of Pound Ranch	49.46	17.62		9.56	4.62	0.86		0.17
upper Pound Ranch lavas, south of Pound Ranch	72.31	12.34	2.94			4.60	0.39	0.03
lower Pound Ranch lavas, south of Pound Ranch	73.00	14.52	1.96		3.65	4.79	0.26	0.05

Chemical data are unpublished data of C. E. Chapin and D. L. White, New Mexico Bur. Min. and Mineral Res. Analyses were done by X-ray florescence.

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[1] Data and stratigraphic section from this road log have been updated and published in New Mexico Geological Society Special Publication No. 7 — see Chapin and others, 1978, Fig. 3.

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This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Charles E. Chapin

Kent C. Condie

Date 4/17/78

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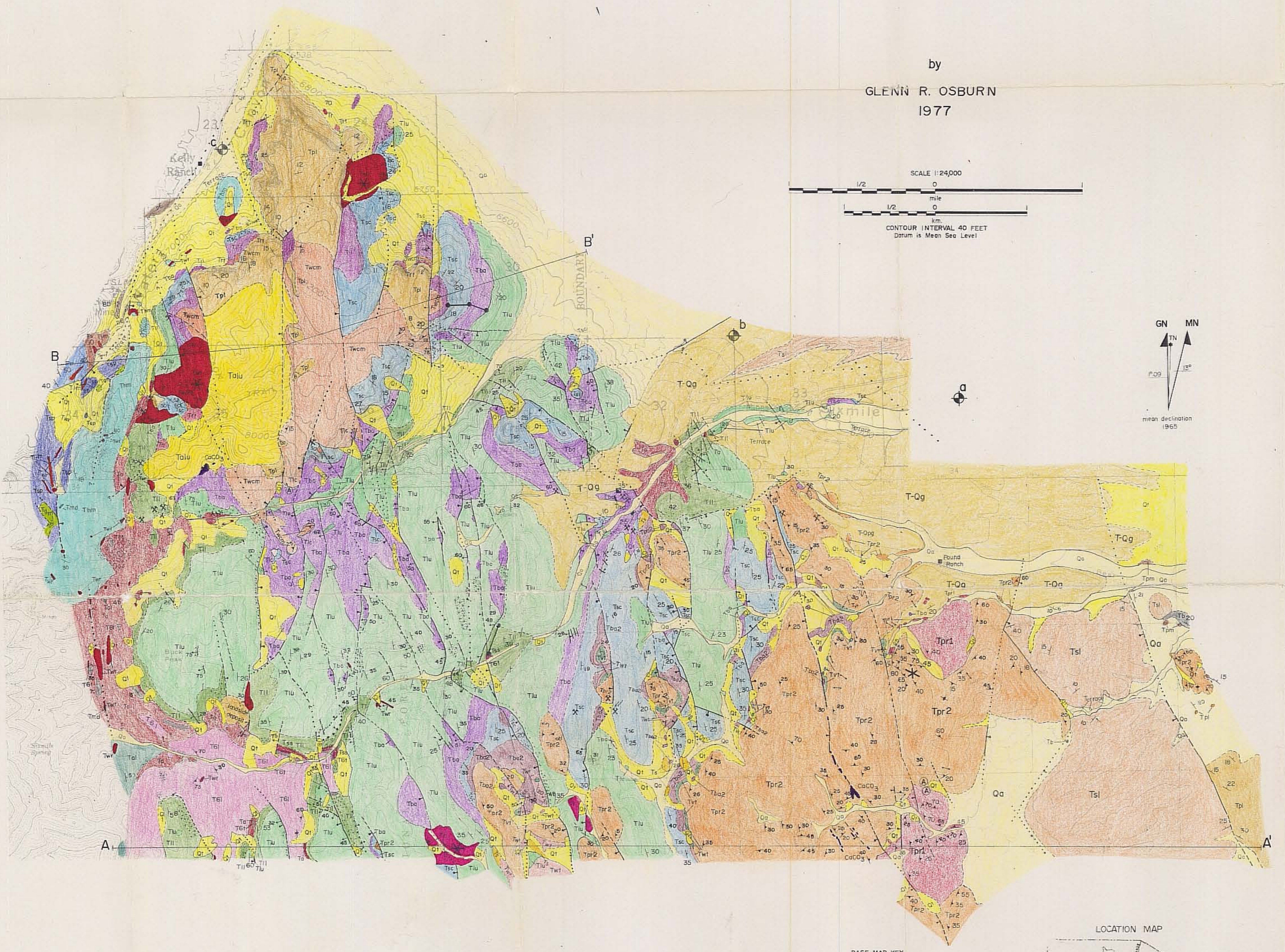
PLATE 1

GEOLOGIC MAP AND SECTIONS OF THE EASTERN MAGDALENA MOUNTAINS
WATER CANYON TO POUND RANCH
SOCORRO COUNTY, NEW MEXICO

by

GLENN R. OSBURN

1977

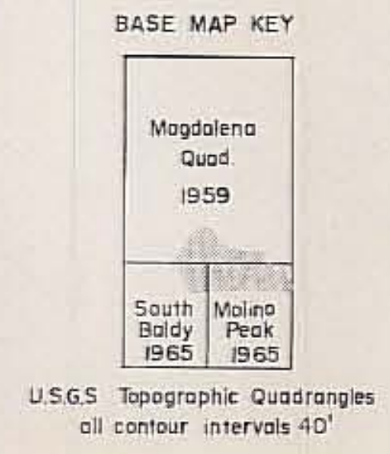


SCALE 1:24,000

1/2 0 mile

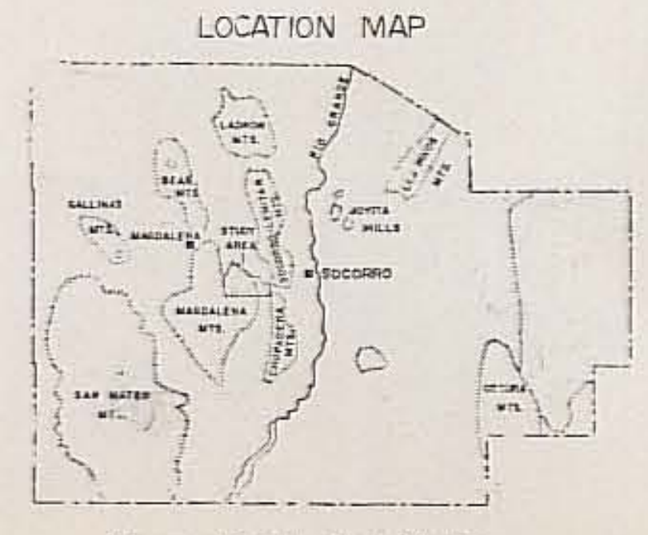
1/2 0 km.

CONTOUR INTERVAL 40 FEET
Datum is Mean Sea Level

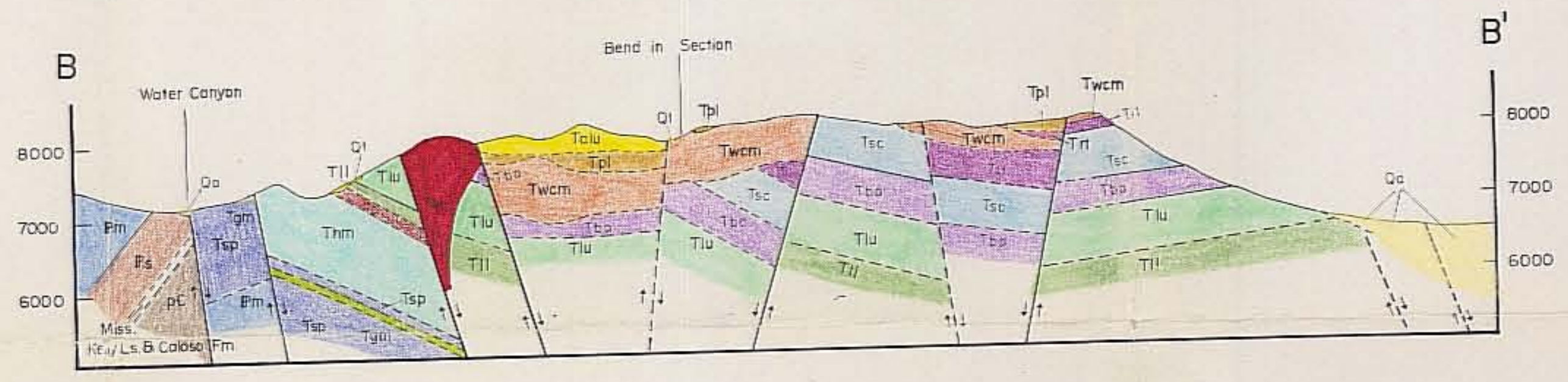


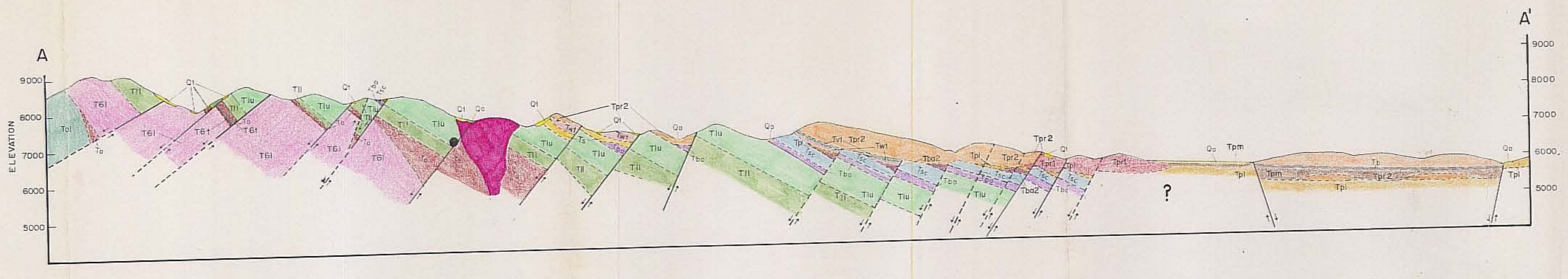
U.S.G.S. Topographic Quadrangles
all contour intervals 40'

LOCATION MAP



Socorro County, New Mexico





EXPLANATION

QUATERNARY

Qa — *alluvium*

Qt — *talus/Colluvium*

Pliocene

T-Qg — *piedmont gravels overlying Tsl, undivided*

Talu — *alluvial deposits of uncertain age*

Tsl — Sierra Ladrones Formation *conglomerates, sands, and mudstones*

Tb — *basaltic lavas*

SANTA FE GROUP

Tpm — Popotosa Formation *mudstones*

Tpr2 / Tvt — upper Pound Ranch lavas (Tpr2) and underlying vitric tuffs, *qtz. latite, 10.5 my.*

Tpr1 / Twt — lower Pound Ranch lavas and associated (?) tuffs *rhyolite, 11.8my.*

Miocene

Ts — *laharic breccias, conglomerates, and sandstone*

Tpl — Popotosa Formation, *laharic breccias*

Tba2 — *basalt to basaltic andesite lavas*

Twr — *white rhyolite domes*

Trt — *rhyolitic tuffs*

Twr — *white rhyolite dikes*

Twcm / Tlc — Water Canyon Mesa lava *qtz. latite, landslide & colluvium deposits (Tlc)*

Til — *intermediate lavas*

Oligocene

Tsc — tuff of South Canyon *rhyolite ash-flow tuff, 26.2 m.y.*

Tba — *basaltic andesite lavas*

Tr — *rhyolite intrusives*

Tlu / Tll — Lemitar Tuff *upper crystal-rich, qtz. latitic and lower mod. crystal poor rhyolitic members, 26.3m.y.*

Ta / Tss / T6l — unit of Sixmile Canyon *mafic lavas & laharic breccias (Ta) laminated sandstone (Tss), ash-flow tuffs (T6t), rhyolitic lavas (T6l).*

Twr — *white rhyolite dikes*

? Tmd — *mafic dikes*

Tal — A-L Peak Tuff (?) *crystal-poor, rhyolitic tuffs*

Tl-m — *latite to monzonite dikes*

Thm — Hells Mesa Tuff *crystal-rich, qtz-rich, ash-flow tuff.*

Tsp / Tgm — Spears Formation *mafic lavas and volcaniclastic sedimentary rocks (Tsp), tuff of Granite Mountain (Tgm)*

PENNSYLVANIAN

ℙm — Madera Limestone

ℙs — Sandia Formation

p€ — Precambrian

SYMBOLS

Contact
Dashed where approximately located

65
Normal Fault
Dashed where approximately located, dotted where covered or inferred, arrow and number indicate dip direction and inclination of fault plane, ball on downthrown block

35
Strike and dip of bedding

55
Vertical Foliation
Strike and dip of flow foliation in lavas

Trend of lineation

Transport direction
in sediments from cross bedding or pebble imbrication

Volcanic vent

65
Shear zone
no proven displacement

Prospect pit

Adit

Shaft

Open cut

Mine dump

Silicification

Breccia zone

Ⓐ
Sample location for K/Ar date

Measured Section

a)
Drill hole data

a) C., Sec.34, 3S, 2W; all upper Santa Fe; 0-20' gravels, 20-40' red clay, 40-110' gravel, 110-380' sandy to gravelly mudstones

b) NW corner, Sec. 33, 3S, 2W, 0-70' gravels (prob. Qa), 70-300' gravelly mudstones (upper Santa Fe)

c) NW/4, SE/4, Sec. 23, 3S, 3W; 0-85' gravels, 85-120' gray to purple andesite (prob. Turkey track andesite of the Spears Fm).