OPEN FILE REPORT 119

GEOLOGY OF THE WEST FLANK OF THE MAGDALENA MOUNTAINS SOUTH OF THE KELLY MINING DISTRICT SOCORRO COUNTY, NEW MEXICO

by

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Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science of Geology

New Mexico Institute of Mining and Technology

November, 1979

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ABSTRACT

The geology of the west flank of the Magdalena Mountains south of the Kelly mining district has been dominated by emplacement of ash-flow tuffs and lavas, caldera collapse structures, and extensional block faulting associated with the Rio Grande rift and uplift of the Magdalena Mountains.

The oldest rock unit exposed is a volcaniclastic sandstone of the early Oligocene lower member of the Spears Formation. This was overlain successively, in the Oligocene, by the Hells Mesa Tuff, the flow-banded member of the A-L Peak Tuff, cauldron fill (including the andesite of Landavaso Reservoir and the unit of Sixmile Canon), the tuff of Lemitar Mountains and an overlying andesite, the tuff of South Canyon, and a xenocrystic andesite. In early and middle Miocene time, this volcanic sequence was covered by fanglomerates, laharic breccias, and sandstones of the Popotosa Formation. In the western half of the thesis area, in late-Miocene time, these sedimentary units were overlain by a broad plain of rhyolite lava flows.

Portions of three overlapping cauldrons, the North Baldy (32 m.y.), Magdalena (32-28 m.y.), and Sawmill Canyon (32-28 m.y.) cauldrons, are found in the thesis area. The collapse of the Magdalena and Sawmill Canyon cauldrons closely followed one another and buried the western and southern margins of the North Baldy cauldron. Their

combined collapse created a large dumbbell-shaped depression that shared cauldron fill in the area of overlap. The emplacement of andesitic and latitic dikes, the movement of hydrothermal fluids, and in the western half of the area, the intrusion of rhyolite domes and flows were largely controlled by the ring fracture zones of these cauldrons.

Beginning in the Oligocene, north-trending, down-to-the-west normal faults that accompanied regional extension overprinted the caldera structures and controlled the emplacement of white rhyolite and andesitic dikes. The movement of hydrothermal fluids was also localized along these structures. Uplift of the Magdalena Mountains, from about 7 m.y. ago to the present, also occurred along these north-trending faults.

Numerous abandoned mines and prospects, largely for copper and gold, are found along zones of mineralization controlled by cauldron ring fractures and north-trending extensional faults. The economic potential for the area is variable. The favorable ore producing horizon in the Kelly district has been downfaulted in the thesis area to a depth where recovery of replacement deposits, if they exist, would be uneconomic. Perlite found in the rhyolite flows frequently contains non-expandable phenocrysts and is uneconomic. However, exploration for gold is presently being carried out on Baldy Ridge and mineralization in Mill Canyon deserves further examination.

INTRODUCTION

Statement of the Problem

The principal objective of this study is to determine the stratigraphic and structural relationships of Tertiary volcanic and sedimentary rocks along the west flank of the Magdalena Mountains south of the Kelly Mining district, and to compare these relationships with those described in studies of adjacent areas.

The major features studied include the margins of the North Baldy, Magdalena, and Sawmill Canyon cauldrons, in the eastern portion of the thesis area, and an extensive field of Miocene rhyolite flows in the western portion. A secondary objective was to evaluate the mineral potential of the area.

This study was undertaken as part of a larger mapping project of the Socorro-Magdalena area sponsored by the New Mexico Bureau of Mines and Mineral Resources.

Location and Accessibility

The Magdalena Mountains are located about 26 km (16 mi) due west of Socorro in central Socorro County, New Mexico. The region under study, on the west flank of the Magdalena Mountains, covers an area of about 52 sq km (20 sq mi), the center of which lies 8 km (5 mi) south of the town of Magdalena (fig. 1). With the exception of a few ranches

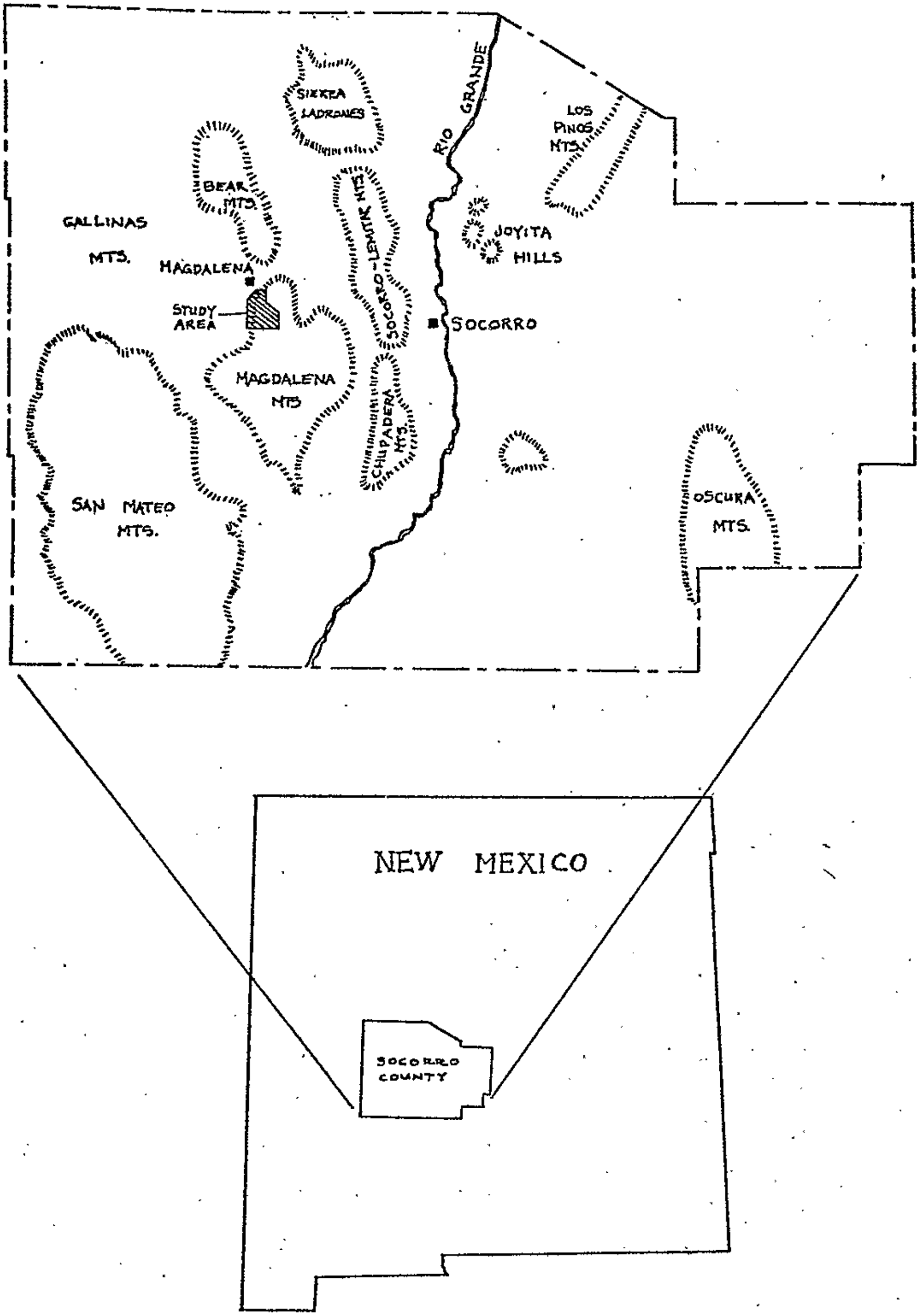


Figure 1. Location map showing relationship of thesis area to major topographic features in Socorro County.

and patented mining claims, the mapped area lies entirely within the Cibola National Forest.

Access to the southeastern portion of the area is by the Langmuir Laboratory road which extends south from U.S. Highway 60. The last 14 km (9 mi) of this road is rough and steep. From the end of this road, near South Baldy Peak, a trail extends approximately 8 km (5 mi) northward along the crest of the range, through the eastern edge of the mapped area, to North Baldy Peak.

Access to the crest of the Magdalena Range in the northeastern portion of the thesis area is by a 6.5 km (4 mi) graded road from Magdalena to the ghost town of Kelly, and thence about 6.5 km (4 mi) up Chihuahua Gulch on a very steep jeep road to North Baldy Peak. Another road leads southward from Kelly to Patterson Canyon.

Access to the head of Hop Canyon is by way of the unpaved Hop Canyon road which turns south from the Kelly road about 2.5 km (1.5 mi) south of Magdalena. Access to Agua Frio Canyon is by a ranch road that turns west from the Hop Canyon road.

Access to Rock Springs and Mill Canyons is by way of an all-weather, dirt road, State Highway 107, which leads south from U.S. 60 at Magdalena. Approximately 12 km (7.5 mi) south of Magdalena turn east on the Mule Shoe Ranch road for 0.8 km (0.5 mi) to the Rock Springs Canyon road, on the left, or continue 2.5 km (1.5 mi) to the Mill Canyon road, also on the left. Both roads are very rough.

Topography and Physiographic Setting

The topography of the western flank of the Magdalena Mountains is characterized by high relief and steep slopes. Elevations in the area mapped range from 2103 m (6900 ft) at the extreme north end of Hop Canyon to 3125 m (10,254 ft) along the ridge between North and South Baldy peaks. Slopes reach a maximum of approximately 1:3, with outcrops of the more resistant units forming steep cliff faces. Canyons east of the range crest drain eastward into Water Canyon; canyons west of the crest drain northwest and west into Hop, Agua Frio, Rock Springs, and Mill canyons. The small springs at the head of Mill Canyon and the extreme head of Agua Frio Canyon typically run throughout the year.

The northern half of the Magdalena Mountains is characterized by westward-dipping, north-trending, fault blocks in which Precambrian, Paleozoic, and Cenozoic rocks are exposed. The fault blocks were formed by extensional faults of the Rio Grande rift and faulting that accompanied uplift of the range. Faulting began in late Oligocene-early Miocene time and continues to the present. In the central Magdalena Mountains, where only Tertiary rocks are exposed, this block faulting overprints a complex of intersecting caldera structures. Three of these structures, the Magdalena, Sawmill Canyon, and North Baldy cauldrons, are present in the mapped area. A panoramic view of the western slope of the Magdalena Mountains is shown in figure 2.

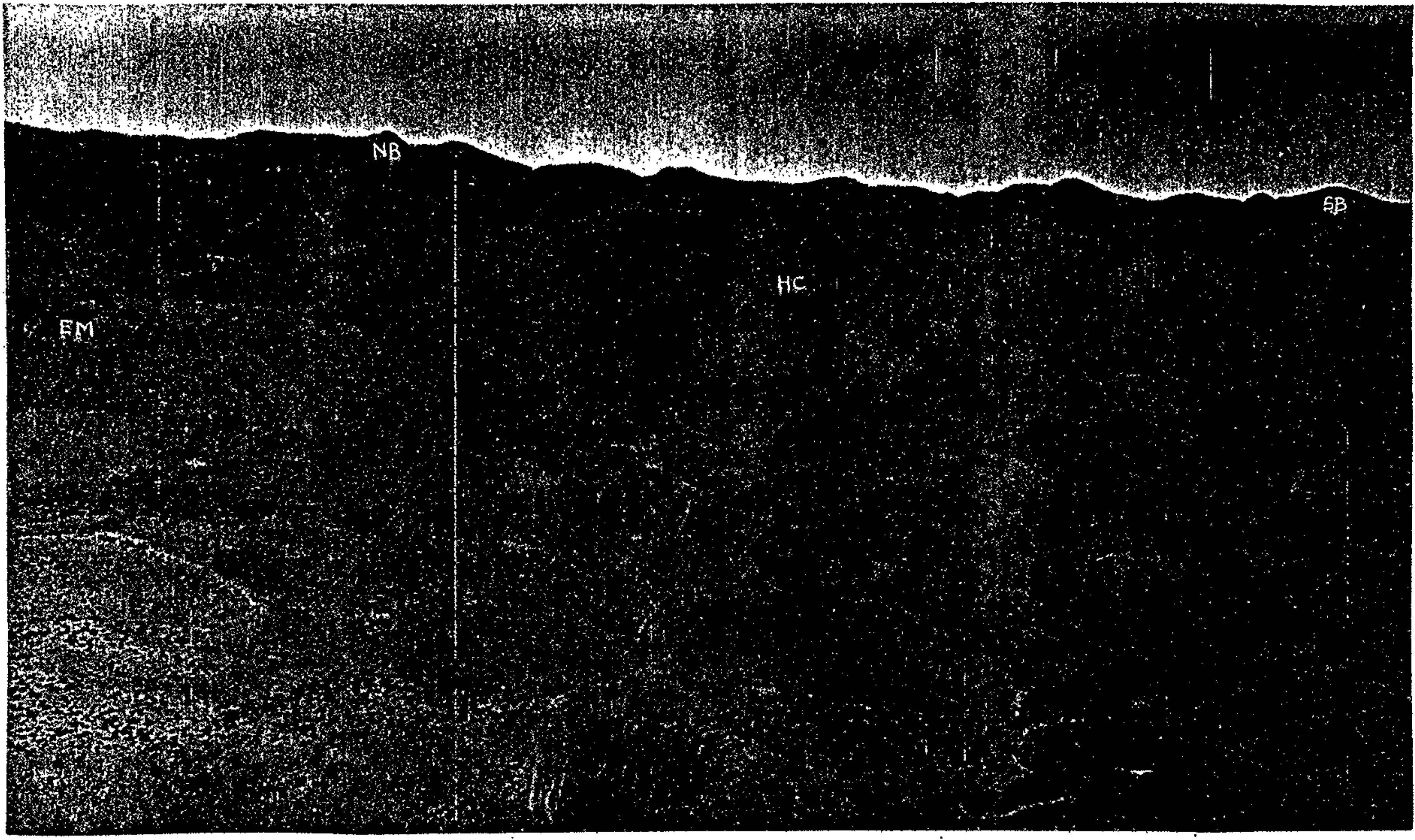


Figure 2. Panoramic view of the western slope of the Magdalena Mountains, looking east. North Baldy Peak (NB), South Baldy Peak (SB), Elephant Mountain (EM), Hop Canyon (HC).

Methods of Investigation

During the summers of 1977 and 1978, geologic mapping was carried out at a scale of 1:12000 on an enlargement of the Magdalena 15-minute quadrangle of the U.S. Geological Survey. Aerial photographs of the GS-VMA series (3-7-56) and U.S. Forest Service (4-13-71) facilitated field mapping. A Brunton compass was used to measure attitudes of bedding and foliation.

Seventy-four thin-sections were made and stained for potassium by etching in fuming HF for 70 seconds and immersion in sodium cobaltinitrite for 3 minutes. The staining procedure follows that given by Deer, Howie, and Zussman (1966). The thin-sections, and the rock samples from which they were taken, were analyzed to aid description and correlation of rock units. The petrographic analysis was carried out with a Zeiss binocular research microscope. Classification of igneous rock types is according to the proposed IUGS classification (Strekeisen, 1967, 1976); classification of sedimentary rocks is according to F.J. Pettijohn (1975).

Previous Work

References dealing with the geology and stratigraphy of the Magdalena Mountains and surrounding area are summarized in the following chronological list. The locations of studies in the Magdalena Mountains-Socorro Peak area are shown in figure 3.

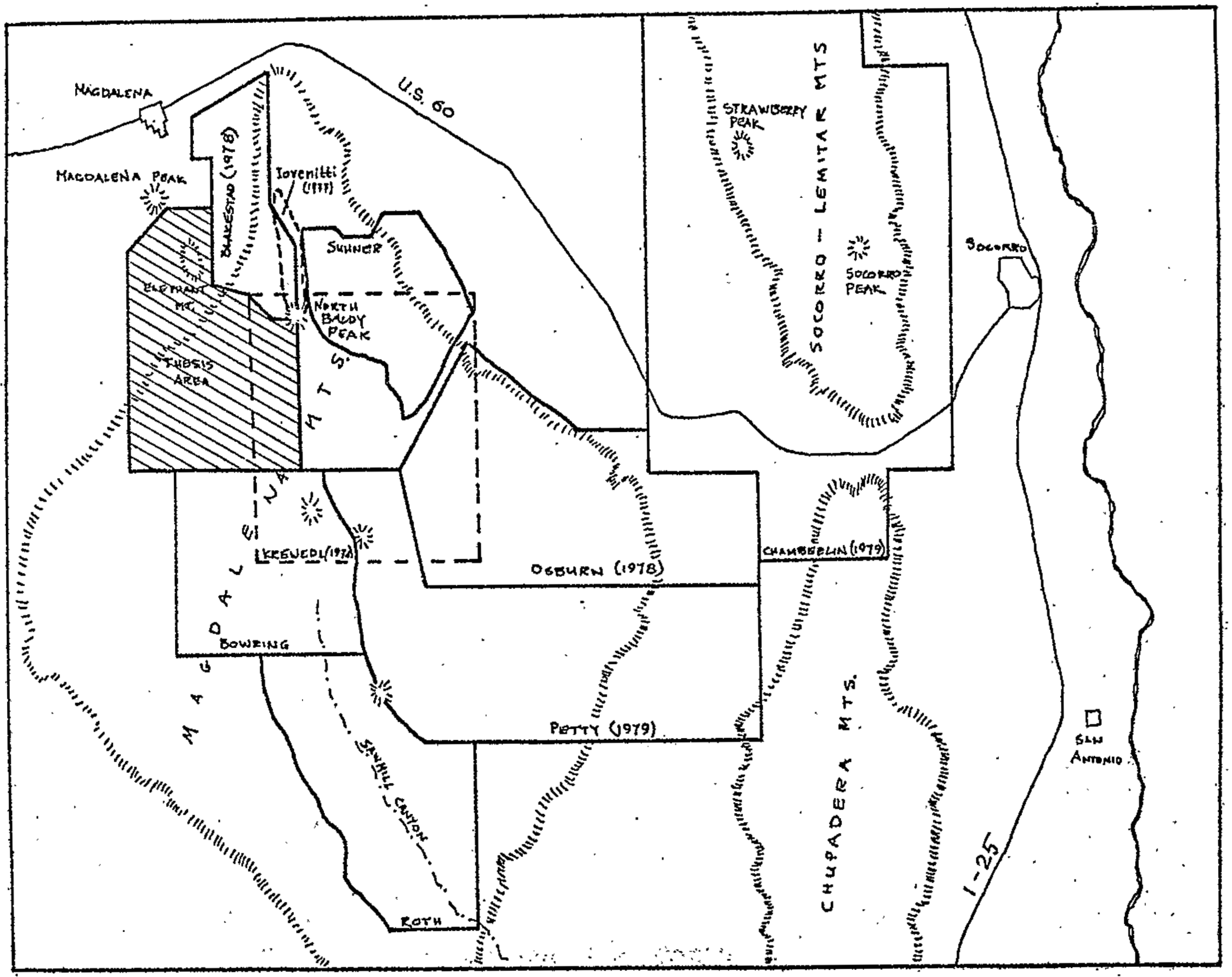


Figure 3. Relationship of thesis area to other studies in the Magdalena Mountains-Socorro Peak area.

1900	Herrick (1900) conducted a reconnaissance survey of portions of Socorro and Valencia Counties and recorded the presence of trachyte and rhyolite intrusives in the Bear, Gallinas, and Datil mountains.
1910	Lindgren, Graton, and Gordon (1910) examined the geology and mining activities west of Water Canyon.
1918	Wells (1918) briefly described the geology of the central Magdalena Mountains.
1932	Lasky (1932) discussed the general geology of the Magdalena Mountains and examined the mineral deposits and mines in Hop and Mill Canyons.
1942	Loughlin and Koschmann (1942) published a professional paper on the geology and ore deposits of the Kelly mining district.
1957	Tonking (1957) mapped the Puertecito 15-minute quadrangle and subdivided the now obsolete Datil Formation into the Spears, Hells Mesa, and La Jara Peak Members.
	Givens (1957) mapped the Dog Springs 15-minute quadrangle and subdivided the Hells Mesa member in the Gallinas Mountains into seven subunits.
	Weber (1957) studied the Stendel perlite prospect and described the petrography of rhyolite flows from a small area on the east side of Agua Frio Canyon in the Magdalena Mountains.
1963	Weber (1963) excluded the La Jara Peak Member from the now obsolete Datil Formation after Willard's (1959) suggestion.
1968	Stacy (1968) studied the geology of the area around Langmuir Laboratory in the central Magdalena Mountains.
1971	Chapin (1971a) discussed the development of the Rio Grande rift and the different characteristics of its northern, central, and southern segments.
	Chapin (1971b) published a K-Ar age for the La Jara Peak Andesite and noted that hydrothermal mineralization had occured both before and after emplacement.
	Park (1971) studied the petrology of the Tertiary Anchor Canyon stock at the north end of the Magdalena Mountains.

Weber (1971) suggested elevating the Datil Formation to Group status.

1972 Brown (1972) mapped the southern Bear Mountains and subdivided the Hells Mesa Formation into a crystal-rich lower member (tuff of Goat Springs) and a crystal-poor upper member (tuff of Bear Springs).

1973 Bruning (1973) examined in detail the lithology and origin of the Popotosa Formation.

Deal (1973) studied the northern San Mateo Mountains and identified the Mt. Withington cauldron which he considered the source of the A-L Peak and Potato Canyon tuffs. The A-L Peak Tuff was renamed from Brown's (1972) tuff of Bear Springs.

Simon (1973) mapped the geology of the Silver Hill area and distinguished the unit of Arroyo Montosa from the Popotosa Formation, placing it between the La Jara Peak Andesite and the older volcanics.

1974 Chamberlin (1974) mapped the geology of the Council Rock district and expanded the A-L Peak Rhyolite to the A-L Peak Formation, subdividing it into four subunits.

Chapin and others (1974) discussed the structural controls on mineralization in the northern Magdalena Mountains.

Krewedl (1974) mapped the geology of the central Magdalena Mountains, including the eastern margin of the thesis area.

1975 Chapin and Seager (1975) discussed the evolution of the Rio Grande rift in the Socorro and Las Cruces areas.

Chapin, Seimers, and Osburn (1975) compiled a summary of radiometric ages of rocks from New Mexico.

1976 Wilkinson (1976) mapped the Tres Montosos area immediately south of the Council Rock district.

1977 Iovenitti (1977) studied the origin of jasperoid in the Kelly Limestone along the crest of the Magdalena Range.

1978 Blakestad (1978) restudied the Kelly Mining district and correlated rock units identified by Loughlin and Koschmann (1942) with the Spears Formation, Hells

Mesa Tuff, A-L Peak Tuff, tuff of Lemitar Mountains, andesite of Landovaso Reservoir, and La Jara Peak Andesite.

Chamberlin (1978) examined the structural development of the Lemitar Mountains and its relationship to the Rio Grande rift.

Chapin (1978) discussed the characteristics and evolution of the Rio Grande rift in reference to it northern, central, and southern segments.

Chapin, Chamberlin, and others (1978) examined in detail the exploration framework of the Socorro geothermal area.

Chapin, Jahns, and others (1978) prepared a geologic road log for the Socorro-Magdalena-San Mateo mountains area.

Osburn (1978) studied the east-central portion of the Magdalena Mountains and defined the unit of Sixmile Canyon. He also renamed the upper tuffs as the tuff of South Canyon.

1979 Petty (1979) mapped the geology of the southeastern portion of the Magdalena Mountains.

In addition to the completed studies above, the following work is in progress:

S. Bowring in the central Magdalena Mountains

R.M. Chamberlin in the Lemitar Mountains-Socorro Peak area

M. Donze in the southwestern Magdalena Mountains

S. Roth in the southern Magdalena Mountains

W. Sumner in the northern Magdalena Mountains.

Acknowledgements

I would like to thank Dr. Charles Chapin for suggesting the problem and for his continued support through its completion; his comments and criticisms improved both the interpretation of the geology and the quality of the written manuscript. I would also like to thank G. Robert Osburn for his suggestions and frequent help in the field. Dr. Clay T. Smith critically read the manuscript and provided helpful comments. Drs. Marc W. Bodine, Jr. and David T. Norman also read the manuscript.

The thesis was supported by a grant from the U.S. Department of Health, Education, and Welfare. The New Mexico Bureau of Mines and Mineral Resources also provided financial and logistical support.

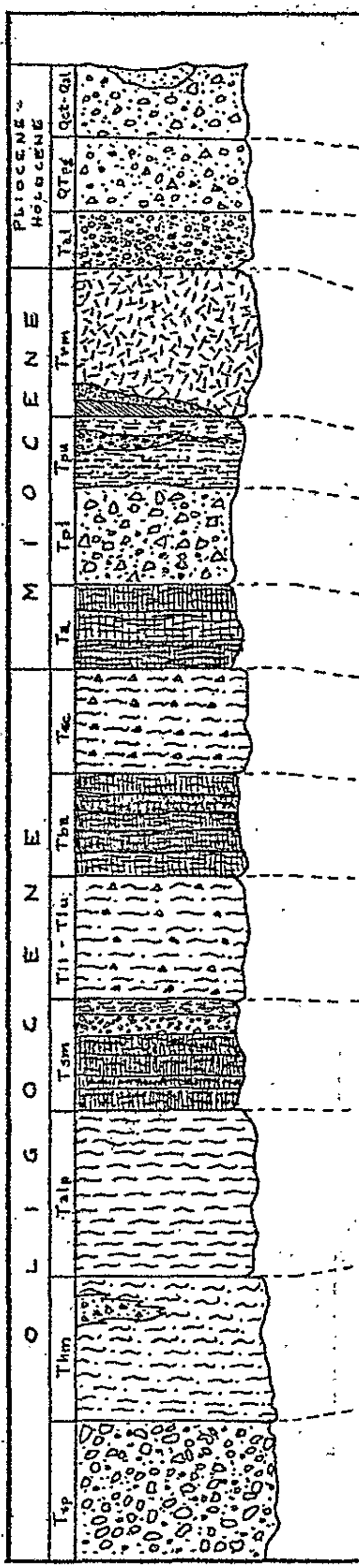
STRATIGRAPHY AND PETROGRAPHY

Tertiary Extrusive and Sedimentary Rocks

Central Socorro County lies within the northeastern portion of the Datil-Mogollon volcanic field of Oligocene to early Miocene age. Near Puertecito, northeast of the Gallinas Mountains, the base of this Tertiary volcanic sequence lies conformably on the Eocene Baca Formation (Tonking, 1957); in the central Magdalena Mountains the volcanic sequence lies unconformably on late Paleozoic rocks (Krewedl, 1974).

The ancestral Magdalena Mountains were uplifted during the Laramide orogeny (Loughlin and Koschmann, 1942) and the erosion that followed exposed the underlying Paleozoic rocks. The resulting detritus was deposited northward into the Baca basin. At the time that volcanism began, about 37 m.y. ago, topographic relief was moderate (Chapin, 1971a).

In the central Magdalena Mountains the oldest units of the Tertiary sequence are the volcaniclastic sedimentary rocks of the Spears Formation of early Oligocene age. In the middle and late Oligocene this was followed by a series of ash-flow tuffs, andesite lavas, and cauldron-fill units. In the thesis area this sequence was overlain in Miocene time by the laharic breccias and sandstones of the Popotosa Formation and by the rhyolites of Magdalena Peak. The Tertiary rock units in the thesis area are shown in figure 4.



Alluvium: (0-15 m, 50 ft) ALLUVIUM and COLLUVIUM: deposits of sand and gravel along stream channels and terraces. Colluvial deposits mantle the lower slopes, with rock glaciers present locally at higher elevations.

Piedmont Gravels: (0-70 m, 230 ft) UNCONSOLIDATED PIEDMONT GRAVELS: gravels predominately of ash-flow tuff, rhyolite, and andesite.

Alluvium: (0-15 m, 50 ft) ALLUVIUM: subrounded pebble- and cobble-size detritus of both aphanitic and crystal-rich rhyolite lavas. Lies above a tuff of the rhyolite of Magdalena Peak.

Rhyolite of Magdalena Peak: 14-13 m.y. (0-130 m, 430 ft) RHYOLITE FLOWS and DOMES: brn. to red-brn., dense, slightly to mod. porphyritic flow-banded rhyolite; vitrophyric and perlitic zones present locally. Buff to gray-brn. ash-flow tuffs interbedded locally in lower and middle parts of flow. Magdalena Peak is the inferred vent.

Upper Popotosa Formation: (0-30 m, 100 ft) CONGLOMERATES and SANDSTONES: buff to brn., mod. to poorly indurated, heterolithic cgl. and cgl. ss.

Lower Popotosa Formation: (0-120 m, 400 ft) MUDFLOW DEPOSITS and SANDSTONES: red-brn., very well-indurated., heterolithic laharic breccias with abundant clasts of underlying volc. units, with minor interbedded sandstones.

Lava Flows: (0-90 m, 300 ft) ANDESITE: gray to red-gray, mod. porphyritic lavas w/ phenocrysts of plg., cpx., biot., and pseudomorphs after ol. Xenocrysts of qtz. and kspar. are also present.

Tuff of South Canyon: 26 m.y. (0-120 m, 400 ft) ASH-FLOW TUFFS: multiple-flow, simple cooling unit of rhyolite ash-flow tuff. Dark-gray to pink-gray, mod. to densely welded, mod. crys.-rich tuff w/ chatoyant sanidine and euhedral qtz.

Lava Flows: (0-150 m, 500 ft) BASALTIC ANDESITE and ANDESITE LAVAS: La Jara Peak-like, dark red-gray, dense basaltic andesites w/ small, red, hematized, ferromag. phenocrysts, and pink-gray to red-brn. andesites w/ phenocrysts of hornblende and biotite.

Tuff of Lemitar Mountains: 28 m.y. (105-180 m, 350-600 ft) ASH-FLOW TUFFS: multiple-flow, comp. zoned, simple to compound cooling unit of densely welded tuff. Lt.-gray to pale-red, crys.-poor lower member 105-120 m (350-400 ft) thk. Md.-red, crys.-rich, qtz.- and biot.-rich, 2-feld. upper member 0-60 m (200 ft) thk.

Unit of Sixmile Canyon: (0-270 m, 900 ft) ANDESITE to BASALTIC ANDESITE LAVAS and SANDSTONES: dark-brn. and red-brn. porphyritic andesites, dark-gray to red-brn. aphanitic andesites, and poorly to well-sorted ss. and conglom. ss. Flows are highly variable.

A-L Peak Tuff - flow-banded member: 32-28 m.y. (0-61 m, 200 ft) ASH-FLOW TUFF: A-L Peak Tuff is a composite ash-flow sheet comprised of basal gray-massive, middle flow-banded, and upper pinnacles members; all densely welded, crys.-poor, 1-feld., rhyolite ash-flow tuffs. Gray to prpl.-gray flow-banded member has lineated pumice and flow folds.

Hells Mesa Tuff: 32 m.y. (365-1158 m, 1200-3800 ft) ASH-FLOW TUFFS: rhyolite, multiple-flow, simple cooling unit of densely welded, crys.-rich, qtz.-rich, 2-feld., massive tuffs. Pink to red-brn. when fresh, gray when propyliticaIly altered. Lenses of laharic breccias of Spears composition interbedded in upper part of tuff between North Baldy Peak and Mill Canyon.

Spears Formation - volcaniclastic unit: 37-33 m.y. (0-100 m, 330 ft) CONGLOMERATES and SANDSTONES: volcaniclastic apron of latite to andesite composition; red to prpl.-brn. coarse ss. and cgl.

Figure 4. Stratigraphic section of the thesis area. Graphic section and descriptions modified after Chapin, Chamberlin, and others (1978). Thicknesses are exposed thicknesses and may not refect the true thickness of poorly exposed units.

Spears Formation

Originally named the Spears Member of the now obsolete Datil Formation by Tonking (1957), the Spears Formation is a sequence of latitic and andesitic conglomerates, volcaniclastic breccias, and sandstones. Ash-flow tuffs and lavas are frequently interbedded in the upper part of the sequence. The Datil Formation was raised to group status by Weber (1971) and Chapin (1971b) raised the Spears to formational status. The Spears Formation was subdivided by Brown (1972) into a lower unit of volcaniclastic conglomerates and sandstones, and an upper unit of interbedded sedimentary rocks and latitic to andesitic ash-flow tuffs and lavas. Detailed studies of the Spears Formation have been made by Brown (1972), Krewedl (1974), Chamberlin (1974), Wilkinson (1976), and Blakestad (1978).

A latite tuff breccia from the Spears Formation at the north end of the Joyita Hills has been dated by the K-Ar method on biotite at 37.1 ± 1.5 m.y. (Weber, 1971). Dates on other samples of the Spears Formation range between 37 and 33 m.y. (Chapin, unpublished dates). These dates are compatible with the 32 m.y. age of the overlying Hells Mesa Tuff.

In central Socorro County, the Spears Formation crops out discontinuously over a broad area from the Datil Mountains in the west to the Joyita Hills in the east, a distance of about 80 km (50 mi). At the type section, on Hell's Mesa in the Puertecito quadrangle, Tonking (1957) measured a thickness of 410 m (1350 ft). In the southern Bear Mountains, Brown (1972) estimated the thickness of the Spears Formation to be about 595 m (1950 ft), and at the south end of the Kelly district, Blakestad (1978) estimated the thickness of an incomplete section to be about 550 m (1800 ft). The outcrops of the Spears Formation in the thesis area are the southern extension of the exposures in the Kelly district measured by Blakestad (1978).

In the thesis area, only part of the lower member of the Spears Formation is exposed. The A-L Peak Tuff has been downfaulted against the Spears Formation along the margin of the Magdalena cauldron and the upper Spears has been cut out. Outcrops of sandstone, which are confined to the south side of Patterson Canyon along the north-central boundary of the thesis area, are discontinuous and largely obscured by colluvium. In the Kelly district, Blakestad (1978) reported that the sandstones of the lower member of the Spears Formation were often cross-bedded. In the thesis area, cross-bedding was not observed; exposures, however, are poor.

In hand specimen the lower member is a well-indurated, volcaniclastic, coarse-grained sandstone that is characterized by a reddish- to purplish-brown color on weathered surfaces and grayish-purple on fresh surfaces. The sub-angular to sub-rounded clasts are poorly to moderately sorted and range from 0.5 to 2.0 mm in the long dimension. Whitish feldspar is common with biotite present in lesser amounts.

North of the study area, in the Kelly district and Bear Mountains, the lower member is more heterogeneous and consists mainly of pebble and cobble conglomerates (Brown, 1972; Blakestad, 1978). Detailed petrography of the Spears Formation has been discussed by Tonking (1957), Chamberlin (1974), and Blakestad (1978).

Hells Mesa Tuff

The Hells Mesa Tuff is a multiple-flow, simple cooling unit of crystal-rich, quartz-rich, two-feldspar, densely welded, rhyolitic ash-flow tuff (Chapin, Chamberlin, and others, 1978). It is widespread and crops out in the Gallinas, Bear, Magdalena, and Lemitar Mountains, and in the Joyita Hills. The tuff conformably overlies the Spears Formation in the Kelly Mining district; in the thesis area the Hells Mesa is in fault contact with younger extrusive units.

The Hells Mesa Tuff was named by Tonking (1957) after a conspicuous peak at the eastern edge of the Bear Mountains. Originally assigned as a member within the now obsolete Datil Formation, the Hells Mesa was raised to formational status by Chapin (1971b) and later subdivided into seven units by Brown (1972). Chapin (1974b) and Deal and Rhodes (1976) restricted the Hells Mesa Tuff to include only the basal crystal-rich, densely welded unit corresponding to Brown's (1972) tuff of Goat Springs. The source of the Hells Mesa Tuff is the North Baldy cauldron located in the central Magdalena Mountains (Blakestad, 1978; Chapin, Chamberlin, and others, 1978).

In the central Magdalena Mountains the cauldron-facies Hells Mesa Tuff has a surface area of greater than 25 sq km (10 sq mi) and reaches an apparent thickness of greater than 1158 m (3800 ft) (Krewedl, 1974). This thickness may be exaggerated by unrecognized faults. In the southern Bear Mountains the thickness of a measured section of outflow-facies Hells Mesa was 195 m (640 ft) (Brown, 1972). At the head of Mill Canyon, in the thesis area, the maximum observed thickness is about 365 m (1200 ft). The stratigraphic top is not exposed, however, and the maximum thickness may be much greater.

Biotite from the Hells Mesa type section has been dated by the K-Ar method at 30.6 m.y. (Weber and Bassett, 1963). Samples from the Gallinas Mountains and the Joyita Hills of a crystal-rich tuff correlated with the Hells Mesa were dated by the same method at 32.1 m.y. and 32.4 m.y., respectively (Burke and others, 1963). These older dates are in better agreement with the fission-track date of the overlying A-L Peak Tuff.

Cauldron-facies Hells Mesa Tuff exposed in the thesis area forms the crest of the Magdalena range between

North and South Baldy peaks. The color of the tuff ranges from pinkish gray to buff on fresh surfaces, and reddish brown to gray on weathered surfaces. Propylitization in some areas, especially southwest of North Baldy Peak, gives the rock a whitish to greenish tint. Outcrops of the Hells Mesa Tuff are best exposed along the crest of the range; at lower elevations the outcrops are usually obscured by broad, steep slopes of blocky talus.

Southwest of North Baldy Peak, in section 18 (T3S, R3W), the Hells Mesa forms a prominent outcrop of a moderately welded, white to grayish-white tuff that contains interbedded grayish-purple lenses of laharic breccias and sandstones (fig. 5). Lithic fragments in these interbedded lenses are predominately of the Spears Formation and vary in size from coarse sand to large cobbles. The sequence of tuff and interbedded lenses of laharic breccia is overlain by an interval of sandstones and conglomerates. About 1000 m (3000 ft) south of North Baldy Peak, the moderately welded, grayish-white Hells Mesa grades into a more densely welded, light-tan tuff. To the south, along the crest of the range and at lower elevations at the head of Hop Canyon, locally prominent outcrops of Hells Mesa show evidence of silicification and numerous small quartz veins.

In hand specimen the Hells Mesa Tuff is a crystal-rich porphyry with distinctive quartz phenocrysts that reach 3 to 5 mm in diameter. Pumice is usually not conspicuous. Both dark and light colored lithic fragments,

Figure 5. Panoramic view of the Hells Mesa Tuff, in section 18 (T3S, R3W), looking southwest from North Baldy Peak. Lenses of laharic breccia (LB) are interbedded in the propylitized tuff. An interval of sandstones and conglomerates (SS) overlies the tuff and forms the crest of hill "9785". The exposures of Hells Mesa Tuff end against the North Baldy cauldron margin (CM).

ranging in size from 2 mm to 1 cm, comprise as much as 3 percent of the rock. The abundance of lithic fragments in the tuff increases in the area southwest of North Baldy Peak, especially in proximity to lenses of laharic breccia.

In thin section sanidine is the most abundant phenocryst and comprises between 15 and 25 percent of the rock. Subhedral laths, sometimes showing carlsbad twinning, average 1 mm or less in length. The sanidine is typically intensely altered. Quartz phenocrysts are anhedral, rounded, and commonly deeply embayed. They are typically clear and average 0.8 mm in diameter.

Subhedral plagioclase phenocrysts, ranging in size from 0.2 to 1.6 mm, comprise between 5 and 10 percent of the rock. The plagioclase shows varying degrees of alteration; some grains are almost totally replaced by calcite. Albite twinning is evident in a few phenocrysts; however, the intensity of alteration has probably obscured the presence of twinning in other phenocrysts. The composition of the plagioclase (8 grains, Michel-Levy method) is about An33. A greater number of grain counts is needed for an accurate determination, however, the measurement compares favorably with Krewedl's (1974) estimate of An32 - An36.

Lath-shaped phenocrysts of biotite averaging 0.4 mm in length comprise about 2 percent of the rock. The biotite is largely altered to magnetite and calcite, though a few grains showed a remnant brown color in plain light. Magnetite is present in trace amounts as rounded grains that average 0.3 mm in diameter. In one sample, trace amounts of what appeared to be an altered clinopyroxene are present. These subhedral grains average 0.8 mm in diameter and show relatively high relief, well-developed cleavage, and angular extinction. The groundmass is completely devitrified and altered. Detailed petrographic descriptions of outflow-facies Hells Mesa Tuff have been made by Brown (1972), Simon (1973), and Chamberlin (1974).

Interbedded Units. Southwest of North Baldy Peak, lenses of laharic breccia are interbedded in the Hells Mesa Tuff (fig. 6); the thickness of this interbedded interval of breccia and tuff reaches about 120 m (400 ft). The clasts in the breccia are angular to subrounded and average 1 to 3 cm in diameter; near North Baldy Peak they increase in size and may reach 0.5 m (1.5 ft) or more in diameter. Blakestad (1978) reported clasts that reach 2 m (6 ft) in size. The clasts are predominately gray to purplish-gray and have Spears Formation lithologies. The matrix appears to consist of a mixture of reworked Spears and Hells Mesa Tuff.

Andesite lavas interbedded in the Hells Mesa Tuff, in approximately the same stratigraphic interval as the laharic breccias, are found south of hill "9730" along the east side of the ridge, in sections 19 and 30 (T3S, R3W). The andesites are heterogeneous and vary between a purplish-gray aphanitic andesite, and a distinctive "turkey track" andesite with highly contorted mineral alignment.

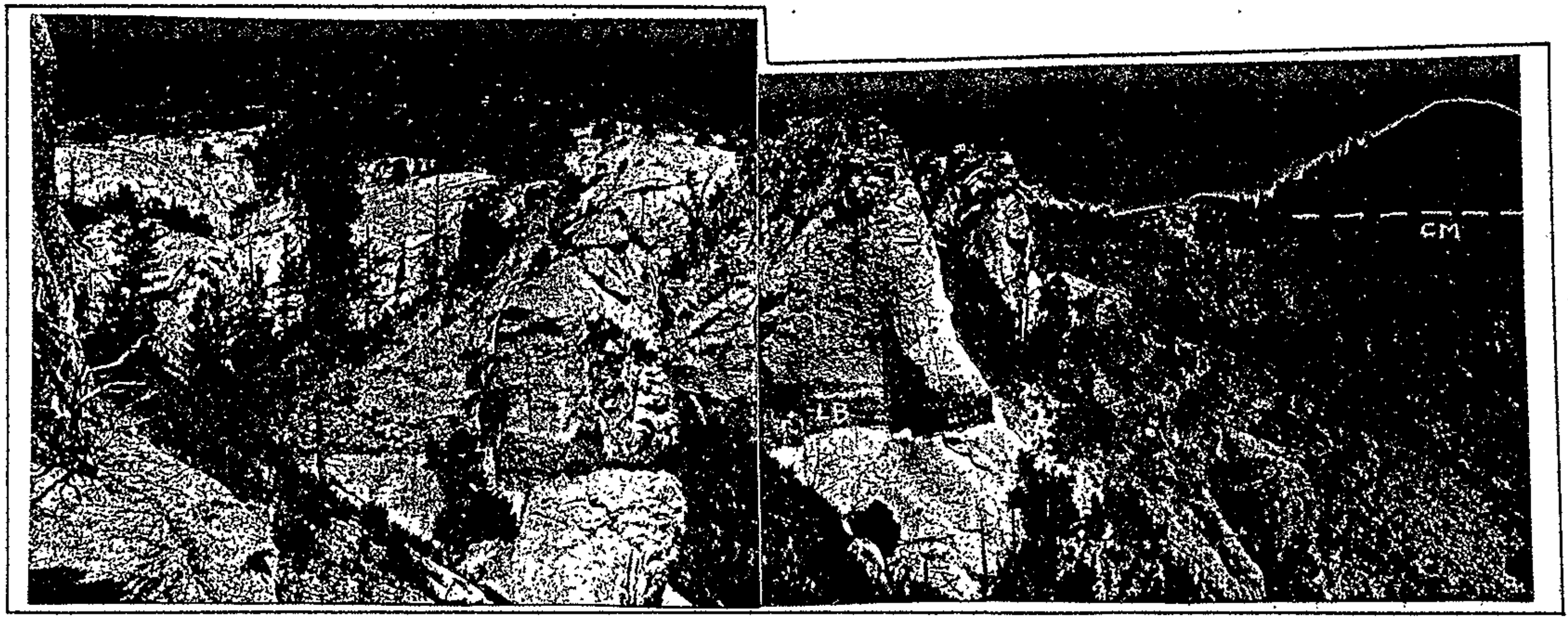


Figure 6. Laharic breccia (LB) interbedded in Hells Mesa Tuff, in section 18 (T3S, R3W). View is to the north; North Baldy Peak is at the far right just outside of the North Baldy cauldron margin (CM).

Basal portions of the flows are commonly autobrecciated. The andesite is less resistant than the Hells Mesa Tuff and exposures are typically discontinuous. However, a prominent outcrop of the andesite is found on the ridge along the north side of Mill Canyon in the N 1/4 of section 31 (T3S, R3W). This outcrop is associated with prominent, northwest-trending outcrops of Hells Mesa Tuff which appear to have been partially silicified by a northwest-trending shear zone. A few prospects have been cut along quartz veins in both andesite and Hells Mesa Tuff.

Southwest of North Baldy Peak on hill "9785", in section 18 (T3S, R3W), the tuffs and interbedded breccias are overlain by a 38 m (125 ft) interval of sandstones and conglomerates. The sandstones are commonly medium- to very coarse-sand size and range from very poorly to moderately sorted. The clasts are predominately of Spears lithologies. The sandstone shows a wide variability in color, ranging from dark purplish gray to buff. Rocks that have been strongly propylitized are pale green to geenish gray in color. A thin, silt to very fine-grain size red sandstone is found on the the south side of hill "9785" near the top of the sandstone interval.

The lenses of laharic breccia, andesite flows, conglomerates, and sandstones are probably confined to the upper portion of the Hells Mesa Tuff. Blakestad (1978) has suggested that the interbedded breccias in this area are similar to the mesobreccia described by Lipman (1976) in the

San Juan Mountains of Colorado. In this interpretation, Spears and other material found in the laharic breccias were shed as land slides from the topographic cauldron margin and became interbedded with cauldron-facies Hells Mesa Tuff during collapse of the North Baldy cauldron (Blakestad, 1978; Chapin, Jahns, and others, 1978).

A-L Peak Tuff

The A-L Peak Tuff is a composite ash-flow sheet (Chapin and Deal, 1976) that crops out over a large area in west-central Socorro County. The tuff was named by Deal and Rhodes (1976) for a densely welded, crystal-poor, one-feldspar, rhyolite ash-flow tuff on the northeast flank of A-L Peak in the San Mateo Mountains. At the type section the A-L Peak Tuff lies unconformably on the Hells Mesa Tuff (Deal and Rhodes, 1976). The A-L Peak correlates with Brown's (1972) tuff of Bear Springs. The A-L Peak Tuff has been divided into three members: a lower gray-massive member, a middle flow-banded member, and an upper pinnacles member; the flow-banded and pinnacles members are frequently separated by a tongue of La Jara Peak Basaltic Andesite (Chapin, Chamberlin, and others, 1978).

In the San Mateo Mountains the complete A-L Peak Tuff section attains a thickness of 610 m (2000 ft); in the Bear Mountains, 20 km (12 mi) north of Magdalena, the A-L Peak is about 305 m (1000 ft) thick (Brown, 1972). In the

Kelly mining district, Blakestad (1978) estimated the thickness of an incomplete A-L Peak section to be 152-244 m (500-800 ft). The A-L Peak Tuff has been dated at 31.8 ± 1.7 m.y. by the fission track method on sphene taken from the basal vitrophyre at the type section (Smith and others, 1976).

Only the flow-banded member, an overlying andesite, and a pumiceous ash-flow tuff of probable local origin are exposed in the thesis area. The thickness of the flow-banded member and associated andesite and tuff are less than 61 m (200 ft). Blakestad has estimated a similiar thickness for the flow-banded member in the Kelly mining district.

The flow-banded member of the A-L Peak Tuff is a densely welded, crystal-poor ash-flow tuff. It is exposed on the south side of Patterson Canyon along the north-central boundary of the thesis area. The flow-banded member is typically streaked with flattened and lineated gas cavities and pumice. On fresh surfaces the rock is gray to light purplish-gray; weathered surfaces are buff to brownish-gray. Where propylitic alteration has occurred, the rock has a greenish tint. The lineated pumice, which comprise between 15 and 25 percent of the rock, are typically light gray in a darker matrix. The more flow-banded exposures tend to fracture along planes of foliation and produce a platy talus.

In hand specimen, phenocryst content is usually less than 10 percent. Euhedral to subhedral sanidine, commonly less than 1 mm in diameter, is the most abundant phenocryst. Quartz phenocrysts are typically rounded and comprise less than 1 percent of the rock. Detailed petrographic descriptions of the A-L Peak Tuff have been made by Brown (1972), Simon (1973), and Chamberlin (1974).

North of the thesis area, in the Bear Mountains and the Kelly district, Brown (1972) and Blakestad (1978) report the presence of andesite interbedded between the flow-banded and pinnacles members of the A-L Peak Tuff. The pinnacles member is absent in the thesis area, however, an andesite overlying the flow-banded member crops out on the south side of Patterson Canyon.

Brown (1972) estimated the thickness of this interbedded andesite to range from less than 3 m (10 ft) to more than 21 m (70 ft); he noted that the variability in thickness may have resulted from erosional topography on the underlying flow-banded member. In the thesis area the andesite lies between the flow-banded member and a tuff of local origin and is less than 10 m (33 ft) thick.

The andesite is a dark purplish gray on weathered surfaces and somewhat lighter in color on fresh surfaces. It is frequently characterized by amygdules of quartz and calcite that weather out on exposed surfaces giving the rock a vesicular appearance. Autobrecciation is sometimes evident in the basal portions of the flows. In hand specimen the andesite is generally aphanitic with a few phenocrysts of what appear to be a clinopyroxene. These subhedral phenocrysts are less than 1 mm in diameter and are typically surrounded with a thin, reddish corona of hematite.

A moderately crystal-rich pumiceous tuff less than 6 m (20 ft) thick, appears locally above the andesite. The tuff is characterized by pumice that average 2 cm in diameter and give the rock a platy fracture. Propylitization has turned the pumice a distinctive greenish hue in a pale purple-gray matrix. In hand specimen, feldspars are the predominant phenocryst; small, smokey quartz grains are present in amounts of less than 1 percent. Biotite was not observed. The tuff was probably of local origin.

The source of the A-L Peak Tuff was initially thought to be the large resurgent cauldron centered about Mt. Withington in the San Mateo Mountains (Deal and Rhodes, 1976). Subsequent work by Chapin and others has shown that additional sources for the complete section of the A-L Peak are probable. At the present time the gray-massive member is considered to have been erupted from the Mt. Withington cauldron, the flow-banded member from the Magdalena cauldron, and the pinnacles member from the Sawmill Canyon cauldron (Chapin, Chamberlin, and others, 1978). Work by Bowring (in progress) on extensive outcrops of A-L Peak Tuff in the Sawmill Canyon area may provide additional evidence for a Sawmill Canyon cauldron source.

Unit of Sixmile Canyon

The unit of Sixmile Canyon and andesite of Landavaso Reservoir both lie in the stratigraphic interval between the A-L Peak tuff and the tuff of Lemitar Mountains. In the central Hop Canyon area, the tuff of Lemitar Mountains is underlain by the thick sequence of andesite lavas and sandstones of the unit of Sixmile Canyon; however on the south side of Patterson Canyon, the Lemitar tuff is underlain by the andesite of Landavaso Reservoir. These two units are here considered correlative but will be treated separately; the reasons for their different characteristics will be considered at the end of this section.

Unit of Sixmile Canyon. The Unit of Sixmile Canyon is a thick sequence of andesite lavas interbedded with rhyolite lavas, ash-flow tuffs, and volcaniclastic sedimentary rocks. Named the Sixmile Canyon andesite by Krewedl (1974), Osburn (1978) changed the designation to unit of Sixmile Canyon to conform with U.S. Geological Survey convention and to indicate its heterogeneous character.

The minimum thickness of the unit of Sixmile Canyon in the central Magdalena Mountains is estimated by Osburn (1978) to be about 305 m (1000 ft); in the area around Buck Peak, he estimates a thickness of as much as 763 m (2500 ft). In the thesis area the unit of Sixmile Canyon underlies the tuff of Lemitar Mountains but is in fault contact with the Hells Mesa Tuff. The maximum observed thickness, in the upper part of Mill Canyon, is about 270 m (900 ft); outcrops are discontinuous, however, and the apparent thickness may be magnified by north-trending faults.

The unit of Sixmile Canyon and the andesite of Landavaso Reservoir lie above the A-L Peak Tuff and below the tuff of Lemitar Mountains, both of which have been dated. The andesites, therefore, were emplaced during the interval 32 to 27 my.

The unit of Sixmile Canyon in the central Magdalena Mountains is characterized by distinctive andesite lavas, rhyolite lava flows, ash-flow tuffs, laharic breccias, and sandstones (Osburn, 1978; Bowring, in progress). In the thesis area, only andesite, intermediate lavas, and sandstones are exposed. Outcrops of the unit of Sixmile Canyon are poor, however, and the rhyolite lavas and ash-flow tuffs which appear in the lower part of the section in the central Magdalena Mountains (Osburn, 1978; Bowring, in progress) may be obscured by talus at lower elevations in Hop and Mill canyons.

The andesite flows in the thesis area are predominantly dark gray to brown on weathered surfaces and gray, sometimes mottled, on fresh surfaces. Outcrops are confined to small discontinuous ledges; weathering produces moderate to steep slopes of rubbly to blocky talus. In hand specimen, the andesites are commonly porphyritic and contain distinctive white, chalky plagioclase phenocrysts.

In thin-section, subhedral, lath-shaped plagioclase phenocrysts range in length from 0.2 to 5 mm, and comprise between 15 and 25 percent of the samples; the plagioclase has a composition about An59 (12 grains, Michel-Levy method). Plagioclase is commonly altered to clay minerals and sericite. Tabular biotite, averaging 0.15 mm in length, comprises between 1 and 4 percent of the samples; the biotite is frequently altered to magnetite and hematite. Magnetite, partially altered to hematite, is present as small round grains in amounts less than 2 percent. The matrix consists predominantly of subparallel plagioclase microlites.

A fine-grained, relatively non-porphyritic andesite lacking plagioclase phenocrysts is less common. This andesite is dark gray to red-brown in outcrop and dark gray on fresh surfaces. Dense and aphanitic, it characteristically contains about 1 percent small red phenocrysts of oxidized pyroxenes, averaging 0.5 mm in diameter.

In Hop Canyon, sandstone intervals are locally interbedded in the andesites. One small exposure of sandstone, estimated to be about 0.5 m (2 ft) thick, was found below the tuff of Lemitar Mountains at the top of the unit of Sixmile Canyon. The sandstone intervals are generally obscured by talus and their thicknesses are difficult to estimate. However, similar intervals, 5 to 15 m (15 to 20 ft) thick, are found to the south in the central Magdalena Mountains (Osburn, 1978; Bowring, in progress).

The sandstone is a dark pinkish gray on weathered surfaces and somewhat lighter in color on fresh surfaces. Thin, planar bedding between 5 and 25 mm thick is evident in one sample but limited exposures prevent examination of larger features. The sandstone intervals show textural variability: a sample from one outcrop is characterized by well-sorted, angular to subrounded, very fine sand-size quartz, feldspar, and magnetite grains; a sample from another exposure is comprised of poorly sorted, angular to subrounded, very fine to medium sand-size grains of quartz, feldspar, magnetite, and biotite. In both samples the magnetite is partially altered to hematite, giving the rocks a characteristic red color. In some outcrops on the north side of Hop Canyon, intense propylitic alteration gives the sandstone a greenish gray color.

A thin interval of conglomeratic sandstone, with thin planar bedding, is exposed on the southeast slope of hill "9618" in Hop Canyon. The conglomerate is characterized by very poorly sorted, angular, very fine sand- to pebble-size lithic fragments of red to brown aphanitic volcanic rocks. In the central Magdalena Mountains, Osburn (1978) has found a similar conglomeratic interval at the top of the unit of Sixmile Canyon. The conglomerate, both on its upper and lower surfaces, grades sharply into moderately sorted to well-sorted, fine- to medium-grained sandstone consisting of quartz, feldspar, and volcanic rock fragments.

A latite porphyry with distinctive phenocrysts of plagioclase, potassium feldspar, and quartz crops out in a limited area at low elevations on both sides of Mill Canyon near Frenchy's cabin. Immediately northeast of these outcrops, in the north fork of Mill Canyon, a breccia comprised of lithic fragments similar in appearance to the porphyry is exposed. Talus blocks of this breccia are also common on the slopes of the hill above the exposures of the latite porphyry and breccia, in the NE 1/4 of section 36 (T3S, R4W). In the vicinity of the Wheel of Fortune mine, in the SE 1/4 of section 25 (T3S, R4W), lithic fragments of the latite are also found in a fine-grained, bedded sandstone. Possible origins for the latite porphyry and associated breccia will be considered at the end of this section.

In hand specimen the latite is light gray to light purplish gray on fresh surfaces and dark to dark brownish gray on weathered surfaces. Lath-shaped, chalky phenocrysts of plagioclase average 4 mm in length but occasionally reach a length of 1 cm. Somewhat more equant potassium feldspars range in length from 3 mm to 2 cm. Quartz is present as small rounded grains.

In thin section, plagioclase feldspar with a composition of about An34 (11 grains, Michel-Levy method) comprises about 10 percent of the rock; potassium feldspar makes up about 8 percent of the latite. Both plagioclase and potassium feldspars are highly altered to quartz and calcite. Tabular biotite, ranging between 0.3 and 0.7 mm in length, comprises about 6 percent of the rock; however, some of the clasts of latite found in the breccia have biotite phenocrysts as large as 2 mm in length. Amphibole phenocrysts, between 0.3 and 2.0 mm in length, comprise about 4 percent of the rock; the phenocrysts have been almost entirely replaced by quartz, sericite, calcite, and magnetite.

Quartz is present, in amounts of about 1 percent, as rounded and embayed phenocrysts about 3 mm in diameter; the phenocrysts are all fractured and have a mosaic appearance. Magnetite is found as rounded grains about 0.2 mm in diameter and in amounts of about 1 percent. The groundmass has been largely replaced by quartz and calcite.

The matrix of the breccia is relatively fine-grained and somewhat darker in color than the clasts; it is compositionally similar to the clasts and contains detrital grains of feldspar, biotite, amphibole, and quartz. A contact between the breccia and latite porphyry is not exposed; however, the relatively wide distribution of the breccia in the talus surrounding the latite porphyry outcrops and the homogeneous character of the clasts and matrix suggest that it may have been formed from autobrecciation of the latite porphyry.

Adjacent to the main entrance of the Wheel of Fortune mine, a reddish-gray, well-sorted, fine grain-sized sandstone contains subrounded pebble- and cobble-sized clasts of the latite porphyry. Some of the samples of the sandstone taken from the mine dump contain crude beds about 1 to 3 cm thick of very poorly sorted, subangular, fine sand- to pebble-size lithic fragments. These thin beds were not observed in the sandstone exposed in outcrop.

Three possible origins for the latite porphyry and associated breccia are suggested.

1.) The latite was emplaced as a thick flow above the Hells Mesa Tuff as part of the cauldron fill of the North Baldy cauldron. A latite porphyry of similar characteristics has been reported by Donze (personal communication, 1979) for a small area about 9.0 km (5.5 mi) south of Mill Canyon, section 26 (T4S, R4W). The latite appears to lie in the interval between the Hells Mesa Tuff and the unit of Hardy Ridge (cauldron fill of the North Baldy cauldron). Bowring (in progress) also notes the association of a similar porphyry and the unit of Hardy Ridge in an area 6.5 km (4 mi) south of Mill Canyon in section 19 (T4S, R3W); the stratigraphic relationship between these two units, however, is not clear. The latite porphyry found at low elevations in Mill Canyon may, therefore, be exposures of a flow lying in place above the

Hells Mesa Tuff. Clasts of the latite found in a sandstone of the unit of Sixmile Canyon were derived from erosion of the latite following collapse of the Sawmill Canyon-Magdalena cauldron.

2.) Origin is similar to the above with the exception that the outcrops of the latite porphyry and breccia in Mill Canyon are exposed remnants of large slide blocks from the topographic wall of the Sawmill Canyon-Magdalena cauldron.

3.) The latite porphyry was emplaced contemporaneously with the accumulation of the andesites and sediments of the unit of Sixmile Canyon as cauldron fill of the Sawmill Canyon-Magdalena cauldron.

Andesite of Landavaso Reservoir. The andesite of Landavaso Reservoir has been the name given to a series of highly variable andesite flows that crop out in the Kelly mining district and in a broad area west and northwest of the Magdalena Mountains. Named for exposures near Landavaso Reservoir, 6.5 km (4 mi) west of Magdalena, the andesites were first described by Simon (1973). At the type locality the andesites lie above the flow-banded member of the A-L Peak Tuff and below the tuff of South Canyon (Simon's "upper tuff") (Simon, 1973; Osburn, personal communication, 1979). Stratigraphic relationships between the andesite of Landavaso Reservoir and the tuff of Lemitar Mountains (Simon's "tuff of Allen Well") are not exposed. Simon

(1973) thought that the tuff of Allen Well (Simon's tuff of La Jencia Creek) was a member of the A-L Peak Tuff and he placed the andesite of Landavaso Reservoir stratigraphically above the tuff of Allen Well. The term "tuff of Allen Well" has since been abandoned because this tuff lies above the A-L Peak Tuff and is equivalent to the tuff of Lemitar Mountains (Osburn, 1978; Chamberlin, in preparation). The andesite of Landavaso Reservoir is probably correlative with andesites that lie above the A-L Peak Tuff but below the tuff of Lemitar Mountains.

Andesites of similar petrology in the Council Rock district, 24 km (15 mi) northwest of Magdalena, were called andesite of Landavaso Reservoir by Chamberlin (1974), but their relationship to other andesites of this name is uncertain. In the Cat Mountain area, south of the Council Rock district, Wilkinson (1976) found a highly variable series of andesite flows above the A-L Peak Tuff which he also correlated with the andesite of Landavaso Reservoir.

Along La Jencia Creek, 5 km (3 mi) northwest of Magdalena, Brown (1972) noted the occurence of andesite flows with interbedded thin volcaniclastic sandstones lying above the A-L Peak Tuff (Brown's "tuff of Bear Springs") and below the Lemitar tuff (Brown's "tuff of Allen Well"). Blakestad (1978), in the Kelly mining district, correlated the andesite of Landavaso Reservoir with units of Loughlin and Koschmann (1942). In the southwest corner of the Kelly mining district, in an area that adjoins this thesis area, Blakestad (1978) mapped Landavaso Reservoir lying below what I interpret as the lower member of the Lemitar tuff (Blakestad's "upper tuff").

The andesite of Landavaso Reservoir and other andesites of this stratigraphic position vary greatly in thickness and are all thinner than the unit of Sixmile Canyon. Simon (1973) estimated a maximum thickness of about 244 m (800 ft) at Landavaso Reservoir. Chamberlin (1974) estimated a maximum of about 122 m (400 ft) at Council Rock; Wilkinson (1976) also found a maximum thickness of about 122 m (400 ft) in the Cat Mountain area. Along La Jencia Creek, Brown (1972) records a thickness of 3 to 21 m (10 to 70 ft). In the thesis area, and in the adjoining southwest corner of the Kelly mining district, the maximum estimated thickness is about 122 m (400 ft).

In the thesis area, exposures of andesites previously referred to as andesites of Landavaso Reservoir (Blakestad, 1978) are confined to the northwest corner. The andesites commonly crop out as thin ledges that weather to low rounded hills of rubbly talus. The flows are frequently autobrecciated in their basal portions.

In hand specimen the andesite is highly variable and both porphyritic and aphanitic rocks are present. The porphyritic rocks are commonly pinkish to reddish gray on fresh surfaces and dark brownish gray to reddish brown on weathered surfaces. Phenocrysts of plagioclase, hornblende, and pyroxene are usually present; the hornblende is commonly surrounded by a red corona of hematite. The more aphanitic andesites are medium gray on fresh surfaces and weather to a dark brownish gray. Small reddish phenocrysts of a ferromagnesian mineral are usually present.

In thin-section the andesite shows greater variability than is evident in hand specimen. Lath-shaped, subhedral to anhedral plagioclase phenocrysts range in length from 0.3 to 2.5 mm, with an average of about 1.2 mm, and comprise between 16 and 18 percent of the rock; the composition of the plagioclase is about An46 (12 grains, Michel-Levy method). Clinopyroxene constitutes about 7 percent of the rock in two samples but was absent in a third. The clinopyroxene is euhedral to anhedral and averages about 0.5 mm in diameter; in one sample the clinopyroxene had been altered to a fibrous, pale-green, slightly pleochloric chlorite.

Subhedral to anhedral hornblende ranges in abundance from a trace to about 4 percent. In one sample the phenocrysts are glomeroporphyritic and range in length from 0.3 to 2.0 mm, with an average of about 1.2 mm; in another, the hornblende averages only 0.5 mm in length and is distributed evenly throughout the thin-section. The hornblende commonly shows corroded interiors and alteration rims of hematite.

"Iddingsite" pseudomorphs after olivine constitute about 4 percent of one sample; the phenocrysts are euhedral to subhedral and range in size from 0.15 to 0.7 mm in length. The pseudomorphs are outlined by a dark rim of magnetite. Magnetite is also present as small rounded phenocrysts averaging 0.15 mm in diameter. The groundmass has a pilotaxitic texture of plagioclase microlites. Secondary quartz occurs in all samples.

Osburn (1978) interprets the great thickness and heterogeneous character of the unit of Sixmile Canyon to represent cauldron fill of the Sawmill Canyon cauldron. The presence of the unit of Sixmile Canyon at the heads of Mill and Hop canyons indicates that these areas either participated in the collapse of the Sawmill Canyon cauldron or were topographically low and close enough to be overrun by flows along the margin of that cauldron.

The andesite of Landavaso Reservoir crops out in a broad arc from the northwest slope of the Magdalena Mountains 16 km (10 mi) west to Cat Mountain. Exposures of the andesite are confined to the Magdalena cauldron, and the andesite has been interpreted as cauldron fill (Blakestad, 1978; Chapin, Jahns, and others, 1978).

The Magdalena and Sawmill Canyon cauldrons were both formed about 32 m.y. ago following the eruption of the flow-banded and pinnacles members of the A-L Peak Tuff, respectively (Chapin, Chamberlin, and others, 1978). The Sawmill Canyon cauldron probably breached the wall of the slightly earlier Magdalena cauldron near the present head of Mill Canyon, creating a composite structure with a large, dumbbell-shaped depression (fig. 7). In the area where the

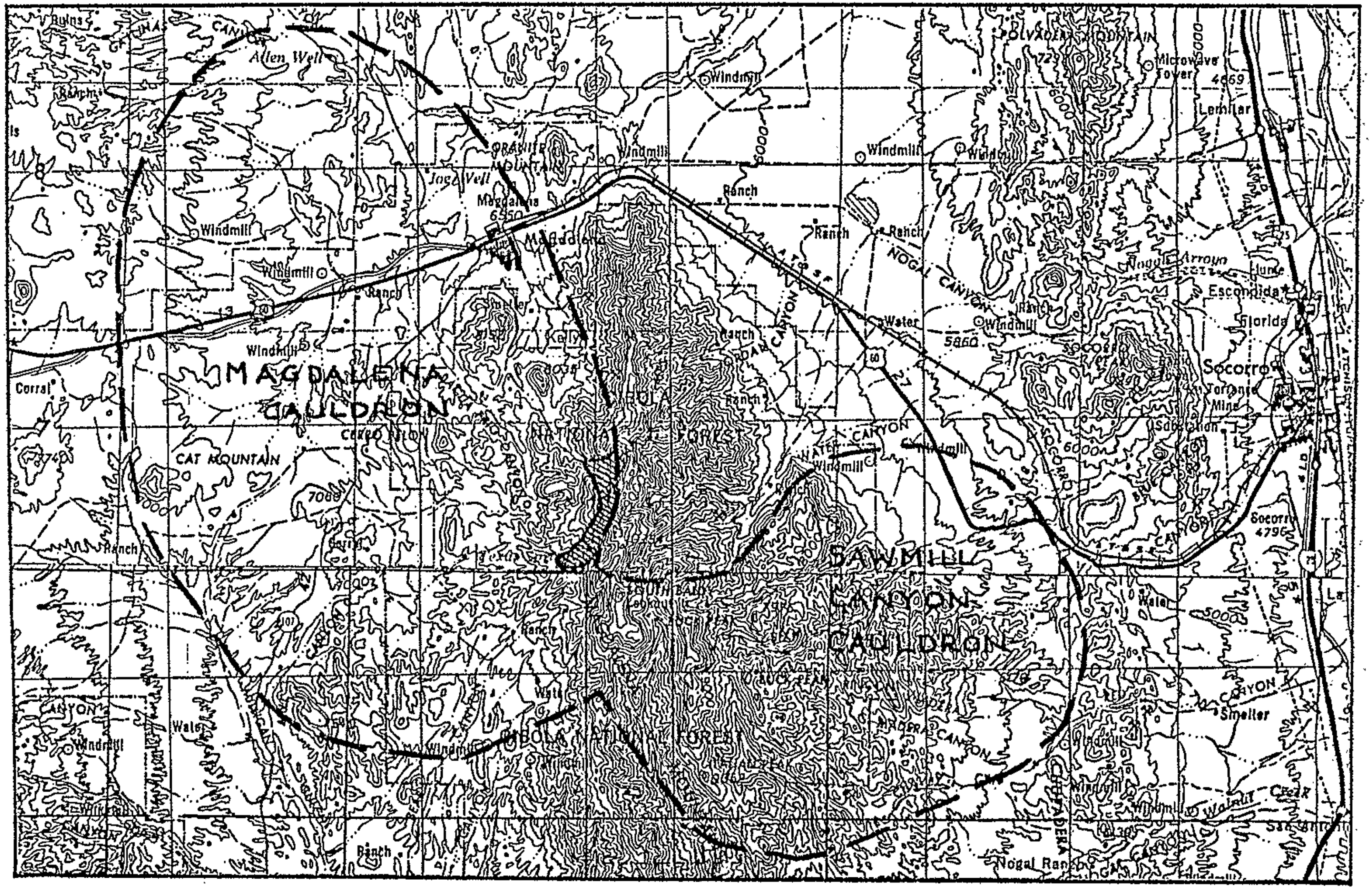


Figure 7. Map showing the relationship between the Magdalena and Sawmill Canyon cauldrons. The area in which Sawmill Canyon cauldron fill crops out in the Magdalena cauldron is shown by hachures.

cauldrons joined, andesite of Landavaso Reservoir from the west met and interfingered with the unit of Sixmile Canyon from the east. The greater thickness and heterogeneity of the unit of Sixmile Canyon is interpreted as the result of the greater subsidence of the Sawmill Canyon cauldron wall and its more severe topographic relief.

Tuff of Lemitar Mountains

The tuff of Lemitar Mountains is a multiple-flow, simple to compound cooling unit of densely welded rhyolite ash-flow tuff (Chapin, Chamberlin, and others, 1978), which has been divided into a crystal-rich upper member and a relatively crystal-poor lower member. A thin transition zone separates the two members. The source of the tuff is believed to have been the Socorro cauldron, centered in the northern Chupadera Mountains (Chapin, Chamberlin, and others, 1978).

The tuff of Lemitar Mountains was first described in detail by Brown (1972) who called it, variously, the tuff of Allen Well and the tuff of La Jencia Creek. Chamberlin (in preparation) renamed the tuff for the Lemitar Mountains and measured a reference section in that area. A detailed description of the tuff of Lemitar Mountains in the eastern Magdalena Mountains has been presented by Osburn (1978), who divided the tuff into upper and lower members.

Samples of the tuff of Lemitar Mountains from Monica Canyon (San Mateo Mountains) and the Lemitar Mountains have been dated at 27.0 ± 1.1 m.y. and 26.3 ± 1.0 m.y., respectively (Chapin, unpublished data). Three dates from the same outcrop in the Joyita Hills gave ages of 28.8 ± 0.7 m.y., 27.6 ± 1.1 m.y., and 28.1 ± 1.2 m.y. (Chapin, personal communication, 1979). The 26.3 m.y. date can be discarded because of potassium metasomatism; the remaining dates average 27.9 m.y. Dating of all samples was by the K-Ar method on biotite.

The tuff of Lemitar Mountains crops out over a broad area from the Joyita Hills, east of the Rio Grande, to the northern San Mateo Mountains. Within the Socorro cauldron the thickness of the lower member is in excess of 245 m (800 ft), and may be much greater; the thickness of the upper member is between 105 and 915 m (350 to 3,000 ft) (Chapin, Chamberlin, and others, 1978). In the outflow sheet the lower member is often absent and has a maximum thickness of 30 m (100 ft); the upper member is very widespread and has a maximum thickness of 120 m (400 ft) (Chapin, Chamberlin, and others, 1978). In the Magdalena Mountains, however, where topographic lows existed along the margins of older cauldrons, these thicknesses are appreciably greater. For example, in Sixmile Canyon the lower member reaches a thickness of 245 m (800 ft), and the upper member 215 m (700 ft) (Osburn, 1978).

Lower Member. Osburn (1978) divided the lower member into three zones (basal, intermediate, and upper) on the basis of outcrop characteristics, welding, lithic and pumice content, and color. The morphology and type and degree of alteration are similar for all zones. In the thesis area the distinction between the three zones as described by Osburn (1978) was not always apparent.

The basal zone is light gray to pinkish gray, pumiceous, and poorly to moderately welded. The basal zone is not everywhere present in the section. Osburn (1978; personal communication, 1979) has suggested that topographic relief at the time of deposition of the lower member may have been responsible for the observed differences in thickness and the discontinuous nature of the basal, poorly welded zone. Alternatively, higher compaction and denser welding of the tuff could increase the relative phenocryst content by reducing the volume of the rock in which phenocrysts are counted. Thus the "basal" zone may not be lacking in some areas but is only more densely compacted (Osburn, personal communication, 1979). Outcrops of the basal zone are infrequent, and where exposed, form rounded hills of moderate slope.

In the intermediate and upper zones, the tuff becomes reddish gray to dark reddish gray and moderately to densely welded. These more densely welded zones of the lower member plus the overlying transition zone and upper member of the tuff of Lemitar Mountains form prominent cliffs on both sides of Hop Canyon, in section 19 (T3S, R3W) and section 24 (T3S, R4W). In the thesis area the observed thickness of the lower member is between 105 and 120 m (350 and 400 ft). On South Baldy, 2.5 km (1.5 mi) south of the thesis area, Bowring (in progress) reports a thickness of 115 m (380 ft).

In thin section the phenocryst content of four samples taken from the lower member ranged from 10 to 16 percent, with an average of 12.5 percent. One sample taken very high in the section, just below the transition zone, had a phenocryst content of about 20 percent.

Sanidine is the most abundant mineral and comprises, on the average, between 8 and 12 percent of the samples; the sample taken high in the section shows a relatively higher sanidine content of about 16 percent. Phenocrysts are typically subhedral and frequently lath-shaped; carlsbad twinning is rare. Sanidine phenocrysts range in size from 0.2 to 2 mm and average 0.6 mm in the long dimension. The sanidine is slightly to highly altered; in the more intensely altered samples, relict grains are frequently plucked during the grinding process leaving only skeletal remains in thin-section. Alteration initially occurs along thin fractures that stain strongly for potassium with sodium cobaltinitrite; clay alteration products are also concentrated along these fractures. As alteration procedes, the sanidine develops "holes", takes on a ragged appearance, and is eventually destroyed. South of the thesis area, Bowring (personal communication, 1979) reports similar alteration of sanidine.

Alteration of the tuff of Lemitar Mountains in the thesis area thus appears to be different than that reported by Osburn (1978) for the east-central Magdalena Mountains. The potassium metasomatism described by Osburn (1978) for that area resulted in the alteration of plagioclase and sanidine was largely unaffected.

Quartz phenocrysts are clear, euhedral to anhedral, and frequently rounded and deeply embayed. They average 0.6 mm in diameter and represent between 2 and 4 percent of the sample.

Biotite and magnetite are present in amounts less than 1 percent. The biotite is deep red-brown, pleochroic, lath-shaped, and averages 0.3 mm in length; magnetite and hemitite are common alteration products. Magnetite, with secondary hematite, also occurs as discrete rounded grains 0.3 mm in diameter. Zircon is present in trace amounts.

Plagioclase was not identified in thin-section. In the more intensely altered samples, plagioclase may originally have been present but subsequently altered and then plucked out during thin-section preparation.

Lithic fragments and pumice show greater variability in abundance than phenocrysts. Lithic fragments range in size from 0.5 mm to 2 cm, with an average of about 1 cm. In the basal zone of the lower member, lithic fragments comprise approximately 10 percent of the rock, but in the sample taken from just below the transition zone they comprise only 5 percent. The pumice is elongate, varies from 0.3 to 2 cm in length, and constitutes between 5 and 15 percent of the samples. The pumice is frequently devitrified to an axiolitic texture; spherulitic texture is also found, giving the pumice a "botryoidal" appearance (Osburn, 1978).

The groundmass, in a sample from the lower zone, is comprised of devitrified worm- and sickle-shaped glass shards. Higher in the section the relict shard structure is less evident and the groundmass has a mosaic appearance.

Transition Zone. The transition zone lies between the lower and upper members of the Lemitar tuff (Osburn, 1978) and is characterized by dense welding and a dark-red to purple-gray color streaked with lenses of pinkish-gray, crystal-rich pumice. The thickness of the zone, where exposed, varies from 0.5 to 3 m (2 to 10 ft).

In thin-section, subhedral sanidine, showing infrequent carlsbad twinning, comprises about 16 percent of the rock; alteration is common along fractures. Plagioclase comprises less than 2 percent of the sample and is highly altered. Quartz makes up 2 percent of the rock and is euhedral to anhedral, frequently rounded and embayed, and clear. Opaque minerals are present in trace amounts. The groundmass retains a relict flow structure of small, flattened, and devitrified glass shards. The phenocryst content of the sample described above is somewhat lower than that of a sample from the transition zone analyzed by Oshurn (1978).

Upper Member. The upper member is a densely welded, medium- to dark-reddish gray, crystal-rich tuff. Phenocryst content is between 30 and 40 percent, which is significantly higher than the lower member.

In the thesis area the thickness of the upper member of the tuff of Lemitar Mountains is 60 m (200 ft) or less. This is appreciably thinner than the thicknesses reported by Osburn (1978), Petty (1979), and Bowring (in progress) for the central and southern Magdalena Mountains. Chamberlin (personal communication, 1979) notes, however, that in the Lemitar Mountains the thickness of the upper member varies, as does the lower, with paleotopography; in places the upper member pinches out and is not present.

The upper member typically crops out as resistant, steep-sided ledges and cliffs and produces steep to moderate slopes of rubbly talus. In hand specimen the tuff is crystal rich and reddish gray on fresh surfaces, brown to reddish brown on weathered surfaces.

In thin-section the most abundant mineral is sanidine which comprises about 25 percent of the rock. The sanidine is subhedral , averages about 1 mm in length, and is usually clear with incipient alteration; carlsbad twinning is rare. Plagioclase comprises about 7 percent of the rock and is highly altered; phenocrysts were frequently removed during grinding leaving only partially rimmed cavities in thin-section. Poorly developed albite twinning was observed in one crystal.

Quartz is euhedral to anhedral and frequenly rounded and embayed; it averages 0.7 mm in diameter and comprises about 2 to 3 percent of the rock. The biotite, coppery in hand specimen, is pale brown to brown and pleochroic in thin-section; euhedral to subhedral laths average 0.7 mm in length, but may be as long as 2 mm. Magnetite is present as rounded grains about 0.3 mm in diameter.

Basaltic Andesite and Andesite Lavas

A sequence of andesitic lavas lies in the interval between the tuff of Lemitar Mountains and the tuff of South Canyon. These andesites vary upward from dark-gray, olivine- and pyroxene-bearing basaltic andesite flows that overlie the tuff of Lemitar Mountains, to gray, hornblende- and biotite-bearing andesites that underlie the tuff of South Canyon.

Basaltic Andesite. The basaltic andesites are similar in appearance to andesites described by Tonking (1957) from the Puertecito quadrangle, 30 km (20 mi) north of Magdalena; Tonking named the sequence the La Jara Peak Member of the now obsolete Datil Formation. The La Jara Peak Member was raised to formational status by Chapin (1971b). At the present time these andesites are referred to as the La Jara Peak Basaltic Andesite (Chapin, Chamberlin, and others, 1978). Similar andesites are found east of the Rio Grande in the Joyita Hills (Spradlin, 1974), in the Lemitar Mountains (Chamberlin, in preparation), in the eastern Magdalena Mountains (Osburn, 1978; Petty, 1979), and in the area north and west of Magdalena (Brown, 1972; Simon, 1973; Osburn, personal communication, 1979).

The La Jara Peak Basaltic Andesite flows may have erupted from the dike swarm that extends about 50 km (30 mi) from the Magdalena area northward onto the Colorado Plateau (Chapin, Chamberlin, and others, 1978). A sample of the La Jara Peak Basaltic Andesite in the Bear Mountain was dated by the K-Ar method at 23.8 ± 1.2 m.y. (Chapin, 1971b); K-Ar dates on the dikes north of Magdalena and on other flows range in age from 30 to 24 m.y. (Chapin, personal communication, 1979).

Tonking (1957) estimated that the maximum thickness of these basaltic andesites in the Puertecito quadrangle was about 760 m (2500 ft). In the northern Lemitar Mountains, Chamberlin (in preparation) reports about 335 m (1100 ft) of these andesites above the tuff of Lemitar Mountains. At the mouth of South Canyon, Osburn (1978) measured 120 m (400 ft) of andesites in the same stratigraphic interval; he noted, however, that cross-sections indicated 120 to 180 m (400 to 600 ft) of andesites further west along South and Sixmile Canyons in the central Magdalena Mountains. In the thesis area the basaltic andesites are exposed on the top and west slope of hill "9618". The maximum estimated thickness is 90 to 150 m (300 to 500 ft), but this thickness may be exaggerated by step faults that are abundant in the area.

Outcrops of the basaltic andesite are characterized by small discontinuous ledges and a rubbly talus that together form moderate slopes and rounded hills. Exposures frequently show the presence of autobrecciation. In hand specimen the basaltic andesites are dark reddish gray to gray on weathered surfaces and reddish gray to light gray on fresh surfaces. Small reddish phenocrysts, approximately 1 mm in diameter, are usually present in an aphanitic groundmass. In some examples the phenocrysts are more tabular shaped and reach 1 to 2 mm in length. Vesicles are also present in some examples.

In thin-section the rock has a pilotaxitic groundmass of plagioclase microlites that range in size from 0.07 to 0.9 mm in the long dimension; clinopyroxene and magnetite fill the interstices. The groundmass has partially altered to clay minerals. Anhedral grains of magnetite averaging 0.2 mm in diameter are present in trace amounts.

Subhedral to anhedral ferromagnesian phenocrysts, averaging 0.7 mm in length and intensely altered to magnetite and quartz, comprise between 5 and 10 percent of the rock. The more euhedral of these phenocrysts show a pseudohexagonal olivine habit with a clear, sometimes reddish-brown to ruby-red, wavy, lamellar structure occupying the center, and magnetite defining the rim. The reddish color and lamellar structure are characteristic of iddingsite and the phenocrysts are probably iddingsite pseudomorphs after olivine. Tonking (1957), Chamberlin (1974), and Wilkinson (1976) have also found olivine, with attendant iddingsite, in basaltic andesites from their thesis areas. The more elongate, subhedral, reddish phenocrysts found in other examples may represent orthopyroxene that has altered to magnetite and hematite.

<u>Hornblende Andesite</u>. Andesites bearing distinctive phenocrysts of biotite and hornblende overlie the basaltic andesites: a hornblende-biotite andesite lies immediately below the tuff of South Canyon and above a biotite-bearing andesite that lacks hornblende. The contacts between the andesites and between andesites and the tuff are not exposed.

The characteristics of the hornblende-biotite and the biotite andesites in outcrop are variable. Typically, exposures of the andesites are confined to small ledges that are surrounded by talus; in areas that have been subject to silicification, however, the andesites form small but prominent cliffs. Color is also variable. On fresh surfaces the andesites range from light gray to dusky red; a sample that had been subject to strong propylitic alteration developed a pale greenish hue. On weathered surfaces the andesites varied from medium gray to very dark brown in color. The biotite andesite is characterized by phenocrysts of dark-brown, tabular biotite that range in length from 0.5 to 3 mm. The hornblende-biotite andesite in addition to biotite contains black phenocrysts of hornblende that range in length from 1 to 5 mm. In both andesites, phenocrysts of white. chalky plagioclase are also evident.

In thin section, euhedral to subhedral, lath-shaped phenocrysts of plagioclase that range from 0.3 to 2.5 mm in length comprise between 13 and 23 percent of the the samples. The plagioclase commonly shows albite twinning and is strongly zoned; its composition is about An50 (20 grains, Michel-Levy method). Though plagioclase was fresh in one sample of the hornblende-biotite andesite, it was strongly altered to a sieve structure; in a sample of the biotite andesite, most of the altered plagioclase had been plucked from the thin-section.

Pale-brown to red-brown, tabular biotite comprises between 4 and 8 percent of the samples; the biotite was commonly altered to sericite or clay and magnetite. In the hornblende-biotite andesite, pale olive to brown, subhedral to anhedral phenocrysts of hornblende between 0.05 and 2 mm in length comprise between 1 and 3 percent of the rock; the hornblende was frequently glomeroporphyritic. Though the hornblende was fresh in one sample, it was frequently altered to clay and magnetite.

A clinopyroxene, possibly augite, comprises between a trace and 6 percent of the rock. The clinopyroxene is clear to very pale green, anhedral, frequently glomeropophyritic, and varies in size between 0.3 and 1.2 mm; the phenocrysts are frequently surrounded by a corona of hematite. Small grains of magnetite, sometimes partially altered to hematite, are present in amounts of less than 1 percent. The groundmass is pilotaxitic.

Tuff of South Canyon

A multiple-flow, simple cooling unit of rhyolitic ash-flow tuff, informally named the tuff of South Canyon by Osburn (1978), lies above the basaltic andesites that overlie the tuff of Lemitar Mountains. This tuff is correlative with portions of the "upper tuffs" described by Simon (1973) in the Landavaso Reservoir area. The tuff of South Canyon crops out in the Lemitar Mountains (Chamberlin, in progress) and is correlative with the upper "Potato Canyon rhyolite" from the Joyita Hills described by Spradlin (1974); it is not correlative with Deal's (1973) Potato Canyon rhyolite from the type section in the San Mateo Mountains (Osburn, personal communication, 1979).

The tuff of South Canyon has been dated at 26.2 ± 1.0 m.y. by the K/Ar method on biotite from a sample taken from the Joyita Hills (Chapin, unpublished data). The tuff has also been dated at 25.8 ± 1.0 m.y. by the K-Ar method on sanidine in a vitrophyre, also from the Joyita Hills (Bachman and Mehnert, 1978).

The thickness of that portion of the "upper tuff" at Landavaso Reservoir correlative with the tuff of South Canyon is about 180 m (600 ft) (Simon, 1973). Chamberlin (in progress) reports an average thickness of 60 m (200 ft) in the Lemitar Mountains; Osburn (1978) found an average thickness of 60-120 m (200-400 ft) in the east-central Magdalena Mountains with a maximum of 190 m (620 ft) in

South Canyon. In the thesis area, on the south side of Hop Canyon, the tuff of South Canyon has a maximum possible thickness of 90 m (300 ft), however, this thickness may be exaggerated by faults.

The tuff of South Canyon crops out as isolated ledges or cliffs surrounded by talus. The contact with the underlying basaltic andesite is not exposed in the thesis area. In outcrop the tuff weathers dark gray to pinkish gray; on fresh surfaces the tuff is characterized by a streaked appearance which results from whitish flattened pumice in a pinkish-gray to reddish-gray matrix. The pumice average 2 cm in length and 2 mm in thickness, although lengths of 4 to 5 cm are not uncommon. The pumice are typically crystal rich and constitute 25 to 35 percent of the rock.

In hand specimen the samples are densely welded and consist predominantly of quartz and sanidine with traces of dark-brown biotite. The sanidine is clear, frequently chatoyant, and may reach 2 mm in long dimension. Quartz phenocrysts are clear, somewhat smaller, and usually exhibit a characteristic "square" habit. Phenocryst content among the samples varies between 15 and 20 percent.

In thin-section the sanidine is euhedral to anhedral, averages 1 to 1.5 mm in length, and constitutes about 15 percent of the sample; carlsbad twinning is common. Quartz is euhedral to subhedral, sometimes rounded and embayed, and constitutes about 8 percent of the sample.

Phenocryst relicts, possibly plagioclase, highly altered and partially plucked from the thin-section, are evident in trace amounts. Biotite and magnetite are also present in trace amounts. The biotite is orange brown to dark brown, lath-shaped, and averages 0.9 mm in length; the magnetite is anhedral, averages 0.3 mm in diameter, and shows translucent red rims of hematite. The pumice is commonly spherulitic with incipient devitrification to cristobalite and feldspar; relict devitrified shards are evident in the groundmass.

The tuff of South Canyon in the thesis area does not exhibit significant variability. Welding characteristics and phenocryst and pumice content suggest that it is correlative with the upper 90 m (300 ft) of Osburn's (1978) "upper streaked interval" at the type section.

Andesite

A flow of andesitic lava overlies the tuff of South Canyon on the south side of Hop Canyon. Discontinuous outcrops also appear in the S 1/2 of section 24 and the N 1/2 of section 25 (T3S,R4W). This andesite is similar to Osburn's (1978) intermediate lava which overlies the tuff of South Canyon on Water Canyon Mesa, 8 km (5 mi) to the east. Similar intermediate composition lavas have been found south of the thesis area (Bowring, in progess).

The andesitic lava in the thesis area has not been dated; however, it lies above the tuff of South Canyon and below the rhyolites of Magdalena Peak, within the time interval 26 to 13 my. Osburn's (1978) intermediate lava is overlain by the Water Canyon Mesa silicic lava which has been dated by the K/Ar method on biotite at 20.0 ± 0.8 m.y. (Chapin, unpublished date). If the andesite in the thesis area is correlative with Osburn's (1978) intermediate lava, then the andesite may have been erupted between 26 and 20 m.y.

Osburn (1978) reports an average thickness of 30 to 60 m (100 to 200 ft) for his intermediate lava. In the thesis area the maximum estimated thickness of the andesite is 90 m (300 ft), but this may be exaggerated by faults.

The andesite crops out as small discontinuous ledges surrounded by a rubbly talus that forms moderate to gentle slopes. On fresh surfaces the rock is light gray to pinkish gray and weathers to a gray to reddish gray. In hand specimen, smoky quartz phenocrysts are present as rounded grains commonly covered by a whitish rind that resists fracture. Both quartz and feldspar phenocrysts are sometimes surrounded by a reddish corona.

In thin-section, plagioclase is the predominant phenocryst and constitutes between 5 and 7 percent of the rock. Euhedral to subhedral laths, commonly albite twinned, average 0.8 mm in length but range from 0.2 to 4.0 mm. The plagioclase generally shows evidence of some alteration, however the degree of alteration varies greatly both within and between samples; some phenocrysts are completely replaced. Alteration is commonly confined to an outer zone which varies in thickness, however, alteration may follow cracks in fractured phenocrysts. The altered zone is rimmed with a thin overgrowth of what may be potassium feldspar. The composition of the plagioclase is about An48 determined by the Michel-Levy method on 12 grains.

Quartz grains are anhedral, rounded, and sometimes embayed. They frequently show what may be authigenic overgrowths in optical continuity that create straight-line or concavo-convex contacts (fig. 8). In a few grains, a thin line of dust appears to preserve an earlier outline of the quartz grain. The grains , either singly or in aggregate, are frequently surrounded by very thin reaction rims (fig. 9). In another sample, single quartz grains are conchoidally fractured along grain edges and reaction rims are lacking. Similar rims have been reported by Osburn (1978) on quartz grains from the intermediate lava on Water Canyon Mesa. The quartz grains range from 0.4 to 1.8 mm in diameter and average about 1.0 mm; they are clear but frequently contain thin needles about 0.05 mm in length of what may be rutile.

Glomeroporphyritic clinopyroxene comprises between 3 and 4 percent of the samples. The clinopyroxene is subhedral, equant, and ranges in diameter from 0.1 to 1.0 mm with an average of 0.7 mm. A few phenocrysts show evidence of zoning.

Figure 8. Composite grain of quartz (Q) and a pseudomorph of "iddingsite" (I) after olivine from the andesite above the tuff of South Canyon. The "iddinsite" in this example is poorly developed but is in association with better preserved examples of pseudomorphic phenocrysts (fig. 10). Magnification is 25x.

Figure 9. Reaction rim on quartz xenocryst (Q) in the andesite above the tuff of South Canyon. Two cavities filled with zeolite (Z) are present in upper right corner. Magnification is 100X.

Euhedral to anhedral pseudomorphs after olivine, with an average length of 0.2 mm, make up between 3 and 6 percent of the rock. The olivine has been completely replaced by ruby-red "iddingsite" (fig. 10).

Primary magnetite is present as anhedral, rounded grains of 0.03 mm average diameter; it comprises about one percent of the rock. Magnetite, both primary and that derived from alteration products, is partially altered to hematite.

Brown, lath-shaped phenocrysts of biotite averaging 0.4 mm in length are present in trace amounts; the biotite is almost completely replaced by magnetite and chlorite. The texture of the groundmass is pilotaxitic and is comprised of plagioclase microlites with small clinopyroxene and magnetite grains in the interstices.

Two origins for the presence of quartz grains in the andesite are suggested:

1.) The crystallization of the andesite may have evolved in two stages. In the first stage, at depth and high pressure, quartz crystallized in equilibrium with the magma. During a second stage, at lower pressure, olivine crystallized and quartz, now in disequilibrium with the magma, was resorbed. Before the quartz completely dissappeared, the magma was quickly brought to the surface. Chapin (personal communication, 1979) has observed that quartz is relatively common in early rift mafic lavas in the Socorro-Magdalena area. This observation suggests that the

Figure 10. Euhedral "iddingsite" (I) pseudomorph after olivine, and plagioclase phenocryst (P) in the andesite above the tuff of South Canyon. Magnetite is concentrated along the edges of the preserved crystal outline; "iddingsite"-like aggregates of hematite, limonite, and an unidentified birefringent mineral occupy the interior.

quartz is not xenocrystic but is related in some manner to early rift magma generation and emplacement.

2.) The quartz grains may be xenocrysts. Evidence for this foreign origin is the following: a) quartz grains appear either conchoidally fractured or rimmed with reaction products which may indicate that the quartz did not crystallize from the magma; b) with the exception noted above, quartz phenocrysts are not a crystallization product of a magma in equilibrium with olivine; c) plagioclase shows great variability in size and degrees of alteration suggesting that it also may be xenocrystic; d) quartz and plagioclase grains are sometimes surrounded by an irregular corona of hematite from the alteration of magnetite; this alteration is selective and adjacent crystals may not show the effect. Evidence against the foreign origin of the quartz grains is the following: a) the relatively large size of the grains; b) the grains are unstrained; c) the lack of sutured boundaries; and d) the lack of obvious rock fragments with sandstone or granitic textures.

In terms of phenocryst content and texture this andesite is similar to Osburn's (1978) intermediate lava from Water Canyon Mesa; if quartz grains are removed, it is also modally similar to the La Jara Peak Basaltic Andesite and the basaltic andesite that overlies the tuff of Lemitar Mountains in the thesis area. Thus, this andesite could be a flow of La Jara Peak Basaltic Andesite that had either undergone a two stage crystallization process or had become locally contaminated with foreign material.

Popotosa Formation

The Popotosa Formation, the basal unit of the Sante Fe Group, crops out discontinuously within north-central Socorro County. The formation consists of bolson deposits of fanglomerate and playa sediments that were deposited as alluvial fans grading down piedmont slopes to basin floor playa lakes (Chapin, Chamberlin, and others, 1978); lithologically, the formation consists of conglomerates, mudflow deposits, sandstones, and mudstones. The sediments were derived from highland source areas surrounding the basin, such as the Colorado Plateau to the northwest, the Sierra Ladrones to the north, and the Gallinas, San Mateo, and Magdalena Mountains to the west and south (Bruning, 1973). That part of the Popotosa basin east of the Rio Grande has been uplifted and the Popotosa Formation removed by erosion (Chapin and Seager, 1975).

The Popotosa Formation was originally described by Denny (1940) who named it after Arroyo Popotosa, a tributary of the Rio Salado located about 35 km (20 mi) northeast of Magdalena. Bruning (1973) divided the formation into fanglomerate and playa facies and designated a new type locality along Cañada de la Tortola, about 5 km (3 mi) south of Arroyo Popotosa. As a result of an unconformity within the formation that occurs at some localities, the Popotosa was later divided into lower and upper members (Chapin, Chamberlin, and others, 1978). The lower member is characterized by red-brown, very well-indurated, heterolithic mudflow deposits and conglomerates with minor intercalations of light-gray sandstones; the upper member is characterized by playa mudstones and buff-colored conglomeratic sandstones (Chapin, Chamberlin, and others, 1978). In the thesis area, scattered outcrops of both the upper and lower members occur in middle and lower Hop Canyon and in Agua Fria Canyon.

In the Lemitar Mountains-Socorro Peak area, Chamberlin (in preparation) describes a composite section of the Popotosa Formation with a maximum thickness of 420 m (1380 ft) for the lower member and 930 m (3050 ft) for the upper member. In the Water Canyon area of the north-central Magdalena Mountains, Osburn (1978) estimated that the lower member may reach a maximum thickness of 120 to 150 m (400 to 500 ft); to the east, in the Pound Ranch area, the upper member consists of mudstones and may reach a thickness of 90 m (300 ft). The Popotosa Formation thins immediately south of Water Canyon, but thickens again in the south-central Magdalena Mountains (Osburn, personal communication, 1979; Petty, 1979).

In the west-central Magdalena Mountains, the lower member reaches a minimum thickness of about 100 m (330 ft); the upper contact is not exposed, however, and it may be much greater. Further west, the lower member may reach 300 m (1000 ft) or more but the area is complicated by faults and the actual thickness is not known (Bowring, in progress). In the thesis area the maximum exposed thickness of the lower member is about 120 m (400 ft) but the unit may be much thicker. The upper member is found only as thin outcrops with lower contacts obscured by talus or alluvium; Bruning (1973) estimated an exposed thickness of 30 m (100 ft) for the upper member on the southeast slope of Magadalena Peak, immediately west of the thesis area.

The basin in which the Popotosa sediments accumulated was formed after the eruption of the tuff of South Canyon at 26 m.y. and was disrupted by intrarift horsts sometime between 7 and 4 m.y. (Chapin, Chamberlin, and others, 1978). The period of depositon, however, probably varied within the basin as a result of paleotopography and differential subsidence.

At the northwest end of the Bear Mountains, the lower member of the Popotosa is interbedded with La Jara Peak Basaltic Andesite (Bruning, 1973) which has been dated at 24 to 30 m.y. (Chapin, personal communication, 1979). Deposition of the Popotosa Formation in the Magdalena Mountains may have begun later; on Water Canyon Mesa the lower member rests unconformably on Water Canyon Mesa silicic lavas dated at 20.0 ± 0.8 m.y. (Osburn, 1978; Chapin, unpublished date). Bowring (personal communication, 1979) has found a rhyolite flow interbedded in the Popotosa Formation in an area about 2 km (1.5 mi) south of the thesis area. A sample of this flow has been dated at 18.0 ± 0.8 m.y. (Chapin, unpublished date).

The younger age limit of the Popotosa shows similar variability. In the Socorro area, volcanism resumed about 12 m.y. ago (Chapin, Chamberlin, and others, 1978) and, on Socorro Peak, a trachyandesite flow that overlies the Popotosa Formation has been dated at 10.7 ± 1.5 m.y. (Burke and others, 1963). In the thesis area, however, rhyolite flows that have been dated at 14.3 m.y. (Weber and Bassett, 1963) and 13.1 ± 0.5 m.y. (Chapin, unpublished date) overlie the Popotosa. Thus, in the Magdalena Mountains, deposition of the Popotosa Formation may have been confined to the period between 20 and 14 m.y.

Lower Member. The lower member of the Popotosa Formation is comprised of well-indurated mudflow deposits with minor interbeds of sandstones. It crops out in two adjacent areas, on the north and south sides of central Hop Canyon, where it forms small, steep-sided cliffs and broad, moderate slopes of talus. The talus frequently obscures the basal contact but, where it is exposed, the lower member overlies the andesite that contains xenocrystic quartz. On Magdalena Peak, Bruning (1973) reports that the Popotosa Formation overlies the andesite of Landavaso Reservoir.

In outcrop the rock is dark brown to very dark reddish brown; fresh surfaces are pink to dark reddish brown. The clasts are predominantly tuff of South Canyon and andesites, including what appears to be the andesite with xenocrystic quartz.

In the laharic breccias, the clasts range in size from 1 m (3 ft), or greater, to less than 1 cm, but commonly are 3 to 10 cm; the clasts are angular to subangular and sometimes rounded. The matrix is typically reddish brown and is composed of sandy mud containing feldspar, quartz, and small lithic fragments. Bedding varies in thickness from about 10 cm to a few meters; in the smaller outcrops, however, bedding may not be evident.

In the minor sandstones the clasts range in size from less than 1 mm to 1 cm; they are very poorly sorted, and range from angular to rounded. Bedding ranges from less than 1 cm to 4 cm in thickness; cross-bedding is not evident.

Upper Member. The upper member of the Popotosa Formation is comprised of conglomerates and conglomeratic sandstones that crop out discontinuously in the northwestern quarter of the thesis area. The upper contact of the Popotosa Formation is usually obscured by talus but, where it is exposed, the upper member lies below the rhyolites of Magdalena Peak. The contact between the upper and lower members is nowhere exposed in the thesis area.

A pink to pinkish-brown rhyolite appears to be interbedded in the upper member of the Popotosa Formation in the SE 1/4 of section 14 (T3S, R4W). Portions of the flow are autobrecciated. The rhyolite is moderately crystal rich with phenocrysts of quartz, plagioclase, potassium feldspar, biotite, and hornblende. A flow with somewhat similar characteristics was reported by Bowring (personal communication, 1979) to be interbedded in the upper portion of the Popotosa Formation, at the head of Bear Canyon, south of the thesis area. Thin-section analysis indicates that the plagioclase has been partially replaced by calcite.

The upper member is characteristically buff to brown and is less well-indurated than the lower member. The clasts are predominantly andesites and ash-flow tuffs, including tuff of South Canyon. The subrounded clasts vary greatly in size from outcrop to outcrop; they may reach 30 cm in diameter but are generally very coarse-sand to pebble size.

The conglomeratic sandstones are poorly to very poorly sorted. Stratification is moderately well-developed with beds ranging in thickness from less than 2 cm to as much as 20 cm, with an average of about 5 to 10 cm. Cross-bedding was not observed. Regular sequences of graded beds are not present; clast size, however, is significantly greater in the basal portions of those outcrops with large vertical exposure. In some exposures, the contact between the upper member of the Popotosa Formation and the overlying poorly-indurated, whitish ash-flow tuff, which accompanies the flow-banded rhyolites, is not sharply defined. This suggests that a short interval of contemporaneous volcanism, erosion, and deposition existed prior to the eruption of the Magdalena Peak rhyolite lavas.

Light-brown to buff outcrops of the Popotosa Formation in the northwestern part of the thesis area, in sections 10 and 11 (T3S, R4W), are different in composition than those in central Hop Canyon. The rock is a fairly well-indurated, poorly sorted conglomerate that contains subrounded pebbles and cobbles that are predominantly derived from A-L Peak Tuff and andesite. Clasts of tuff of South Canyon, which appear in the Popotosa Formation in central Hop Canyon, are absent. Many of the clasts contain disseminated limonite pseudomorphs after pyrite and have been altered to yellow or yellow-brown colors by hydrothermal alteration. These conglomerates are similar in appearance to the Tertiary-Quaternary gravels described by Chamberlin (1974) in the Council Rock area. Transport directions inferred from pebble imbrication indicates a source area to the west and northwest. Chapin (personal communication, 1979) suggests that these gravels were shed eastward into the Mulligan Gulch graben from highland areas in the Tres Montosas-Gallinas Mountains area. Roadcuts along U.S. Highway 60, about 8 km (5.5 mi) west of Magdalena, have exposed conglomerates of similar composition. Large areas of bleached and hydrothermally altered Hells Mesa and A-L Peak tuffs in the Tres Montosas area provide a logical source region for the altered clasts.

Imbrication of clasts is common in both the upper and lower members. In the exposures of the Popotosa Formation in central Hop Canyon, in section 24 (T3S, R4W), pebble imbrication indicates flow direction is predominantly towards the north and northeast. In the northwestern portion of the thesis area, in sections 11 and 14 (T3S, R4W), the flow directions are toward the east (fig. 11). Transport directions of the Popotosa Formation in central Hop Canyon are consistent with an ancestral Magdalena highland area shedding sediments northward into the Popotosa basin (Bruning, 1973). Transport direction and composition of clasts of the Popotosa Formation in the northwestern part of the thesis area indicate derivation from a highland area to the west.

Clasts of the tuff of South Canyon are present in both the upper and lower members; they are the predominant clast in the lower member in the central Hop Canyon area. In the upper member, in the northwestern part of the thesis area, clasts of tuff of South Canyon are not present indicating that at the time the upper member was being deposited, the tuff of South Canyon had largely been eroded from the highland area to the west.

Rhyolite of Magdalena Peak

The rhyolite of Magdalena Peak consists of pink to red-brown, flow-banded, rhyolite lava that was erupted from a vent on Magdalena Peak. Buff to gray-brown, rhyolite ash-flow tuffs underlie the rhyolite lava and are occasionally interbedded between overlapping lobes of the

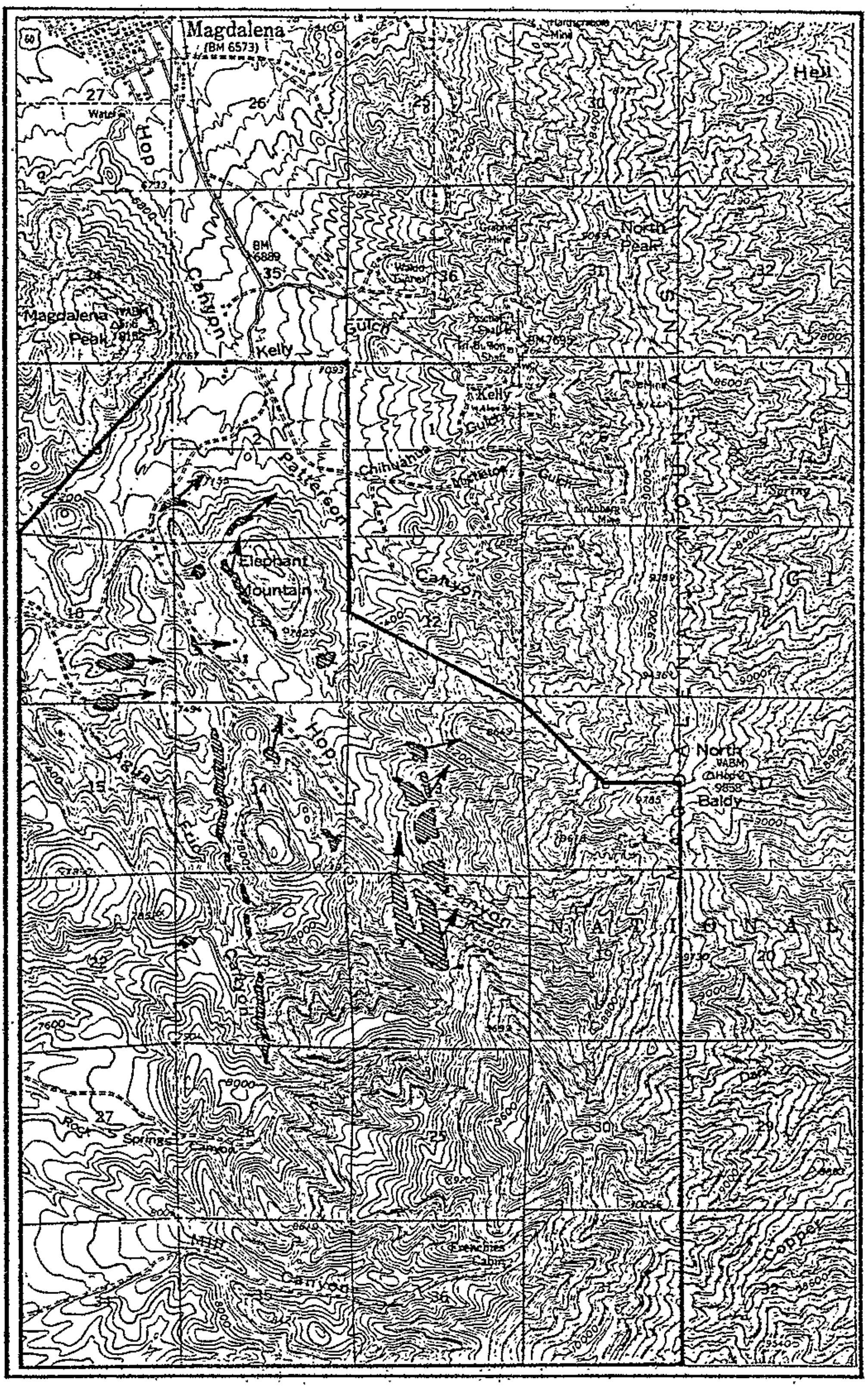


Figure 11. Map showing transport directions of the Popotosa Formation determined from clast imbrication.

flows. The rhyolites crop out along the west flank of the Magdalena Mountains in a broad pattern that extends 20 km (12 mi) from Magdalena Peak on the north to the area of Alameda Spring on the south. The rhyolites were possibly erupted in a north-trending topographic depression that may have controlled its lateral extent. Where the basal contact is exposed, the rhyolites overly the upper member of the Popotosa Formation.

The rhyolite was first described by Loughlin and Koschmann (1942) who identified it as "pink rhyolite" and noted its occurrence on Elephant Mountain and Magdalena Peak. The "pink rhyolite" that they mapped in the Kelly mining district, however, was later shown by Blakestad (1978) not to be the rhyolite of Magdalena Peak. The first detailed study was made by Weber (1957) on a suite of rocks from the Stendel perlite deposit located in section 14 (T3S, R4W), in the north-central portion of the thesis area. Weber (1957) identified a sequence of rocks that consisted of three intervals of rhyolite lavas and associated basal vitrophyre separated by thin units of tuff and breccia.

Deal (1973), in the area south of Mill Canyon (Squaw Peak quadrangle), identified a porphyritic "quartz latite" lava that lay above his Beartrap Canyon Formation; he correlated this lava with the rhyolite of Magdalena Peak. Osburn and Donze (personal communication, 1979) report that these lavas extend as far south as section 36 (T4S, R5W), 1.6 km (1 mi), west of Alameda Spring. Bowring (in progress) has mapped about 3.5 sq km (1.4 sq mi) of rhyolite tuffs and lavas that are contiguous with the rhyolite of Magdalena Peak on the southern boundary of the thesis area. In the eastern Magdalena Mountains, Osburn (1978) found similar rhyolites interbedded in the Popotosa Formation which he named the Pound Ranch lavas; these rhyolites are not contiguous with the rhyolite of Magdalena Peak. Rhyolites interbedded in the Popotosa Formation are also found in the Socorro Peak area (Chamberlin, in preparation).

On Magdalena Peak, the sequence of rhyolite tuffs and lavas overlies the Popotosa Formation and reaches a maximum thickness of about 180 m (600 ft). At the Stendel perlite deposit the thickness of the sequence is about 130 m (430 ft); this thickness appears to be representative of the rhyolite sequence throughout the thesis area. South of Mill Canyon the rhyolite appears to thin: Bowring (personal communication, 1979) reports a maximum thickness of about 120 m (400 ft) in the Bear Canyon area. Measurements taken from a cross-section of Deal (1973) indicate a thickness of between 90 and 120 m (300 and 400 ft) north of Alameda Spring. In the eastern Magdalena Mountains, Osburn (1978) reports a minimum thickness of 120 m (400 ft) for the lower Pound Ranch lavas and 183 m (600 ft) for the upper Pound Ranch lavas.

Apparent flow direction, determined from tension fractures and flow lineation in the flow-banded rhyolite, is generally towards the south but local variations are present (fig. 12). The source of the Magdalena Peak rhyolite lava in the northern part of the thesis area is probably the vent at Magdalena Peak. The Magdalena Peak vent can be seen at the prominent outcrop on the east face of that peak. It is characterized by a central core of steeply dipping to vertical intrusive rhyolite that grades into flows of more moderate inward dip. Other vents have not yet been found. Bowring (personal communication, 1979) found no evidence of vents in the rhyolite flows south of Mill Canyon. In the eastern Magdalena Mountains, Osburn (1978; personal communication, 1979) identified one vent and reported that there is some evidence for a second vent in an area of rhyolite covering about 10 sq km (4 sq mi). In the Socorro Peak-Strawberry Peak area, Chamberlin (in preparation) has identified numerous vents for the rhyolite flows.

Dates for the Magdalena Peak and similar rhyolites have been obtained using the K-Ar method. Perlite from the Stendel perlite deposit has been dated by Weber and Basset (1963) at 14.0 ± 0.7 m.y.; a sample of rhyolite from Magdalena Peak has been dated at 13.1 ± 0.5 m.y. (Chapin, Jahns, and others, 1978). A rhyolite interbedded in the Popotosa Formation, at the head of Bear Canyon, south of the thesis area, has been dated at 18.0 ± 0.8 m.y. (Chapin, unpublished date). In the eastern Magdalena Mountains, the lower and upper Pound Ranch lavas have been dated at 11.8 ± 0.5 m.y. and 10.5 ± 0.4 m.y. respectively (Chapin, unpublished dates). Further east in the Socorro Peak area,

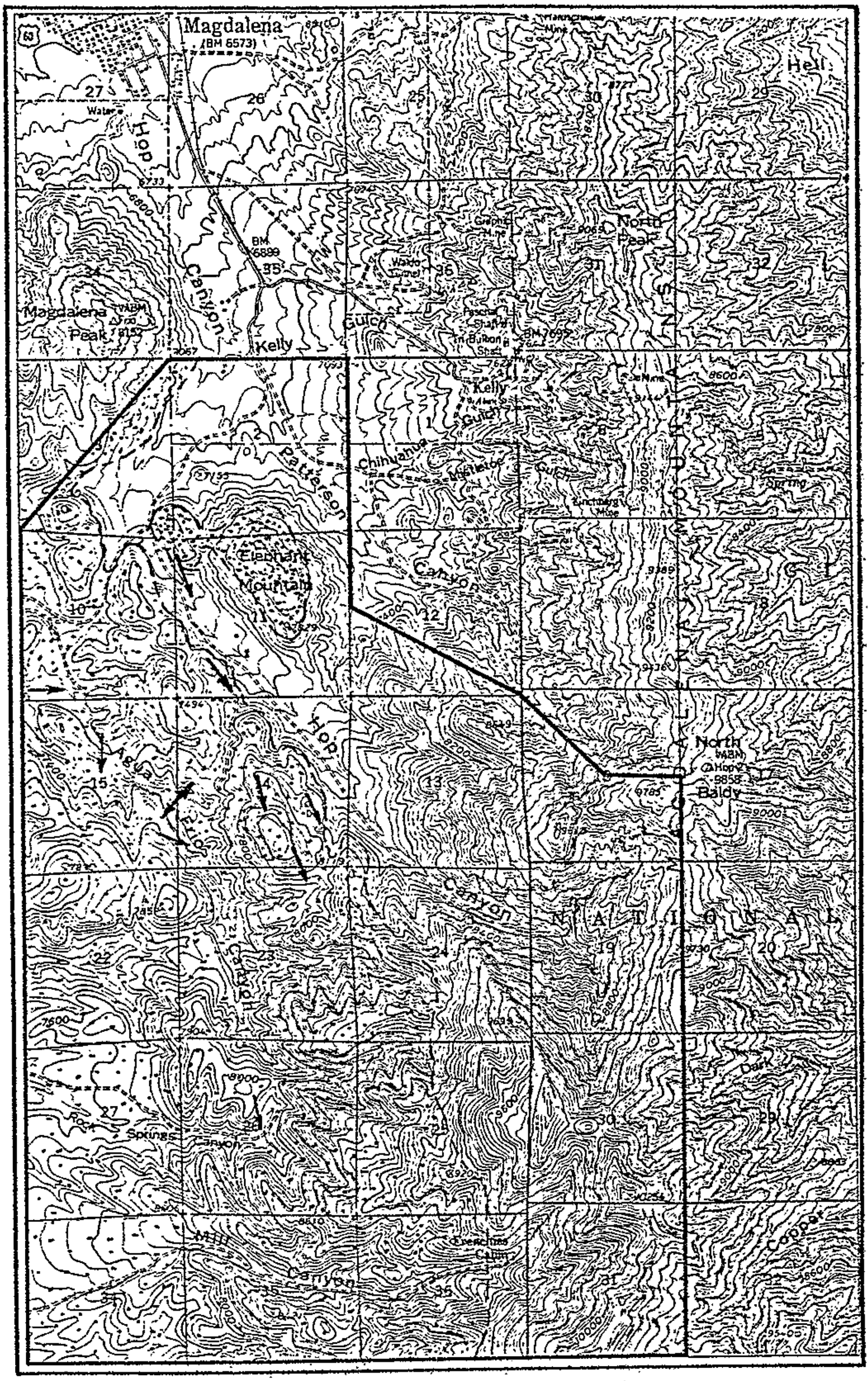


Figure 12. Map showing transport direction of the rhyolite of Magdalena Peak. Transport axis : ⟵⟶ . Transport direction : ⟶ .

rhyolite flows of similar lithology to the Pound Ranch lavas, have been dated at 12 to 7 m.y. old (Chapin, Chamberlin, and others, 1978).

Tuffs. Buff to gray-brown ash-flow tuffs are commonly present directly below the rhyolite flows. In some areas, however, they may be interbedded between overlapping lobes of rhyolite lava, or the tuffs may be absent altogether. Outcrops of the tuffs are generally restricted to small areas such as gullies and stream beds where erosion has cut through the overlying talus. Tuffs exposed along the west side of Hop Canyon are between 8 and 18 m (25 and 60 ft) thick. In some outcrops the tuff is associated with breccias comprised of tuffs and vitrophyre. At the Stendel perlite deposit, where exposures of the rhyolites are particularly good, two intervals of tuff interbedded in perlite, rhyolite, and vitrophyre can be identified.

In hand specimen the tuffs commonly contain dark reddish-brown lithic fragments that range in size from 0.5 to 15 mm in diameter and comprise between 1 and 10 percent of the rock. Ovoid, white to buff pumice is also common. Phenocrysts are scarce or lacking in samples with abundant lithic fragments; in the less common, lithic-poor samples, quartz, feldspar, and biotite are sometimes present.

Microscopically, all samples are porphyritic although variable in composition. In most samples, quartz is lacking or present only in trace amounts; one sample, however, contains about 3 percent anhedral, rounded and embayed quartz phenocrysts that average 0.7 mm in diameter. Plagioclase is also commonly absent or found only in amounts less than 1 percent. When present the plagioclase is tabular, averages between 0.5 and 1.0 mm in length, and has a composition of about An33 (14 grains, Michel-Levy method). Potassium feldspar is the most abundant phenocryst and comprises between a trace and 8 percent of the rock. The sanidine is subhedral to anhedral, frequently corroded and embayed, and ranges from 0.3 to 1.5 mm in diameter; carlsbad twinning is infrequent. Greenish-brown to dark-brown biotite is present in trace amounts; the biotite is lath-shaped and averages 0.5 mm in length. One sample contains about 2 percent biotite, a trace of greenish-brown hornblende, and a trace of rounded grains of magnetite.

Rhyolite Flows. The rhyolite lavas are commonly pink, buff, or gray on fresh surfaces and weather to a brown to reddish brown. The rhyolite is frequently flow-banded but may be massive in appearance. The basal portion of rhyolite flows frequently grade downward into a black to dark-gray vitrophyre; in some outcrops the vitrophyre may in turn grade downward to a medium-gray perlite (fig. 13). Where the transition between rhyolite and vitrophyre is gradational, thin lamellae of reddish-brown devitrified glass are commonly interlayered in the vitrophyre giving it a flow-banded appearance. Frothy, almost pumiceous, flows

Figure 13. Flow-banded rhyolite of Magdalena Peak that grades downward into a black vitrophyre. Photograph taken in SE 1/4 of section 10 (T3S, R4W).

are occasionally present in association with perlite or vitrophyre.

A good example of the relationship between rhyolite, vitrophyre, and perlite can be found at an outcrop located in the saddle northwest of hill "7494", in section 10 (T3S,R4W). The base of the perlite is autobrecciated; clasts of perlite averaging 5 to 15 cm (2 to 6 in.) in diameter, but reaching a maximum of about 0.5 m (1.5 ft), lie in a finely comminuted perlitic matrix (fig. 14). Autobrecciated perlite is also found in the vicinity of the Stendel perlite deposit.

The rhyolites are frequently vesicular. In the more homogeneous rhyolites, the vesicles are typically less than 2 mm in diameter and irregular in shape, suggesting that movement continued after exsolution of volatiles. In the foliated rhyolites, the vesicles have migrated toward regions of lower pressure along shear planes; vesicles are frequently round or ovoid, sometimes forming "trains" of cavities within the flow planes. In the more vesicular rhyolites, larger gas cavities may also be found. These cavities, commonly cylindrical in shape, are typically 0.5 to 2 cm in diameter and 3 to 5 cm (1.5 to 2 in.) in length; however, they may reach a diameter of 40 cm (16 in.) and a length of 3 m (10 ft). A good exposure of these cylindrical gas cavities is found on the west side of Hop Canyon in section 14 (T3S, R4W) (fig. 15).

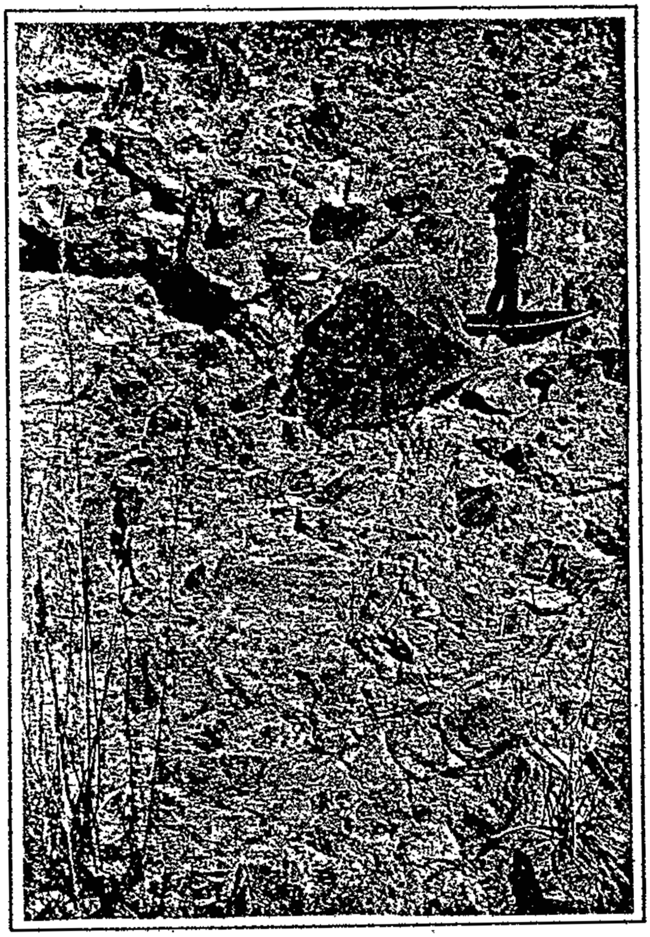


Figure 14. The autobrecciated basal portion of a perlitic flow in the rhyolite of Magdalena Peak. Photograph taken in the SE 1/4 of section 10 (T3S, R4W).

Figure 15. Cylindrical gas cavities in the rhyolite of Magdalena Peak. Photograph taken in the NE 1/4 of section 14 (T3S, R4W).

Primary folding of the flow foliation is common in the more fluidal horizons of the rhyolites. The folds are typically recumbent and isoclinal; the upper limbs are sometimes sheared and truncated by movement of the overlying flow. Axes of the primary folds lie approximately perpendicular to lineation and inferred transport direction. The scale of primary folding ranges from a few centimeters to less than 0.5 m (1.5 ft). Folds with similar characteristics in a rhyolite lava in Nevada have been described by Christiansen and Lipman (1966).

Secondary folding is present in some outcrops. This folding appears to have formed in lava that was in a more viscous state than that in which the primary folds developed. The secondary folding is characterized by large scale folds that are frequently rolled and broken; gas cavities, when present, are oriented parallel to fold axes and the cavities are typically misshapen and deformed. The fold axes commonly parallel the primary lineation and, hence, the original transport direction.

Secondary folding may have resulted from two independent mechanisms:

1.) Rhyolite lavas, in areas where they were not laterally confined by the walls of paleovalleys, formed steep-sided lobes that slumped along their edges producing secondary folds. The axes of these folds tended to lie parallel to the initial transport direction.

2.) The rhyolite lavas probably flowed along small paleovalleys cut into the piedmont gravels of the Popotosa Formation. Secondary folding may have resulted from slumping of lava from these valley walls towards the valley axis after the initial primary flow had ceased. Chapin (personal communication, 1979) noted the similarity of the structures in the rhyolites of Magdalena Peak to flow structures in the ash-flow tuffs of the Gribbles Run paleovalley, in central Colorado. The secondary flow structures in the Gribbles Run ash-flow tuffs have been interpreted as the result of secondary, post-depositional movement of the viscous tuff down the sides of the valley wall. This secondary movement was perpendicular to the direction of the primary flow which followed the axis of the valley (Chapin and Lowell, 1979).

Transport direction is inferred from the orientation of flow lineation and tension fractures. Flow lineation is characterized by closely spaced grooves and ridges having a corrugated appearance that are sometimes found on the relatively planar exposed foliation planes of the rhyolites. The subparallel corrugations are typically 1 cm or less in relief and run discontinuously across exposed flow planes. They are somewhat similar in appearance to grooves described by Schminke and Swanson (1967) for flow structures in ash-flow tuffs, and by Christiansen and Lipman (1966) for flow structures in rhyolite lava. The grooves described by these authors, however, were typically less than 10 mm long and less than 1 mm in relief; their origin was attributed to scoring by phenocrysts or lithic fragments. Flow lineation is developed parallel to transport direction.

Sometimes small tension fractures are found within and perpendicular to the grooves. More commonly, the tension fractures appear as a series of irregular, sometimes ragged, subparallel tears across exposed planar surfaces. The width of the fractures is usually less than 2 mm. When viewed in cross-section, the tension fractures lie along shear planes that developed between more viscous layers of the flow. The tension fractures dip toward the direction of movement (Chapin and Lowell, 1979). Transport directions of the rhyolites of Magdalena Peak, inferred from flow lineation and tension fractures, are shown in figure 12.

The large cylindrical gas cavities found on the west side of Hop Canyon, in the SW 1/4 of section 11 (T3S, R4W), probably lie parallel to the initial transport direction. Chapin and Lowell (1979) note that within the foliation of the ash-flow tuff in the Gribbles Run paleovalley, stretched gas cavities produced a lineation that paralleled the transport axis. They concluded that concurrent with the collapse of the ash-flow tuff, gases were concentrated along shear planes and gas pockets formed where the volume of gas exceeded that which could be accomodated on the shear planes. The gas pockets were pulled into elongate forms by subsequent laminar flow of the welded tuff. A gas cavity formed in this manner would lie parallel to the transport axis.

An additional mechanism may have operated during formation of secondary folding during slumping. As these folds developed in response to shearing of the somewhat cooler, more viscous magma, regions of low pressure formed along the fold axes. Volatiles, which had already migrated to shear planes, were concentrated in these regions of low pressure along fold fronts and formed elongate cavities which were perpendicular to the secondary flow direction and generally parallel to the initial transport direction of the lava. The size of the cavities appears to be dependent upon the amount of volatiles present in the flow, the viscosity of the flow, and the magnitude and wavelength of the folds.

The rhyolite lavas typically form steep, sometimes vertical cliff faces that may reach 120 m (400 ft) in relief. Ramp structures are found in the more viscous rhyolites, especially in the southern portion of the thesis area. A good exposure of these structures is found at the entrance to Mill Canyon in the NW 1/4 of section 35 (T3S, R4W). The rhyolite weathers to blocky talus that commonly obscures the base of the sequence of tuff and rhyolite lavas.

In hand specimen the rhyolites and vitrophyres are variable in appearance. On fresh surfaces the rhyolites are light brown to pinkish gray and, infrequently, light pink to white; they range from massive to vesicular and may be flow-banded or homogeneous in appearance. The rhyolites, which are commonly porphyritic, contain phenocrysts of quartz, feldspar, and biotite. The vitrophyres are black, reddish black, and dark gray; the perlites are light gray to medium gray. The vitrophyre and perlite are also both commonly porphyritic and contain quartz, feldspar, and biotite. The feldspars and quartz give the dark vitrophyres a speckled appearnce; the lighter perlites are similarly speckled with dark-brown biotite.

In thin-section the vitrophyres have spherulitic and perlitic texture. Quartz phenocrysts are rounded and embayed, average 1 mm in diameter, and comprise about 1 percent of the rock. Subhedral to anhedral, zoned plagioclase phenocrysts frequently have a heavily corroded sieve structure; the phenocrysts average 1 mm in length and comprise about 4 percent of the rock. The composition of the plagioclase is about An34 (10 grains, Michel-Levy method). Anhedral phenocrysts of sanidine, heavily corroded, averaging 0.8 mm in length, are present in trace amounts. Subhedral, lath-shaped, brown biotite, averaging 0.5 mm in length, comprises about 1 percent of the rock. Euhedral to subhedral, brown to reddish-brown hornblende is also present in trace amounts as small phenocrysts 0.3 mm in length.

The rhyolites in thin-section commonly have a devitrified groundmass, though spherulitic texture is sometimes present. Rounded and frequently deeply embayed quartz phenocrysts average 1.0 mm in diameter and comprise between a trace and 6 percent of the rock; quartz grains typically show internal fracture. Plagioclase is the most abundant phenocryst, comprising about 8 percent of the rock. The subhedral to anhedral plagioclase is usually strongly zoned and resorbed; sieve structure is common. Smaller, fresh-appearing phenocrysts are sometimes found. The plagioclase is present both as discrete grains averaging 1.2 mm in length and as glomeroporphyritic clumps. The composition of the plagioclase is about An38 (20 grains, Michel-Levy method).

Anhedral sanidine phenocrysts average 1.2 mm in diameter and comprise between 0 and 3 percent of the samples. Lath-shaped, brown to greenish-brown biotite averages 0.6 mm in length and is found in amounts of less than 1 percent. Euhedral to subhedral, brown to reddish-brown hornblende phenocrysts are present in trace amounts; the hornblende is usually fresh in appearance but it is sometimes moderately to intensely altered. Trace amounts of small rounded magnetite grains are also present.

Regional Relationships. The relationship between the Magdalena Peak, Pound Ranch, and Socorro Peak-Strawberry Peak lavas is unknown. Certain characteristics, however, are common to all three lavas: 1) the lavas are rhyolitic to rhyodacitic in composition; 2) they are poorly to moderately crystal rich; 3) each of the lavas is associated with a cauldron; 4) the lavas postdate the cauldrons in which they lie by about 16 to 18 m.y. (and thus can not be considered ring-fracture volcanism associated with cauldron resurgence of the type described by Smith and Bailey, 1968); 5) the major portion of the lavas were probably extruded in the interval 14 to 10 m.y. ago; and 6) the three areas of rhyolite flows lie along the Socorro transverse shear zone (Chapin, Chamberlin, and others, 1978).

The proximity of the rhyolite lava flows to three stuctural features: the Socorro transverse shear zone, the ring-fracture zones of their respective cauldrons, and north-trending extensional faults of the Rio Grande rift, suggest that the extrusion of these lavas was probably controlled by the interaction of these structures (fig. 16). The proximity of the three rhyolite fields to each other and the overall similarity in the compositions of their lavas suggests a common origin. A compilation of chemical analyses of these lavas from different sources (Chapin and others, 1979) is shown in table 1. A comparison of the chemical compositions of these lavas is inconclusive because of the limited number of analyses and the lack of trace-element data.

Alluvium

Alluvium characterized by subrounded pebble- and cobble-sized clasts is located in the vicinity of the saddle

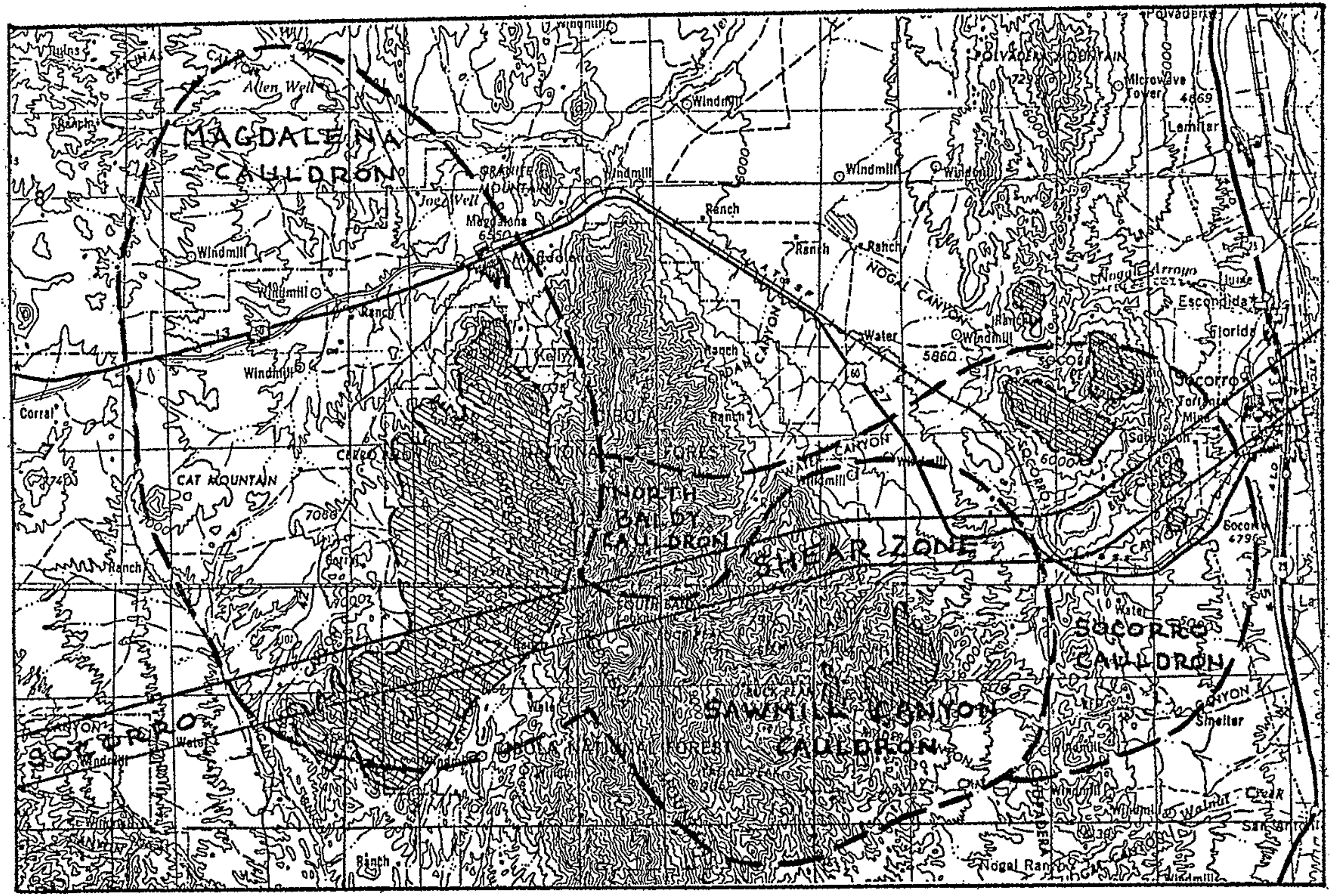


Figure 16. Map showing the relationship between rhyolite flows, cauldrons, and the Socorro shear zone (Bowring, in progress; Chamberlin, in progress; Chapin, Chamberlin, and others, 1978; Osburn, 1978; personal communication, 1979).

	RHYOLITE OF MAGDALENA PEAK		POUND RANCH LAVAS		SOCORRO PEAK AREA				
	Sterdel Perlite Deposit	Magdalena Peak Vent	Lower	Upper	Railroad Quarry Dome	GREFCO Dome	Signal Flag Dome	Socorro Peak	Strawberry Peak
SiO_2	75.04	72.06	73.00	72.31	69.79	73.86	75.06	68.28	68.50
Al_2O_3	13.35	13.43	14.62	12.34	14.83	13.17	13.90	15.84	14.38
TiO_2	0.12	0.41	0.26	0.39	0.38	0.06	0.15	0.47	0.14
$\sum$ Fe as Fe_2O_3	1.28	2.98	1.96	2.94	2.97	0.20	2.15	3.48	3.17
MgO	0.18	1.72	0.51	3.41	1.12	< 0.01	0.34	1.91	1.14
CaO	0.95	2.07	1.38	2.01	2.01	0.57	2.00	2.93	2.66
Na_2O	2.88	3.87	3.65	1.93	3.39	2.86	2.11	2.20	1.98
K_2O	5.15	3.33	4.79	4.60	4.40	4.86	3.61	3.57	3.55
Total	98.95	99.87	100.07	99.93	98.89	95.59	99.32	98.68	95.63
$Sr^{87/86}$		0.7068	0.7070		0.7065			0.7048	0.7050
K-Ar Date	14.0 m.y.	13.1 m.y.	11.8 m.y.	10.5 m.y.	9.0 m.y.	7.4 m.y.	10.5 m.y.	12.0 m.y.	11.8
Source	(1)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

(1) Weber (1957)

(2) Chapin, Sanford, and others, 1979

Table 1. Table of chemical analyses of rhyolite flows from the Magdalena Peak, Pound Ranch, and Socorro Peak areas.

in the NW 1/4 of section 23 (T3S, R4W). The loose detritus is about 15 m (50 ft) thick and mantles a tuff of the rhyolite of Magdalena Peak. The material is comprised predominantly of fragments of pinkish-gray to light-brown, crystal-rich, quartz-rich lava and a gray to dark-gray aphanitic lava, both of probable rhyolitic composition. The absence of outcrops of these rhyolitic lavas in the thesis area and the rounded character of the clasts suggest transport of the detritus from outside the thesis area. The alluvium is probably a remnant of a fluvial deposit along an abandoned stream course of Pliocene age.

Tertiary Intrusive Rocks

Tertiary dikes and domes are found in the eastern half of the thesis area where they intrude rocks of Oligocene age; dikes have not been found in the Popotosa Formation or the Magdalena Peak rhyolites, both of Miocene age. The period of intrusion of the dikes is not known; there is evidence, however, to suggest that intrusion occurred predominantly in the interval 30 to 20 m.y. A discussion of this evidence will be found at the end of this section.

In the thesis area the dikes are predominantly north-trending and intrude both extensional faults associated with the Rio Grande rift and ring fractures of the Magdalena cauldron. The intrusives can be classified into three groups: the latite porphyry of Mistletoe Gulch, white rhyolite dikes and dome, and basaltic andesite dikes.

Latite Porphyry of Mistletoe Gulch

The latite porphyry of Mistletoe Gulch intrudes the Hells Mesa Tuff in the northeast corner of the thesis area. In the Kelly mining district, immediately to the north, the latite-porphyry is a major intrusive that attains a maximum width of 305 m (1000 ft). The latite-porphyry narrows towards the south and is further reduced after it crosses the east-trending North Fork Canyon fault (the North Baldy cauldron ring fault). In the thesis area the dike is between 0.5 to 1.5 m (2 to 5 ft) in width and stands about 0.5 m (1.5 ft) above the less resistant cauldron facies of the Hells Mesa Tuff. The dike extends southward into the thesis area only about 800 m (2600 ft) before it becomes obscured by talus in the vicinity of the north fork of Hop Canyon. Because of the sharply reduced size of the intrusion as it moves southward it is probable that the dike does not extend further south than is observed in outcrop.

In hand specimen the rock is greenish gray on fresh surfaces and gray to light reddish brown on weathered surfaces. The texture is porphyritic and is characterized by distinctive dark-brown, platy biotite phenocrysts that reach 5 to 8 mm in length and comprise about 7 percent of the rock. Plagioclase and hornblende phenocrysts were not observed though Blakestad (1978) reported their presence in samples from the Kelly district.

In the Kelly district, the latite porphyry occupies faults along a major north-trending zone that has been interpreted as ring fractures of the Magdalena cauldron; displacement along the fault occupied by the porphyry has been estimated to be about 457 m (1500 ft) (Blakestad, 1978). In the thesis area south of the North Fork Canyon fault, the porphyry has been intruded into the Hells Mesa Tuff which shows little or no vertical displacement.

White Rhyolite

White rhyolite dikes are confined to the eastern quarter of the thesis area where they intrude the Hells Mesa Tuff. Similar white rhyolite dikes are found to the north, in the Kelly mining district (Blakestad, 1978) and Bear Mountains (Brown, 1972), and to the east in North Fork and Copper canyons of the north-central Magdalena Mountains (Krewedl, 1974). White rhyolite dikes are less common, or absent, in the south-central Magdalena Mountains (Osburn, 1978; Petty, 1979; Bowring, in progress).

Because of cross-cutting relationships, Blakestad (1978) in the Kelly district and Krewedl (1974) in the central Magdalena Mountains both considered the white rhyolite dikes to be the youngest of the intrusives. In the thesis area, however, three lines of evidence suggest that the rhyloites are not the youngest intrusive: 1) the white rhyolite dikes are not found in rocks of 27 m.y. age or younger; 2) where exposed, the attitude of the white rhyolite dikes has been rotated between 0 and 25 degrees to the west, whereas, the attitudes of andesite dikes have not been rotated; 3) the andesite dikes intrude faults associated with uplift of the Magdalena Range, the white rhyolite dikes do not.

The dikes are typically narrow and long; they range in thickness from 1.5 to 3 m (5 to 10 ft) and extend as much as 4 km (2.5 mi) in length. They predominantly intrude north trending faults, however, departure from this trend is not infrequent and the character of the dikes is sinuous. The dikes dip steeply to the east, roughly perpendicular to the dip of the Hells Mesa Tuff which they intrude.

The dikes commonly crop out as resistant walls that rise as much as 7.5 m (25 ft) above the Hells Mesa Tuff (fig. 17). Hexagonal and rectangular shaped columnar jointing, perpendicular to the intruded surfaces, is found at some outcrops (figs. 18 and 19). Where jointing is present, the white rhyolite weathers to a blocky talus. Flow banding is also present at some exposures. A white rhyolite dome of similar lithologic characteristics intrudes the Hells Mesa Tuff near the head of Mill Canyon; it also produces a blocky talus, with some blocks reaching a diameter of a meter (3 ft) or more.

In hand specimen the white rhyolite is white to pale-pinkish gray on fresh surfaces and weathers to a buff to light gray. The white rhyolite is porphyritic, though a flow-foliated, aphanitic white rhyolite was observed at one outcrop. Quartz is the most abundant phenocryst, comprising between 5 and 10 percent of the rock; the phenocrysts are subhedral to anhedral and average about 1 mm in diameter. In the white rhyolite from the dome, quartz phenocrysts are somewhat less abundant and appear more rounded. Potassium feldspar, averaging about 1 mm in length, comprises between 3 and 7 percent of the samples. Limonite pseudomorphs after

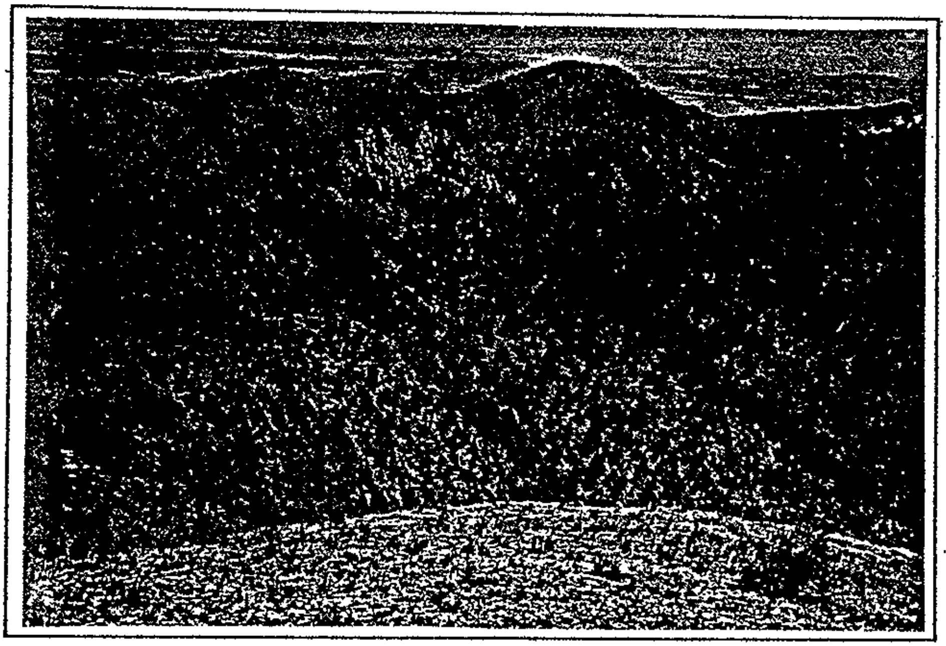


Figure 17. North-trending white rhyolite dike along the east side of the ridge between North and South Baldy peaks. White exposure on upper far right is the prominent outcrop of Hells Mesa Tuff (fig. 5) that lies adjacent to North Baldy Peak.

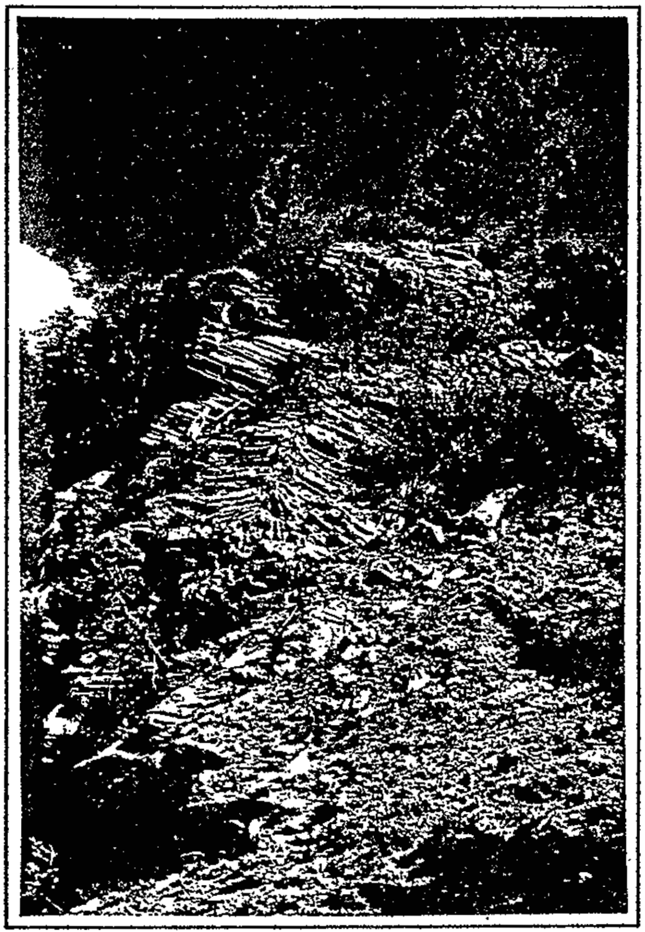


Figure 18. White rhyolite dike showing its resistant nature relative to the surrounding Hells Mesa Tuff. Columnar jointing is perpendicular to the bounding surfaces. Photograph is looking south, in the NE 1/4 of section 31 (T3S, R3W).

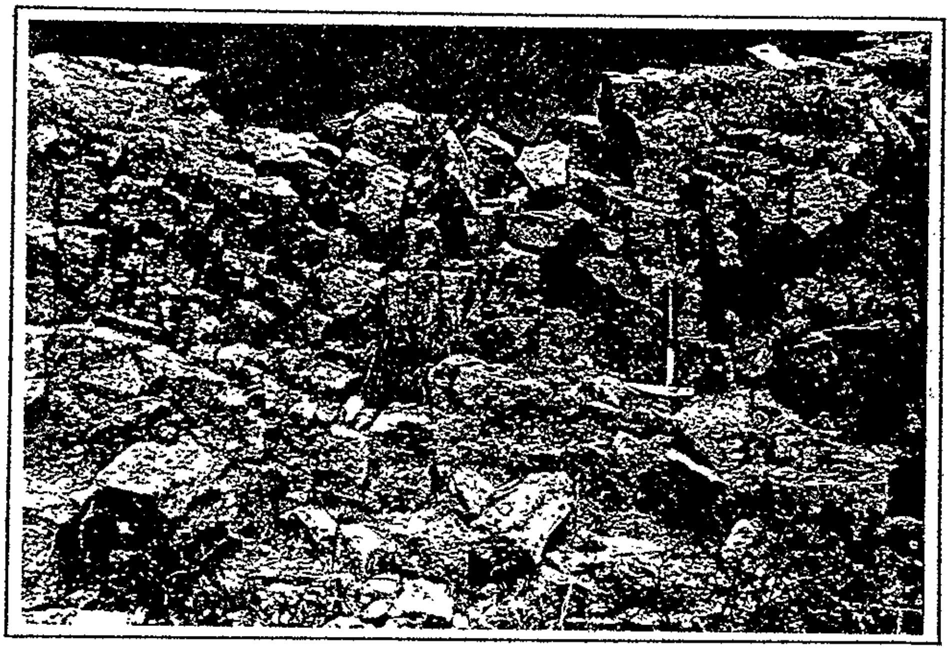


Figure 19. Columnar jointing in the white rhyolite dike shown in figure 18.

pyrite, about 0.3 mm in diameter, give the rock a speckled appearance; the pseudomorphs are present in most samples in amounts less than 5 percent.

The association of limonite pseudomorphs after pyrite has been observed by Blakestad (1978) in the Kelly district, and Krewedl (1974), Osburn (1978), and Petty (1979) in the central Magdalena Mountains; these authors have also noted the association of these dikes with later hydrothermal alteration. Blakestad (1978) states that evidence in the Kelly mining district suggests that the same extensional faults that were intruded by dikes acted as conduits for hydrothermal solutions. Osburn (1978) notes that in the central Magdalena Mountains the dikes frequently show silicic alteration; at the head of South Canyon one of these silicified dikes had been mined for gold. In the thesis area the white rhyolite dikes are also frequently silicified and gold has been mined from the wall of a dike near the saddle between Mill and Copper Canyons. The ridge which runs between North Baldy and South Baldy Peaks parallels, or is capped by, a white rhyolite dike; throughout most of its length small prospects have been cut into the more silicified outcrops of the dike or the adjacent Hells Mesa Tuff. A further discussion of hydrothermal alteration associated with the dikes will be found in the section on economic geology.

Basaltic Andesite

Basaltic-andesite dikes crop out at a few scattered locations on both sides of Hop Canyon. On the north side of the Canyon, dikes cut the Hells Mesa Tuff and the tuff of Lemitar Mountains with its overlying andesite; on the south side, basaltic andesite intrudes a fault that separates the tuff of Lemitar Mountains from the tuff of South Canyon.

The dikes range between 1.5 and 3 m (5 and 10 ft) in width and extend from a few m to 400 m (1300 ft) in length. They have been intruded along faults that trend predominantly north-south. In outcrop the basaltic andesites are dark brown to dark orange brown; on fresh surfaces they are dark reddish gray to purplish gray.

In hand specimen the andesite is commonly porphyritc, however, phenocrysts vary in abundance and type. A slightly porphyritc sample contains small, lath-shaped and round, reddish ferromagnesian phenocrysts in an aphanitic groundmass; a more porphyritic variety is characterized by large chalky, white phenocrysts of plagioclase that vary in length from 0.8 to 4 mm.

In thin-section the plagioclase, which comprises between 4 and 7 percent of the rock, is intensely altered and its composition could not be determined. A ferro-magnesian mineral, probably a pyroxene, comprised about 5 percent of the samples; the phenocrysts were rounded or lath-shaped and completely altered to clays and calcite. Pale-brown biotite phenocrysts that average 0.4 mm in length comprise about 2 percent of the rock. Small, rounded grains of magnetite, averaging 0.3 mm in length, are present in trace amounts. The groundmass is trachytic in texture.

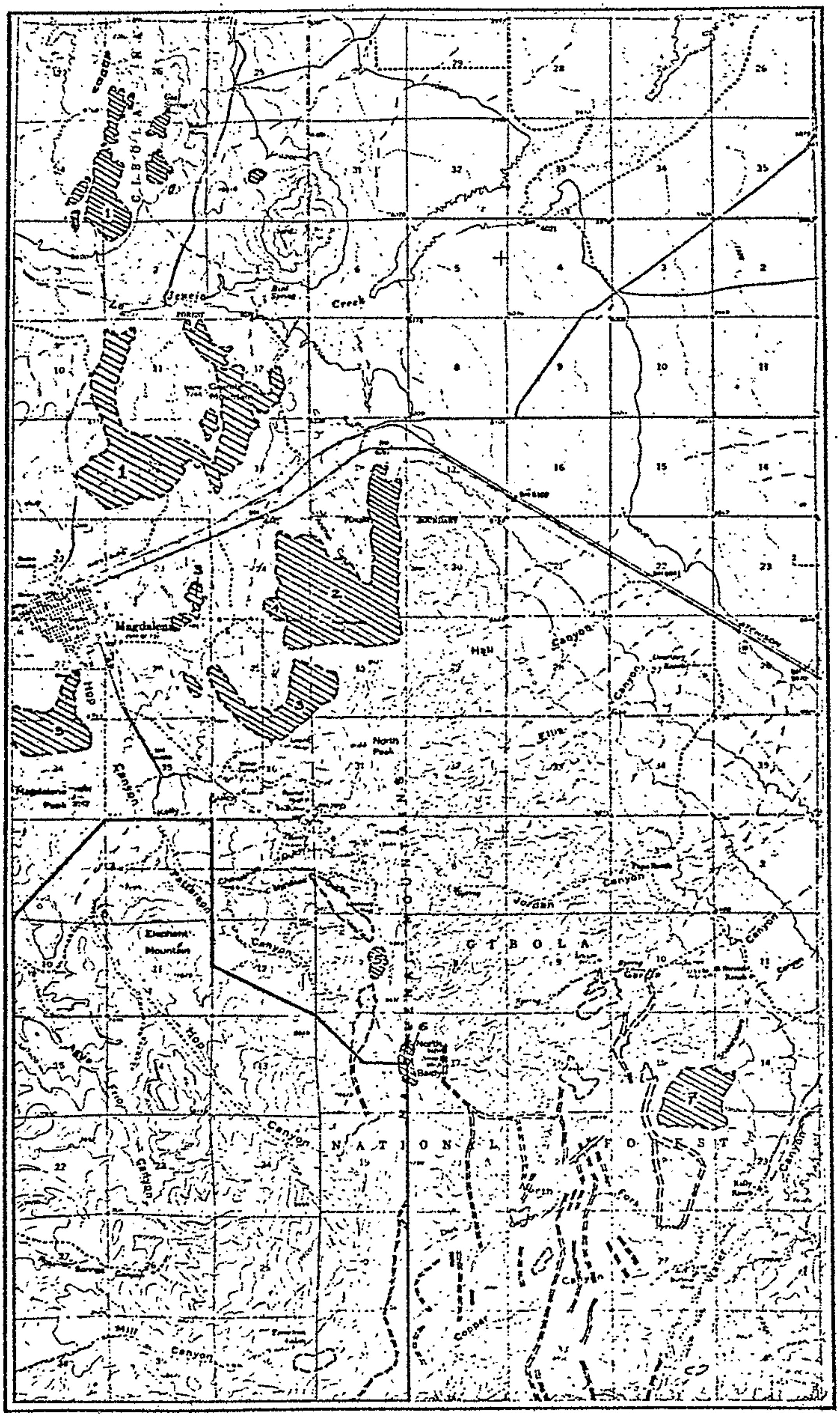
Sources

The source and times of emplacement of the dikes and dome are not known; however, in the northern Magdalena Mountains the dikes appear to be spatially related to stocks or inferred stocks (Krewedl, 1974; Blakestad, 1978)(fig. 20). Two large stocks, the Anchor Canyon and the Nitt, are located in the Kelly mining district (Loughlin and Koschmann, 1942; Blakestad, 1978). Eight km (5 mi) north of the Kelly district, Brown (1972) identified a monzonite stock, intruding a north-trending fault zone, that he named the La Jencia stock and noted its similarity to the Nitt and Anchor Canyon stocks. These stocks are considered to be part of a large composite pluton called the Magdalena pluton which varies in composition from andesite through mafic monzonite to granophyre (Park, 1971; Chapin and others, 1974); it is about 6.5 km (4 mi) wide and extends 10.5 km (6.5 mi) in a north-south direction (Blakestad, 1978; Chapin, Jahns, and others, 1978). Three smaller intrusives in the Kelly mining district, the Vindicator intrusive, the Linchburg stock, and the North Baldy stock, have also been identified (Blakestad, 1978).

Figure 20. Location of Tertiary stocks and prominent dikes in the northern Magdalena Mountains and their relationship to dikes in the eastern part of the thesis area. Compositions of dikes range from latite to rhyolite. The larger intrusives are as follows:

(1) La Jencia Creek stock,
(2) Anchor Canyon stock,
(3) Nitt Monzonite,
(4) Vindicator intrusive (1, 2, 3, and 4 are parts of the Magdalena composite pluton),
(5) Linchburg stock (subsurface),
(6) North Baldy stock (subsurface),
(7) Water Canyon stock.

Locations of intrusives outside of the thesis area are from: Brown (1972), Chapin (unpublished map), Blakestad (1978), Sumner (in progress), and Krewedl (1974).


C I B O L A
1
1
2
3
5
6
7
9
Magdalena
Canyon
Hop
Creek
North Peak
Magdalena Peak
Kelly
Hall
Canyon
Ellis
Jordan
Canyon
Elephant Mountain
Patterson
Canyon
Hop
Alve
Frio
Canyon
Canyon
Canyon
C I B O L A
N A T I O N A L F O R E S T
North Baldy
Baldy
North Fork
Canyon
Copper
Water
Canyon
Mill
Canyon
Savage
Spring
Garcia
Kelly Ranch
NATIONAL
BOUNDARY

Another large stock of quartz monzonite composition is found in Water Canyon (Krewedl, 1974). Between the Water Canyon stock and the Magdalena pluton is a heavy concentration of white rhyolite, mafic, and latite-monzonite dikes; Krewedl (1974) has proposed the existence of a buried North Fork Canyon stock to explain this concentration. The relationship between the Water Canyon and inferred North Fork Canyon stocks and the Magdalena pluton are not known.

Three stocks from the northern Magdalena Mountains have been dated by the K-Ar method; the Nitt and Anchor Canyon stocks at 28.0 ± 1.4 m.y. and 28.3 ± 1.4 m.y., respectively (Weber and Bassett, 1963), and the Water Canyon stock at 30.5 ± 1.2 m.y. (Chapin and others, 1974).

The stocks of the Magdalena pluton are located along the Magdalena cauldron margin (32-28 m.y.) which probably acted as the dominant structural control. The Water Canyon stock is similarly located along the North Baldy cauldron margin. If the dikes in the thesis area are genetically related to the composite pluton and its stocks, they were intruded no earlier than 32-28 m.y. On hill "8648" west of North Baldy Peak, in section 13 (T3S, R4W), the tuff of Lemitar Mountains (28 m.y.) is silicified and cut by small veins of barite and quartz. This indicates that some of the mineralization is younger than 28 m.y. On Water Canyon Mesa, Osburn (1978; personal communication, 1979) notes that a white rhyolite dome, overlain by the

Popotosa Formation, appears to intrude the Water Canyon Mesa lavas dated at 20 m.y.

In the San Juan Mountains, Colorado, Lipman and others (1976) reported that the mineralization and associated intrusions occurred along caldera structures 5 to 15 m.y. after the caldera formed. This suggests that the intrusion of dikes and domes in the northern Magdalena Mountains probably occurred in the period between 28 m.y. and sometime after 20 m.y. Chapin (personal communication, 1979) notes that some of the undated stocks in the subsurface, such as the Linchburg, could be substantially younger than 28 m.y.

The character of the intrusives in the southern Bear Mountains, the Kelly district, and the northern Magdalena Mountains is different than that in the southern Magdalena Mountains. In the north, the intrusives are typically linear white rhyolite and mafic dikes of a general northerly trend. In the south, however, these linear features largely die out and the white rhyolite, where present, takes the form of domes and relatively short radial dikes.

The major structural feature that separates the northern from the southern Magdalena Mountains is the Socorro shear zone. This suggests that the primary source of the intrusives in the northern Magdalena Mountains was the Magdalena pluton and other stocks along cauldron margins. Lateral movement of this magma towards the south, at mid- and upper-crustal depths, may have been prevented by the transverse shear zone in a manner similar to that suggested by Chapin, Chamberlin, and others (1978) for the present magma body that underlies Socorro. Another factor may be the much deeper level of erosion in the northern Magdalena Mountains. The abundance of stocks and dikes seems to increase with deeper levels of erosion.

Quaternary-Tertiary Deposits

Piedmont Gravels

Gentle, westward-sloping surfaces of unconsolidated piedmont gravels grade from moderate colluvium-covered slopes downward into stream terraces and stream beds. These surfaces are developed from individual or coalescing alluvial fans. The gravels are comprised of poorly sorted cobble-, pebble-, and sand-sized clasts of predominantly ash-flow tuff, rhyolite, and andesite lithologies.

Quaternary Deposits

Alluvium

Unconsolidated detrital material deposited by running water in stream beds and on stream terraces is mapped as Quaternary alluvium. The largest areas of alluvium in the thesis area are found in central and lower Hop Canyon, and in lower Agua Fria Canyon.

Landslide Deposits

A landslide, comprised largely of debris from the rhyolite of Magdalena Peak, is found on the northeast side of Elephant Mountain, in section 2 (T3S, R4W). The source of the landslide can be seen in the rhyolite that crops out above the debris. A shallow depression with low, rounded sides of lateral debris deposits marks the course of the landslide.

Colluvium and Talus

Unconsolidated soil and rock fragments deposited by mass wasting are mapped as colluvium-talus. Talus is found mantling steep slopes; it is commonly lithologically homogeneous and associated with specific outcrops of tuff or lava. Colluvium mantles more moderate slopes and typically grades into piedmont slopes or stream terraces.

STRUCTURE

The structural development of the Magdalena Mountains can be divided into four periods: Laramide uplift and erosion (about 75-45 m.y.), Oligocene volcanism and caldera collapse (37-26 m.y.), extensional faulting and development of the Rio Grande rift (32 m.y. to Recent), and regional uplift and block faulting of the Magdalena Mountains (about 7-4 m.y.).

Laramide Uplift and Erosion

During the Laramide orogeny the Magdalena Mountains area was situated on a broad, north-trending uplift or series of uplifts that extended from San Acacia, 35.5 km (22 mi) northeast of Magdalena, south to the San Mateo Mountains (Chapin, 1974; Chapin, Chamberlin, and others, 1978).

There are at present no accurate controls on the timing of the uplift of the ancestral Magdalena Mountains during the Laramide. In southern Colorado, the Laramide uplift of the southern Rocky Mountains was truncated by a late-Eocene erosion surface (Epis and Chapin, 1975), and uplift is considered to have ceased between middle and late Eocene (Tweto, 1975). Woodward and others (1972) noted that uplift of the north-trending Nacimiento Mountains of north-central New Mexico also ceased during the Eocene. Slack and Campbell (1976) and Callender and Zilinsky (1976) reported, however, that the uplift of the Lucero monocline, 65 km (40 mi) north of Magdalena, may have continued into early Oligocene time.

In central Socorro County, efforts to date the Baca Formation, which provides an upper limit to the Laramide uplift in the Magdalena area, have shown mixed results. Snyder (1969) reported the identification of two fossils that indicated the Baca Formation was of Eocene age. S.C. Hook and D.L. Wolberg (personal communication, 1979) note, however, that the identifications are doubtful and that the Baca Formation has not been accurately dated. Laramide uplift in the Magdalena area probably ceased during the middle Eocene, however, it may have continued into the late Eocene.

In the Magdalena Mountains area, the Laramide uplift was eroded down to late-Paleozoic rocks; the resulting detritus was deposited to the north in the west-trending Baca basin where it buried rocks of upper Cretaceous age (Blakestad, 1978; Chapin, Chamberlin, and others, 1978). In the Kelly mining district, located on the northern flank of the Magdalena uplift, the Spears Formation at the base of the Oligocene volcanic sequence rests on the Abo formation of Permian age; north of the uplift, in the northern Bear Mountains, the base of the volcanic rocks rests on the Baca Formation. In the thesis area, rocks earlier than the Oligocene are not exposed.

Oligocene Volcanism

The period of Oligocene volcanism began about 37 m.y. ago with the eruption of the andesitic to latitic magmas of the Spears Formation (Chapin, 1974a). In the Magdalena Mountains, explosive volcanic activity began about 32 m.y. ago with the collapse of the North Baldy caldera; this was followed, over the next 7 m.y., by the formation of at least four additional overlapping cauldrons in the area between Socorro Peak and the southern San Mateo Mountains, a distance of 80 km (50 mi) (Chapin, Chamberlin, and others, 1978). The cauldrons lie on or near the east-northeast trending transverse shear zone that has had a major influence on the distribution of magmatism in the Socorro area (Chapin, Chamberlin, and others, 1978). The thesis area lies on the margins of three of these structures, the North Baldy, Magdalena, and Sawmill Canyon cauldrons, and possibly on the margin of a third, the Hop Canyon cauldron (fig. 21).

The North Baldy cauldron was formed about 32 m.y. ago following the eruption of the Hells Mesa Tuff. The northern margin of the cauldron is defined by the North Fork Canyon and Unity faults (Blakestad, 1978) that trend west-northwest along the boundary between the thesis area and the Kelly district (fig. 22). Though the full areal extent of the cauldron has not been firmly identified, the western margin of the cauldron probably lies somewhere in

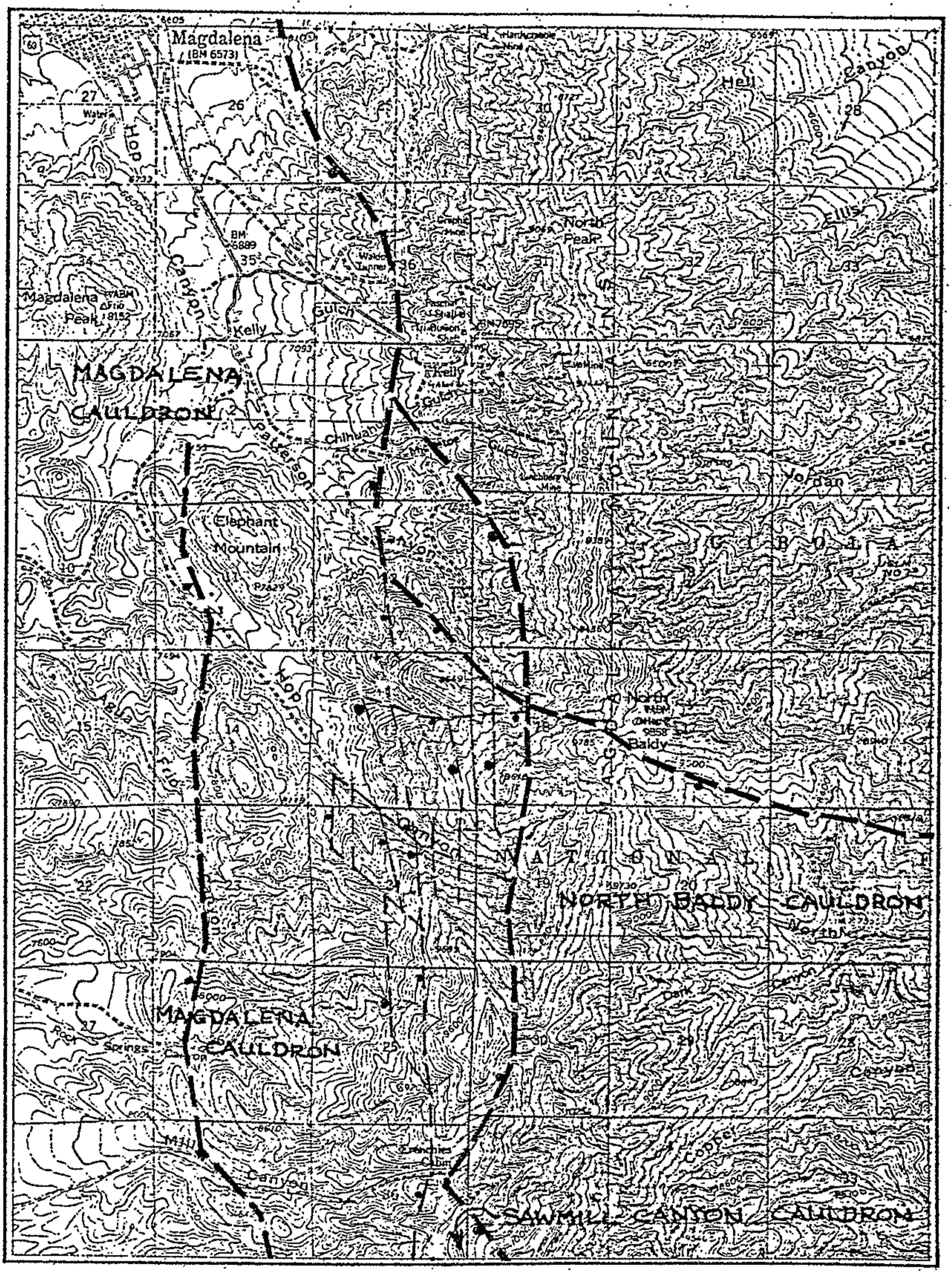


Figure 21. Map showing normal faulting and the location of the Magdalena, North Baldy, and Sawmill Canyon cauldrons. Location of cauldron margins outside of the thesis area from Krewedl (1974) and Blakestad (1978).

Figure 22. Photograph showing locations of the Magdalena and North Baldy cauldron margins and the prominent white outcrop of Hells Mesa Tuff. View is to the north with hill "9618" in the center and North Baldy Peak on the skyline at far right.

the subsurface of the thesis area. Lenses of volcaniclastic breccia are interbedded in the upper Hells Mesa Tuff and extend from North Baldy Peak, in the north, southward 4 km (2.5 mi) to Mill Canyon. Blakestad (1978) first recognized the similarity of these breccias to the mesobreccia described by Lipman (1976) and suggested that they were deposited adjacent to the topographic wall of the cauldron.

The dip-slip component of offset for the North Fork Canyon fault has been estimated to be about 425 m (1400 ft) (Krewedl, 1974). As the cauldron floor subsided, the Spears, Abo, and Madera formations became progressively exposed on the cauldron wall; partial collapse of the wall produced the breccias that are interbedded in the upper Hells Mesa Tuff. The North Fork Canyon fault terminates in a pair of faults that trend northwest and west-northwest and which themselves terminate in the north-trending South Camp fault (fig. 21).

The Magdalena and Sawmill Canyon cauldrons were both created between 32 and 28 m.y. ago with the eruption of the flow-banded and pinnacles members of the A-L Peak Tuff; their joint collapse produced a large dumbell-shaped double cauldron. The center of the Magdalena cauldron is believed to be southwest of the town of Magdalena, and that of the Sawmill cauldron, in the east-central Magdalena Mountains.

The north-trending ring fracture zone that marks the eastern margin of the Magdalena cauldron lies in the eastern quarter of the thesis area. In the Kelly district to the north, this margin is delineated by four broad structural-lithologic zones, each down-faulted to the west with respect to the other (Blakestad, 1978). These broad fault zones, however, terminate at the North Fork Canyon fault; south of that fault the cauldron margin is marked by a single fault or by a narrow fault zone (plate 1). Bowring (in progress) reports that the Magdalena ring fracture zone continues south of the thesis area into the west-central Magdalena Mountains.

The Hells Mesa Tuff lies on the east side of this ring fracture zone and the unit of Sixmile Canyon on the west, or Magdalena cauldron side. In the central Magdalena Mountains this same relationship is found along the northern margin of the Sawmill Canyon cauldron (Petty, 1979); this suggests that the Magdalena and Sawmill Canyon cauldrons shared cauldron fill in the area where they joined, in the vicinity of Mill Canyon.

The present attitude of the Magdalena ring fault in the thesis area is probably vertical or steeply dipping; the fault, however, is everywhere obscured by talus and its actual attitude is unknown. Blakestad (1978) reports that most of the faults in the Waldo-Madera fault zone dip steeply eastward as a result of later rotation during uplift; the original attitude was probably vertical or dipping steeply westward, towards the center of the cauldron. The displacement along this fault in the thesis area is probably between 550 and 600 m (1800 and 2000 ft);

in the Kelly district the total offset may be as much as 760 m (2500 ft) (Blakestad, 1978).

The latite porphyry of Mistletoe Gulch forms an arcuate band in the Kelly district and is interpreted by Blakestad (1978) to be a ring dike marking the eastern margin of the Magdalena cauldron. In the thesis area, south of the North Fork Canyon fault (the North Baldy cauldron ring fracture), the latite porphyry intrusion departs from the cauldron margin fault and quickly dies out. Though the Magdalena cauldron truncated the North Baldy cauldron, the deep-seated ring fracture of the North Baldy cauldron probably exerted some control over the southward movement of intrusive magma and hydrothermal fluids.

The existence of a cauldron nestled within the Magdalena cauldron has been suggested by Chapin, Jahns, and others (1978) to account for the apparent termination of Magdalena cauldron rocks within the Magdalena cauldron. The proposed cauldron has been named the Hop Canyon cauldron. It has been suggested that the Hop Canyon cauldron is the source of the 26-m.y.-old tuff of South Canyon and, therefore, the youngest of the cauldrons in the Socorro-Magdalena-San Mateo Mountains area (Chapin, Jahns, and others, 1978). Additional evidence is needed to evaluate the existence and areal extent of the cauldron.

Oligocene Extensional Faulting

In the Magdalena Mountains an extensional stress field existed at the time of the eruption of the A-L Peak Tuff whose age is bracketed between the 32 and 28 m.y. ages of underlying and overlying tuffs, respectively (Chapin, Chamberlin, and others, 1978). The faulting associated with this extension followed north-trending zones of weakness that had developed during the late Paleozoic and early Tertiary orogenies (Chapin, 1978). In the Lemitar Mountains, 24 km (15 mi) east of Magdalena, Chamberlin (1978) has documented the development of north-trending, high-angle normal faults beginning between 32 and 28 m.y. ago; he suggests that this style of faulting, which continued until 20 m.y. ago, was probably associated with high heat flow and rapid rates of crustal extension.

In the northern Magdalena Mountains, the extensional stress field produced a series of north-trending, steeply dipping faults that probably facilitated the intrusion of the 28-m.y.-old stocks of the Magdalena composite pluton along the earlier formed Magdalena cauldron ring fracture zone (Chapin and others, 1974a; Krewedl, 1974; Blakestad, 1978). Stocks of similar age and composition have been found in the Lucero uplift by Callender and Zilinsky (1976), where they had been intruded along north-trending faults.

The north-trending faults in the northern Magdalena Mountains were also intruded by magmas of mafic, monzonitic, and rhyolitic compositions which had been derived from the stocks of the underlying Magdalena composite pluton (Krewedl, 1974; Blakestad, 1978). In the thesis area these Oligocene faults are marked by white rhyolite and mafic dikes that intrude the Hells Mesa Tuff. Though the dikes and adjacent Hells Mesa Tuff are frequently silicified, there is no evidence of post-intrusive movement. In the Kelly district, Blakestad (1978) also finds little or no post-intrusive movement along faults occupied by dikes; he notes, however, that the faulting associated with the later uplift of the Magdalena Range rotated the Oligocene faults about 30 degrees to the west. This rotation is also seen in the thesis area: the long white rhyolite dike in sections 30 and 31 (T3W, R3S), probably originally vertical, presently dips between 0 and 70 degrees to the east.

Chapin (1978) has divided the Rio Grande rift into three segments that differ somewhat in structural history. He noted that the southern segment, in which the Magdalena Mountains lie, is characterized by a relatively wider rift comprised of a series of parallel, north-trending basins and ranges. Differential spreading of the rift has resulted in the development of transverse shear zones that have acted as incipient transform faults; these shear zones trend northeast and follow earlier zones of weakness in the

Precambrian basement (Chapin, 1978). Chapin, Chamberlin, and others (1978) have shown that these shear zones separate fields which have undergone opposite directions of rotation and step faulting. For example, in the Magdalena Mountains north of the Morenci lineament, the rotation is toward the west and step faulting is down to the east; south of the lineament, the reverse is true. The reactivation of the Morenci lineament and formation of the transverse shear zone was concurrent with the development of an extensional stress field. As separation along the rift progressed, a shallow basin developed in the Socorro area, that by 26 m.y. ago began accumulating sediments of the lower member of the Popotosa Formation (Chamberlin, 1978; Chapin, 1978).

In the Lemitar Mountains, Chamberlin (1978) has described closely spaced, subparallel normal faults which have undergone progressive rotation; he has characterized this style of faulting as "domino style". Chamberlin (1978) also observed that the dip of the fault planes became progressively shallower with increase in age.

Chamberlin (1978) has compared the faulting found in the Lemitar Mountains with faults described by Morton and Black (1975) in the Afar depression, and by Proffett (1977) in the Yerrington area of Nevada. Chamberlin and these authors have attributed this style of normal faulting and block rotation to rapid extension of a relatively thin, brittle crust above a ductile substratum. In the Lemitar Mountains, Chamberlin (1978) has also shown that during periods of inferred lower heat flow, thicker crust, and lower rates of extension, faulting occurred along normal faults of higher dip angle and there was relatively little block rotation.

The relationship between block rotation and normal faults described by Chamberlin (1978), and later found by Osburn (1978) and Petty (1979) in the eastern Magdalena Mountains, was not observed in the thesis area. Faults in the northwestern Magdalena Mountains, where exposed, are vertical or dip steeply to the west; fault blocks are rotated toward the dip of the fault. With one exception, strata dip to the northwest and west-northwest between 15 and 35 degrees; there is no consistent variation with age as was found in the Lemitar Mountains. Similar dips and orientation are found to the north in the Kelly district (Blakestad, 1978). The one exception to the general pattern is the upper member of the Popotosa Formation which generally has dips of less than 10 degrees. Exposures of the upper member lie to the west of the major range-bounding faults and were not subject to significant rotation; strata of the upper member that may have experienced rotation during uplift have been eroded from the upthrown blocks.

West-dipping faults and associated west-dipping fault blocks found in both the thesis area and in the Kelly mining district to the north occupy an area of about 12 km (7.5 mi) long by 2 km (1.5 mi) wide. Portions of this area have been structurally dominated by the Magdalena cauldron margin; faulting associated with regional extension in this area, therefore, may not be representative of the structural style of the northern Magdalena Mountains.

Late-Miocene and Pliocene Uplift

Between about 7 and 4 m.y. the Popotosa basin was broken up into the series of narrow, parallel basins and ranges that presently characterize the southern segment of the rift (Chapin, 1978). The north-trending block faulting that fragmented the basin and elevated the Magdalena Mountains was part of a broad epeirogenic uplift that occurred in the southern Rocky Mountains and adjacent areas (Chapin, 1978). The rate of uplift may have been rapid at times; in the Kelly district, Blakestad (1978) has mapped remnants of large landslides which were the result of over-steepened slopes. In the northwestern Magdalena Mountains, significant displacement along normal faults may have taken place in a stress field in which vertical forces were predominant and horizontal forces subordinate.

The displacement along the northwestern margin of the Magdalena Mountains occurred primarily along north-trending, range-bounding faults. These range-bounding faults continue south of the thesis area along the west flank of the central Magdalena Mountains (Bowring, in progress). In the Kelly district, Blakestad (1978) reports that displacement follows the Waldo and South Camp faults with an estimated offset of about 460 m (1500 ft); at the south end of the Kelly district this displacement is distributed along the South Camp and Smith faults. Displacement also occurred along a probable north-trending fault that cuts the rhyolites of Magdalena Peak between Elephant Mountain and Magdalena Peak (plate 1, fig. 21).

The north-trending ring fracture zone of the Magdalena cauldron probably experienced renewed movement at this time, especially south of the North Fork Canyon fault. In the thesis area, total displacement along the range-bounding faults is probably in excess of 885 m (2900 ft). In the west-central Magdalena Mountains, an estimate based upon the position of the Popotosa Formation exposed south of South Baldy Peak gives a displacement of about 820 m (2700 ft); however, the tuff of South Canyon is missing in this section and the displacement is probably greater (Bowring, personal communication, 1979).

In the Hop Canyon area the range-bounding faults occupy a zone that is about 3.0 km (2.0 mi) wide; south of Hop Canyon this fault zone narrows to about 1.5 km (1.0 mi), the eastern edge of which is marked by the Magdalena cauldron ring fracture (plate 1, fig. 1). North of Hop Canyon, the west slope of hill "8649" is characterized by a series of down-to-the-west step faults, each of small displacement. A few faults, on both sides of Hop Canyon, are occupied by narrow mafic dikes. White rhyolite was not observed to intrude range-bounding faults.

Faults oriented transverse to the north-trending fabric were found in, and north of, Hop Canyon; these transverse faults appear to have developed in response to local differential movement of the range-bounding faults. A local transverse shear zone also appears to follow the upper portion of Mill Canyon. Displacement along transverse faults was local; no aggregate displacement between the north and south portions of the thesis area was observed.

A north-trending fault truncates the eastern edge of the rhyolite flows of Magdalena Peak. A second north-trending fault is probably located immediately west of Elephant Mountain and along the central portion of Agua Frio Canyon. The rhyolite flows to the east of this fault form distinctive flat-topped benches of significantly greater elevation than the exposures of rhyolite to the west. Outcrops of rhyolite tuff and the Popotosa Formation underlying the flow-banded rhyolite also occur at lower elevations west of the fault. The Magdalena Mountains are still undergoing uplift as is shown by recent fault scarps to the north and east of the present range. Rates of uplift, however, are low compared to the period 7 to 4 m.y. (Chapin, 1979).

ECONOMIC GEOLOGY

The thesis area lies immediately south of the Kelly mining district where ore was first discovered in 1866. Between 1881 and 1939, the district produced about 234 million pounds of zinc, 88 million pounds of lead, 12 million pounds of copper, 4 million ounces of silver, and minor amounts of gold. Total production to the present, at original prices, has been over 52 million dollars (Loughlin and Koschmann, 1942; Chapin, Jahns, and others, 1978). Production came predominantly from zinc-lead replacement bodies in the Mississippian Kelly Limestone (Blakestad, 1978).

There are no surface exposures of limestone in the thesis area; however, the hydrothermal systems that produced the replacement deposits in the Kelly district are also evident in the area to the south of the district. Continued reference will be made to the Kelly district in examining mineralization and the economic potential in the thesis area.

Controls of Mineralization

The major structural controls of mineralization are the ring fracture zones of the North Baldy, Magdalena, and Sawmill Canyon cauldrons and the late Oligocene north-trending extensional faults. In the Kelly district, Blakestad (1978) has noted the association between stocks and mineralization; the intensity of mineralization was found, in general, to be inversely proportional to the distance from the intrusive bodies. The areas showing the greatest degree of alteration in the thesis area lie in Hop and Mill Canyons, and along Baldy Ridge. Central Hop Canyon lies adjacent to the North Baldy stock and the hydrothermal fluids which altered the tuffs and andesites in that area may have been derived from that source.

Loughlin and Koschmann (1942) and Blakestad (1978) have noted the spatial relationship between white rhyolite dikes and exposed stocks in the Kelly district. In the north-central Magdalena Mountains, Krewedl (1974) has suggested the existence of a North Fork Canyon stock to explain the high concentration of white rhyolite and monzonite dikes in that area. The white rhyolite dikes along the flank of Baldy Ridge are a southwest extension of the dikes in the North Fork Canyon area; the hydrothermal fluids that later silicified these dikes and adjacent Hells Mesa Tuff may have originated from this inferred stock.

In the Kelly district the primary stratigraphic control to mineralization is the reactive Kelly Limestone (Blakestad, 1978). This limestone is not exposed in the thesis area; however, it may still act as a favorable horizon to mineralization at depth.

Alteration

The two most common types of alteration in the thesis area are propylitization and silicification. Propylitization is best developed in the Hells Mesa Tuff and the interbedded mudflow deposits, conglomerates, and sandstones exposed southwest of North Baldy Peak in section 18 (T3S, R3W). Alteration products are generally epidote, chlorite, calcite, and sericite; the chlorite and epidote frequently give the rocks a greenish-gray tinge. Propylitic alteration is less commonly found in the andesites and sandstones of the unit of Sixmile Canyon; alteration when present in this unit is restricted to small areas.

Silicification tends to be localized along faults and is found in all rock units of Oligocene age. Silicification occurs in two general areas. In the eastern quarter of the thesis area, hydrothermal fluids rose along north-trending extensional faults and dikes that lie in the Hells Mesa Tuff to the east of the Magdalena cauldron margin. The most conspicuous area of silicification is the zone which parallels the long white rhyolite dike along the eastern boundary of the thesis area. The Hells Mesa Tuff intruded by the dike is frequently cut by quartz veins and both the dike and the tuff are partially replaced by silica. Small cubes of pyrite, now altered to limonite, are found on the walls of the dike.

A second area of silicification is found along normal faults that accompanied the elevation of the Magdalena Mountains after about 7 m.y. Examples of this alteration are the silicified zones in the tuff of Lemitar Mountains and its overlying basaltic andesite north of Hop Canyon, in section 13 (T3S, R4W). The silicification is apparently controlled by north-trending faults and shear zones.

Mineral Occurrences

Hop Canyon

Numerous small mines and prospects are found along Hop Canyon in section 19 (T3S,R3W) and in section 24 (T3S,R4W). In 1905, C.H. Gordon (Lindgren and others, 1910) reported vigorous prospecting operations by the Hop Canyon Mining Company on the south side of the canyon on the Marguerite, Oshkosh, Lucy, and Lookout claims; the ore lay in a shear zone trending N10W and dipping about 70SW (Lasky, 1932). An adit about 335 m (1100 ft) long was driven S20E to intersect the shear zone 152 m (500 ft) below the outcrop; though no ore was found, assays are said to have given some values in gold (Lindgren, 1910).

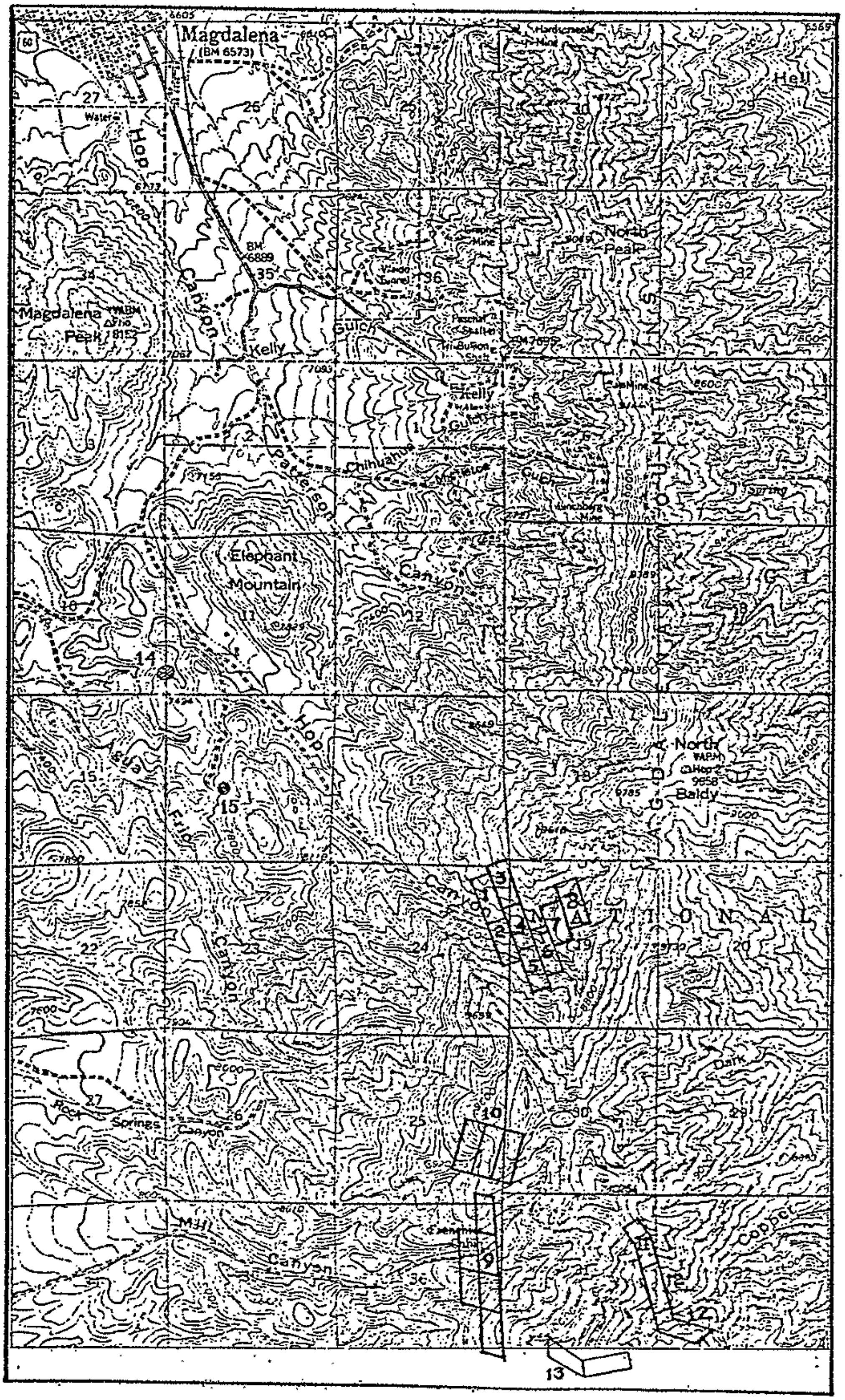
The Hop Canyon Mining Company claims were staked between 1897 and 1900 and the descriptions of the claims did not contain references to township and range survey markers; as a result, their exact location is uncertain. The location and size of mine dumps observed in the field, however, have been correlated with Lasky's (1932) and Gordon's (Lindgren and others, 1910) descriptions and a tentative location for these prospecting activities is shown in figure 23. The only mineralization found at present is minor malachite on andesite from one mine dump.

Adjoining the Hop Canyon properties, down the canyon to the northwest, are the Calumet and New Mexico Mining Company claims and the Kery Prospect (Lasky, 1932). Prospecting activity was confined to driving several adits, each about 30 m (100 ft) long, on both sides of the canyon (Lasky, 1932). Mineralization observed by Lasky (1932) from the Kery Prospect dump was confined to some copper sulfide and copper carbonate-stained pebbles. All mining activity had been abandoned when Lasky (1932) visited Hop Canyon in 1929.

Baldy Ridge

A number of mines and prospects that have been excavated along the margins of white rhyolite dikes and in the adjacent silicified zones are located on the ridge extending from North Baldy to South Baldy peaks (fig. 23). Prospects in the silicified Hells Mesa Tuff are frequent, but commonly only 1 to 2 m deep; mining activity along the dikes, however, was more substantial. The largest of these mines, the Crestone Lode and Golden Sunrise No. 1 and No. 2 patented claims, was developed along the contact of a white

Figure 23. Map showing locations of the Stendel perlite deposit and selected mining claims in Hop and Mill canyons. The location of the Hop Canyon Mining Co. claims is only approx. The claims are: Lookout (1), Lucien (2) Mountain Queen (3), Oshkosh (4), Lucy (5), Marguerite (6), Mabel (7), Slide Rocks Mining claim (8), Old Soldier vein (9), Wheel of Fortune (10), Crestone Lode (11), Golden Sunrise (12), and Copper Lode (13), the large perlite prospect (14), and the Stendel perlite deposit (15).


Magdalena
(BM 6573)
Hell
Water
Hop
Canyon
BM 6889
Magdalena
Peak
North
Peak
Kelly
Gulch
Kelly
Gulch
Chihuahua
Mistletoe
Gulch
Spring
Patterson
Elephant
Mountain
Canyon
Hop
Agua
Fria
Canyon
North
Baldy
9858
Rock
Springs
Canyon
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rhyolite dike and the Hells Mesa Tuff just southeast of the saddle dividing Mill and Copper Canyons. An adit and shaft had been driven at one locality in the Crestone claim; its length could not be determined but it is probably less than 30 m (100 ft). A number of cuts were also driven along the contact between the dike and the tuff.

The mineralization occurs along the walls and in fractures in the dike. Small specks of what appears to be gold are sometimes found in small grains of limonite pseudomorphs after pyrite. Gold is also reported to have been found in the quartz veins that fill fractures in the dike (Krewedl, 1974). Similar relationships are reported by Petty (1979) for the Timber Peak gold mine in the central Magdalena Mountains.

The Crestone claim appears to have had a sporadic history. The claim was patented in 1905 and worked for an unknown length of time. In the early 1970's, an attempt to reopen the mine failed. In 1978, a road was built to the Crestone claim from Mill Canyon, and in 1979 work was begun to develop the property.

A second mine associated with the white rhyolite dike is the Copper Lode patented claim located on Baldy Ridge about 1.5 km (1.0 mi) south of the Crestone claim. The claim lies just south of the thesis area where the north-trending dike terminates against the west-trending ring fracture zone of the Sawmill Canyon cauldron. The intersection of the dike and the ring fracture zone probably controlled the alteration; the surface exposures of the dike and surrounding Hells Mesa Tuff are strongly silicified. A partially caved shaft marks the entrance to the mine; the size of the dump indicates that the underground workings may have reached 90 meters (300 ft) in length. No economic mineralization was seen on the dump.

Mill Canyon

The mines and prospects in Mill Canyon were largely prospected and developed by August Riviere in the first half of this century. The first record of Riviere, rumored to have been a veteran of the Franco-Prussian War, is a quitclaim deed of 1903 when he acquired one half interest in the Gold Rock and Gold King claims in the north fork of Mill Canyon. The major prospects and mines which he worked, however, were the Iron Cap vein, the Wheel of Fortune mine, and the Old Soldier vein, all located in section 36 (T3S, R4W) and section 31 (T3S, R3W).

The Iron Cap vein is "situated in Mill Canyon Maine Branche 12 Mile south of Magdalena near the Divide in North West side of the creek facing east" (Riviere, 1926). The prospects, which consist of cuts, shafts, and short adits, are located along a northeast-trending mafic dike in Hells Mesa Tuff (plate 1). The dike and tuff are frequently brecciated and silicified and locally show iron staining. In 1929, when Lasky (1932) visited the prospect, he found traces of pyrite, chalcocite, covellite, and malachite in the adit at a depth of 10 m (35 ft) below the outcrop.

The Wheel of Fortune mine is located about 0.8 km (0.5 mi) northwest of the Iron Cap vein, in the SE 1/4 of section 25 (T3S, R4W) (fig. 23). The mine was first described by Gordon in 1905 (Lindgren and others, 1910); he noted that the ore occurred along a northwest-trending fissure zone, about 8 m (25 ft) wide, in "birdseye porphyry" andesite. When Lasky (1932) visited the mine in 1929, the ore body had already been worked out; 300 tons of ore containing 6 to 9 percent copper and some gold were said to have been shipped before 1919 to smelters at El Paso, Texas, and Douglas, Arizona.

Lasky (1932) noted that the ore occurred as fracture fillings in shattered porphyry and consisted of chalcocite, covellite, malachite, and chrysocolla; some specimens containing free gold were also said to have come from the mine. Lasky (1932) reported that the pipelike orebody was about 15 m (50 ft) long, 3 to 8 m (10 to 25 ft) wide, and at least 23 m (75 ft) deep. An adit was driven at a 137 m (450 ft) lower elevation to intersect the downward extension of the vein but was abandoned because of swelling and caving ground (Lasky, 1932). Though the location of that adit is not definitely known, a caved adit which fits the general description given by Lasky (1932) is located on the north side of the north fork of Mill Canyon (plate 1).

The Old Soldier vein strikes north-northwest about 0.5 km (0.25 mi) west of Frenchy's (Riviere's) cabin. Mineralization occurs along a shear zone, about 8 m (25 ft) wide, in what appears to be a highly fractured and altered andesite; the shear zone lies on or near the Magdalena cauldron ring fracture zone. Lasky (1932) reports that the main workings on the south side of Mill Canyon consisted of approximately 305 m (1000 ft) of shafts, drifts, and cross-cuts; at the present time the openings to the mine have been caved and only a large pit remains. The chief gangue mineral was calcite stained black with manganese oxides; minor galena was found with the calcite (Lasky, 1932). At the present time, samples taken from the dump of the large pit contain black calcite, galena, and minor chalcopyrite. A small prospect about 0.5 km (0.25 mi) south along the fault zone also showed black-stained calcite but no galena. At the present time an attempt is being made to reopen the main workings.

Agua Frio Canyon

On the northwest side of Agua Frio Canyon, in sections 10, 11, 14, and 15 (T3S,R3W), numerous perlite prospects have been cut in the rhyolite flows of mid-Miocene age. The largest of these prospects lies on the north slope of hill "7494" which is located on the common corner of the sections listed above (fig. 23). The north and northeast slopes of the hill have been partially stripped of overburden in order to expose the underlying rhyolite, vitrophyre, and perlite. In the saddle below the north slope an adit has been driven about 25 m (85 ft) S30E into perlite breccia. It is not known if any perlite was shipped from this area, but the presence of significant amounts of hornblende and biotite phenocrysts suggest that the perlite was uneconomic.

About 1.2 km (0.75 mi) southeast of hill "7494", in section 14 (T3S, R3W), lies the Stendel perlite deposit which was prospected in 1950 but never mined (Weber, 1957). A detailed study of the perlite from that deposit and its relationship to overlying rhyolites and vitrophyres was made by Weber (1957).

Economic Potential

Exploratory drilling on the flanks of North Baldy Peak has indicated the presence of approximately 50,000 tons of material grading 5 percent combined zinc and lead; the mineralization is found in a hedenbergite-garnet skarn in the upper Kelly Limestone where it occurs adjacent to white rhyolite dikes and the buried monzonitic stock (Blakestad, 1978). In the North Baldy Peak area, Blakestad (1978) recommended further exploration in two locations: 1) along the North Fork Canyon fault west of North Baldy, where he had earlier noted the presence of north-trending quartz veins containing lead, zinc, and copper; and 2) on the western, downfaulted side of the North Baldy fault, just east of the peak, in the Kelly Limestone.

Blakestad's (1978) favorable assessment of the economic potential of the North Baldy Peak area is probably not applicable south of the North Fork Canyon fault (the North Baldy cauldron margin). Significant mineralization may not extend south of the fault, and favorable replacement horizons, if they exist, may have been dropped by the collapse of the North Baldy cauldron too deep beneath the surface for economic recovery.

The North Fork Canyon fault apparently acted as a vertical conduit for magmas and hydrothermal fluids. Adjacent to the fault the Hells Mesa Tuff is strongly propylitized; this alteration, however, significantly decreases to the south away from the fault. The white rhyolite dikes associated with the North Baldy stock terminate against the North Fork Canyon fault; the fault also sharply limits the southward extension of the latite porphyry of Mistletoe Gulch. This suggests that the fault permits vertical movement of magma and hydrothermal fluids but limits their north to south horizontal movement. Significant mineralization of the Kelly Limestone may not exist south of the North Fork Canyon fault.

The maximum thickness of the Madera Limestone in the northern Magdalena Mountains has been estimated to be 550 m (1800 ft) from a drill hole 1.5 km (1 mi) west of North Baldy Peak (Krewedl, 1974). This thickness would place the Kelly Limestone more than 1830 m (6000 ft) below the top of the Hells Mesa Tuff if the following thicknesses are assumed to be representative for the area immediately south of North Baldy Peak: Hells Mesa Tuff, 610 m (2000 ft); Spears Formation, 457 m (1500 ft); Abo Formation 152 m (500 ft); and Madera Limestone and Sandia Formation, 610 m (2000 ft). If the Kelly Limestone had been mineralized by hydrothermal solutions from the North Baldy stock, the replacement deposits would lie at too great a depth to be of economic importance. Exploration possibilities in the thesis area adjacent to North Baldy Peak are probably not favorable unless limestone is present at shallower depths on step-faulted blocks or in breccia zones.

Mineralization of possible economic importance occurs along Baldy Ridge as gold-bearing quartz found in fracture fillings and on the walls of the white rhyolite dike. Where the presence of the gold-bearing quartz has been observed, however, its limited quantity and erratic nature have been stressed (Pardee, 1978). The large number of abandoned prospects and mines along the dike also attest to the erratic nature of the mineralization. Work has begun to reopen the Crestone Lode claim; the economic potential of the claim, however, is not known.

Mineralization in upper Mill Canyon, both along the mafic dike and in the shear zones in the andesites interbedded in the Hells Mesa Tuff, appears to be of local occurrence and of no economic importance. Mineralization in andesite both at the Wheel of Fortune mine and at the Old Soldier vein deserves further examination. Mineralization in both mines follows a north-northwest trend that is also seen in other small prospects on both sides of Mill Canyon.

Mineralization may thus extend laterally between the Wheel of Fortune mine and the Old Soldier vein; it may also extend vertically below the zone where mineralization was observed to pinch out at the Wheel of Fortune mine. Other factors which suggest possible economic potential are: 1) location on a cauldron margin, 2) presence of a large white rhyolite intrusive, 3) considerable silicification, and 4) the presence of a porphyry with quartz phenocrysts. Mineralization in the andesites of the unit of Sixmile Canyon in Hop Canyon, however, does not appear to have any economic potential.

An assessment of the economic potential of perlite from the Hop Canyon area was made by Weber (1957). He concluded that the presence of non-expandable materials in the altered and spherulitic zones, that are present in about 75 percent of the perlite in the Stendel deposit, made the development of commercial grade perlite difficult. The Stendel perlite deposit and other nearby exposures of perlite have not been developed. Perlite exposed elsewhere in the thesis area is similar in appearance and texture to that of the Stendel deposit.

SUMMARY AND CONCLUSIONS

The following conclusions can be made from this study of the western flank of the northern Magdalena Mountains south of the Kelly mining district.

Stratigraphy

The rocks in the thesis area are predominantly ash-flow tuffs, interbedded andesite lavas, and an overlying rhyolite flow, or flows, all of Oligocene to Miocene age. In ascending order, from oldest to youngest, the following units have been identified: Spears Formation, Hells Mesa Tuff, flow-banded member of the A-L Peak Tuff, unit of Sixmile Canyon, tuff of Lemitar Mountains, andesite flows, tuff of South Canyon, a xenocrystic andesite, the lower and upper members of the Popotosa Formation, and the rhyolite of Magdalena Peak. With minor additions and modifications this sequence follows the stratigraphy previously developed for the Magdalena Mountains-Socorro Peak area (Chapin, 1974; Chapin, Chamberlin, and others, 1978). Characteristics of the stratigraphy that are unique to the thesis area are the following:

1.) Outcrops of Hells Mesa Tuff between North Baldy Peak and Mill Canyon contain interbedded lenses of laharic breccias and andesite flows. Southwest of North Baldy Peak this sequence of tuff and breccia is overlain by sandstones and conglomerates. The material found in the breccias is of Spears Formation lithology and was probably shed from the topographic cauldron wall and interbedded in the Hells Mesa Tuff during collapse of the North Baldy cauldron.

2.) The andesite of Landavaso Reservoir, cauldron fill of the Magdalena cauldron, and the unit of Sixmile Canyon, cauldron fill of the Sawmill Canyon cauldron, are considered correlative. The collapse of the Sawmill Canyon cauldron, closely following that of the Magdalena cauldron, breached the wall of the Magdalena cauldron and created a composite, dumbell-shaped depression. In the area where the cauldrons joined, near the head of Mill Canyon, andesite of Landavaso Reservoir from the west met and interfingered with the unit of Sixmile Canyon from the east.

3.) An andesite containing quartz xenocrysts appears above the tuff of South Canyon. If the xenocrysts are removed, the andesite is compositionally similar to La Jara Peak Basaltic Andesite and it may represent a locally contaminated flow of the La Jara Peak. The andesite is also similar to Osburn's (1978) intermediate lava from Water Canyon Mesa and is in approximately the same stratigraphic interval.

4.) Flow directions for the deposition of the upper member of the Popotosa Formation were inferred from pebble imbrication. Outcrops in the northwestern part of the thesis area have east-trending flow directions, consistent with a Tres Montosas-Gallinas Mountains highland shedding sediments eastward into the Mulligan Gulch graben. In central Hop Canyon, flow directions in the lower member were northeast-trending, consistent with an ancestral Magdalena highland area shedding sediments northward into the Popotosa basin.

5.) The flow-banded rhyolite of Magdalena Peak crops out in a broad belt along the west flank of the Magdalena Mountains. In the north portion of the flow, or flows, transport directions are mainly southward. Magdalena Peak is the inferred source. The location of other vents, to the south, has not been established.

6.) The rhyolite of Magdalena Peak shares similar characteristics with the Pound Ranch and Socorro Peak-Strawberry Peak rhyolitic lavas. The extrusion of these lavas was probably controlled by the interaction of the Morenci lineament, cauldron ring-fracture zones, and north-trending extensional faults of the Rio Grande rift. The proximity of the three lava fields and the overall similarity of compositions suggest a similar origin.

7.) Cylindrical gas cavities were observed in some areas of the flow-banded rhyolite. The orientation of these cavities appears to be generally parallel to initial transport direction and they are probabley primary flow features. Some cavities, however, may have developed concurrent with slumping and secondary folding.

8.) In the eastern half of the thesis area, Tertiary dikes and a dome intrude Oligocene rocks. The oldest of these intrusions is probably the latite porphyry of Mistletoe Gulch, which occupies a ring fracture of the Magdalena cauldron in the Kelly district to the north. The eastern margin of the area is intruded by a white rhyolite dike along which later mineralization of the Hells Mesa Tuff was localized. A large white rhyolite plug intrudes Hells Mesa Tuff near the head of Mill Canyon.

Structure

The major structural features of the thesis area are north-trending extensional faults associated with the Rio Grande rift, and the North Baldy, Magdalena, and Sawmill Canyon cauldrons.

1.) The north-trending, eastern margin of the Magdalena cauldron cuts through the eastern half of the thesis area where it truncates the west-trending North Baldy cauldron margin and exposures of the Hells Mesa Tuff.

2.) A short segment of the Sawmill Canyon cauldron margin meets the Magdalena cauldron at the southeast corner of the thesis area where it truncates exposures of the Hells Mesa Tuff.

3.) Movement associated with regional uplift and block faulting of the Magdalena Mountains between about 7 and 4 m.y. ago probably reactivated some of the magdalena cauldron margin faults.

Economic Geology

Numerous mines and prospects are found in Hop and Mill canyons, and along Baldy Ridge.

1.) The major structural controls of mineralization are the ring-fracture zones of the North Baldy, Magdalena, and Sawmill Canyon cauldrons, and the late Oligocene north-trending extensional faults.

2.) Prospecting activity in Hop Canyon was largely confined to the first quarter of the century. Mineralization in andesite was local and minor; no large-scale mining was undertaken.

3.) A number of small mines and prospects have been excavated along the silicified margins of the white rhyolite dike on the east side of Baldy Ridge. Interest was largely directed towards gold in quartz veins and in small limonite pseudomorphs after pyrite. A formerly abandoned mine is presently being developed.

4.) Mines and prospects in Mill Canyon have been mined out or abandoned. There has been some recent activity at the Old Soldier vein which lies on or near the Magdalena cauldron margin. Mineralization associated with the Wheel of Fortune mine and the Old Soldier vein deserves further examination.

5.) Prospects have been cut in the perlite intervals of the rhyolite of Magdalena Peak in the Agua Frio Canyon area. No significant mining activity has taken place.

6.) Economic potential for the area is variable: a) the favorable base metal replacement horizons found in the Kelly district have been downfaulted in the thesis area by the collapse of the North Baldy cauldron and recovery would probably be uneconomic, b) mineralization of economic importance along Baldy Ridge appears limited and erratic, c) the mineralization in the Mill Canyon area deserves further examination because of favorable structural and intrusive characteristics, and d) Weber's (1957) study of the Stendel deposit concluded that development of commercial grade perlite would be difficult because of the presence of non-expandable phenocrysts.

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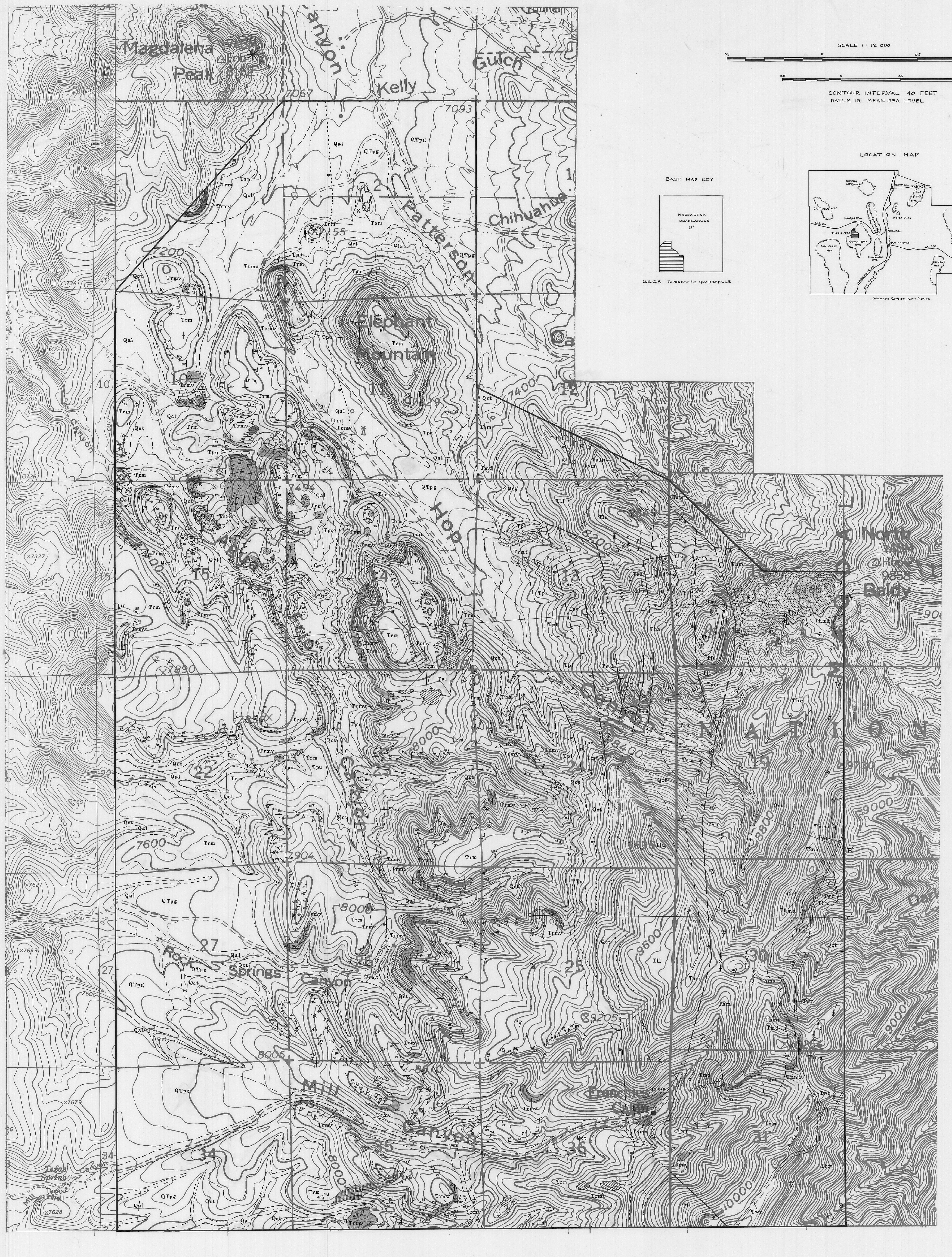
GEOLOGIC MAP AND SECTIONS OF THE WEST FLANK OF THE MAGDALENA MOUNTAINS
SOUTH OF THE KELLY MINING DISTRICT
SOCORRO COUNTY, NEW MEXICO

by
Philip Allen
1979



SCALE 1 : 12 000

0.5 0 0.5 1 MILE

0.5 0 0.5 1 KILOMETER

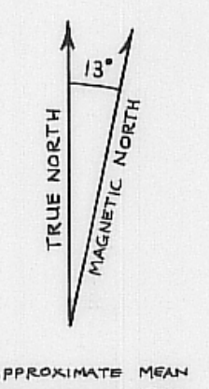
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

BASE MAP KEY

U.S.G.S. TOPOGRAPHIC QUADRANGLE

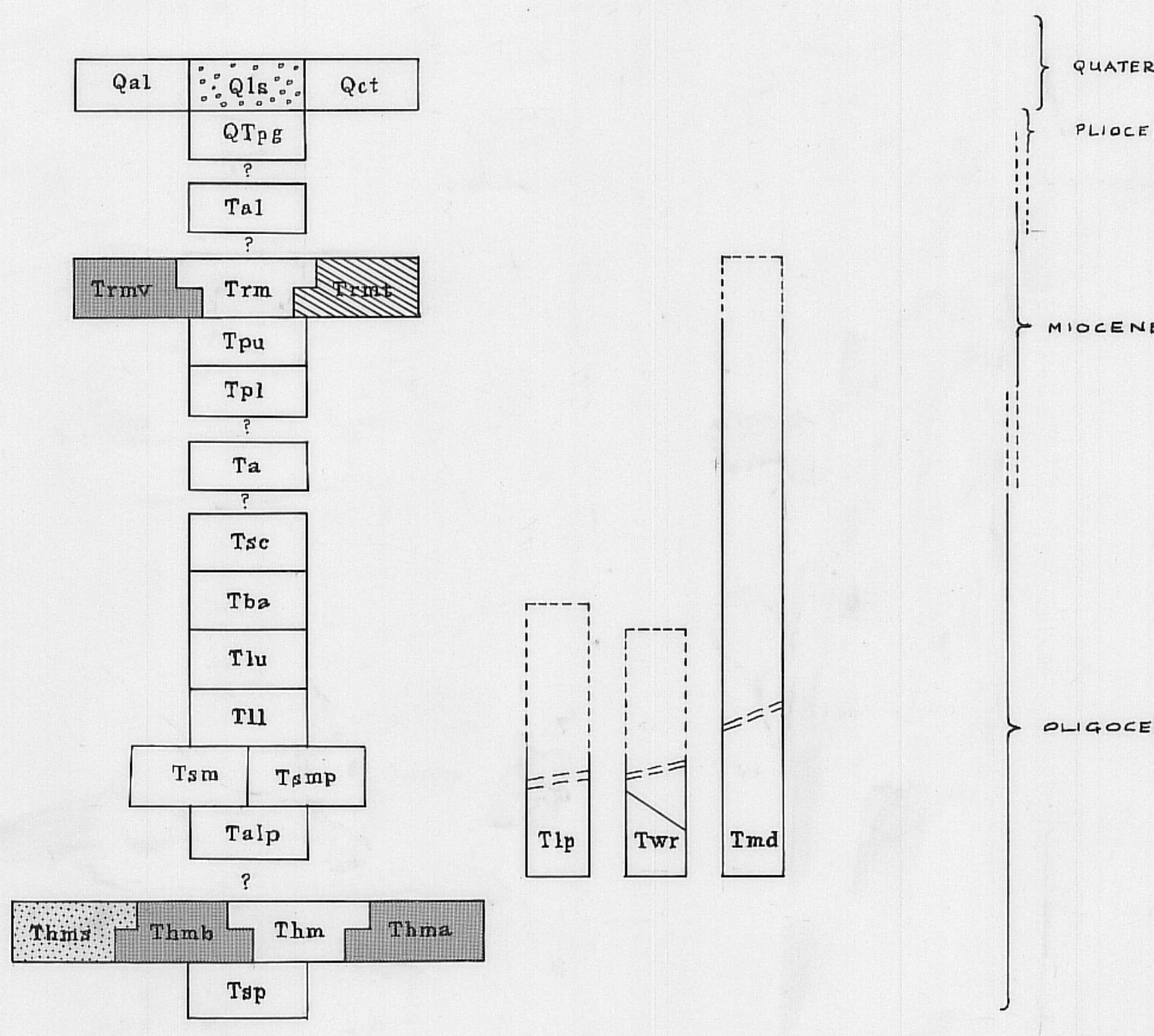
LOCATION MAP

Socorro County, New Mexico



APPROXIMATE MEAN DECLINATION 1975

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

EXTRUSIVE AND SEDIMENTARY ROCKS

Qal	ALLUVIUM
Qls	LANDSLIDES
Qct	COLLUVIUM - TALUS
QTpg	PIEDMONT GRAVELS and older valley fill
Tal	ALLUVIUM
Trm	RHYOLITE OF MAGDALENA PEAK — Flow banded where foliation trends shown, undivided elsewhere. Locally includes : Trmv and Trmt
Trmv	Vitrophyre and perlite
Trmt	Tuffs
Tpu	POPOTOSA FORMATION — Upper member
Tpl	POPOTOSA FORMATION — Lower member
Ta	ANDESITE
Tsc	TUFF OF SOUTH CANYON
Tba	BASALTIC ANDESITE AND HORNBLENDE ANDESITE
Tlu	TUFF OF LEMITAR MOUNTAINS — Upper member
Tll	TUFF OF LEMITAR MOUNTAINS — Lower member
Tsm	UNIT OF SIXMILE CANYON — Locally includes : Tsmp
Tsmp	Latite porphyry
Talp	A-L PEAK TUFF — Flow-banded member
Thm	HELLS MESA TUFF — Locally includes : Thms, Thmb, and Thma
Thms	Sandstones and conglomerates
Thmb	Laharic Breccias
Thma	Andesites
Tsp	SPEARS FORMATION

INTRUSIVE ROCKS

Tlp	LATITE PORPHYRY OF MISTLETOE GULCH
Twr	WHITE RHYOLITE DIKES AND DOME
Tmd	MAFIC DIKES

SYMBOLS

——— - - - -	CONTACT — Dashed where approximately located
—•—— — — ···	FAULT — Dashed where approximately, dotted where concealed, ball on downthrown block
⊥ 20	STRIKE AND DIP OF BEDS
50 ⊥ vertical	STRIKE AND DIP OF FLOW LAYERING
→	TRANSPORT DIRECTION
✳	VOLCANIC VENT
┈┈	SILICIFIED ZONE
75	VEIN — Arrow shows inclination
X	PROSPECT
⚒	MINE — Includes adits, shafts, and large open pits