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GEOLOGY OF THE SAWMILL CANYON AREA

OF THE MAGDALENA MOUNTAINS

SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The southern Magdalena Mountains are characterized by a thick pile of Tertiary cauldron-facies volcanic rocks and associated intrusives. Structural style is controlled by cauldron structures and normal faults that are related to the Rio Grande rift.

The oldest rock unit exposed in the area is the Hells Mesa Tuff of Oligocene age. Overlying the Hells Mesa are its cauldron-fill deposits and, in ascending order, the A-L Peak Tuff and its cauldron-fill deposits, the tuff of Lemitar Mountains, the tuff of South Canyon, and the rhyolite lavas and pyroclastic rocks of the unit of Sawmill Canyon. An overlying sequence of mudflow deposits and fanglomerates is represented by the Popotosa Formation of early to middle Miocene age.

Several overlapping cauldron structures are located in the Magdalena Mountains area. The North Baldy cauldron (32 m.y.) underlies the entire study area and is largely buried by younger rocks. A portion of the Sawmill Canyon cauldron (32-28 m.y.) margin is located in this thesis area and controls the structural trend here.

Regional extension began in middle Oligocene time concurrent with cauldron activity and has continued until the present day. Normal faulting as a result of this extension has been superimposed on cauldron structures in a dominantly

north-northwest trend. In the southern Magdalena Mountains, blocks are dropped down to the west and strata is tilted to the east. Rhyolite and latite dikes have been intruded along these faults and follow the same general trend.

The study area is within the regional potassium-metasomatism anomaly. Intense hematite staining in the area is the result of oxidation of pyrite that is localized along fracture surfaces in ring-fracture rhyolite domes and A-L Peak Tuff along the margin of the Sawmill Canyon cauldron.

Minor manganese mineralization is present in the southern part of the study area and does not constitute an economic deposit at present prices.

INTRODUCTION

Geologic Setting

The Magdalena Range is located where the Rio Grande rift is overprinted on the northeast corner of the Datil-Mogollon volcanic province. The range is a north-trending fault block uplift within the southern portion of the rift (Chapin, 1971a). A transverse shear zone that trends east-northeast separates the range into two structural zones. The northern Magdalena Mountains are characterized by normal faults that are stepped down to the east and strata that are tilted to the west. The southern part of the range, where this study area is located, contains down-to-the-west faults and strata that are tilted to the east. No pre-Tertiary rocks are exposed in the southern part of the range, although Precambrian and Paleozoic rocks are exposed in the northern portion. At least two overlapping cauldron structures are present in the southern Magdalena Range. The entire study area is within the North Baldy cauldron; the southern margin of the Sawmill Canyon cauldron is located within the area mapped.

Objectives

The primary objectives of this study are: 1) to extend the regional stratigraphic framework into the southern Magdalena Mountains, 2) to evaluate the existence and nature of suggested cauldron structures, and 3) to evaluate the mineral potential of the area.

Location and Accessibility

The study area is located approximately 10 mi (16 km) south and 15 mi (24 km) west of Socorro in the southern Magdalena Mountains (Fig. 1). It encompasses an area of about 20 square mi (52 square km), the boundaries of which are defined by the limits of Bowring's (1980) study to the north, Hardy Ridge to the west, approximately the edge of the South Baldy quadrangle to the east, and the mouth of Sawmill Canyon to the south. The northern half of the study area is within the Cibola National Forest. Part of the southern half is administered by the U.S. Bureau of Land Management; the rest is privately owned. Figures 2 and 3 are aerial photographs of the study area.

Access from Socorro is by way of Interstate 25 south to the San Marcial exit, then northwest on Forest Road 472 to the mouth of Sawmill Canyon. From there, a jeep trail to the junction of the West Fork and East Fork of Sawmill Canyon is passable using a four-wheel drive vehicle.

Methods of Investigation

Detailed geologic mapping was carried out during the summer and fall of 1978 and the spring of 1979. The base map consists of portions of the South Baldy, Molino Peak,

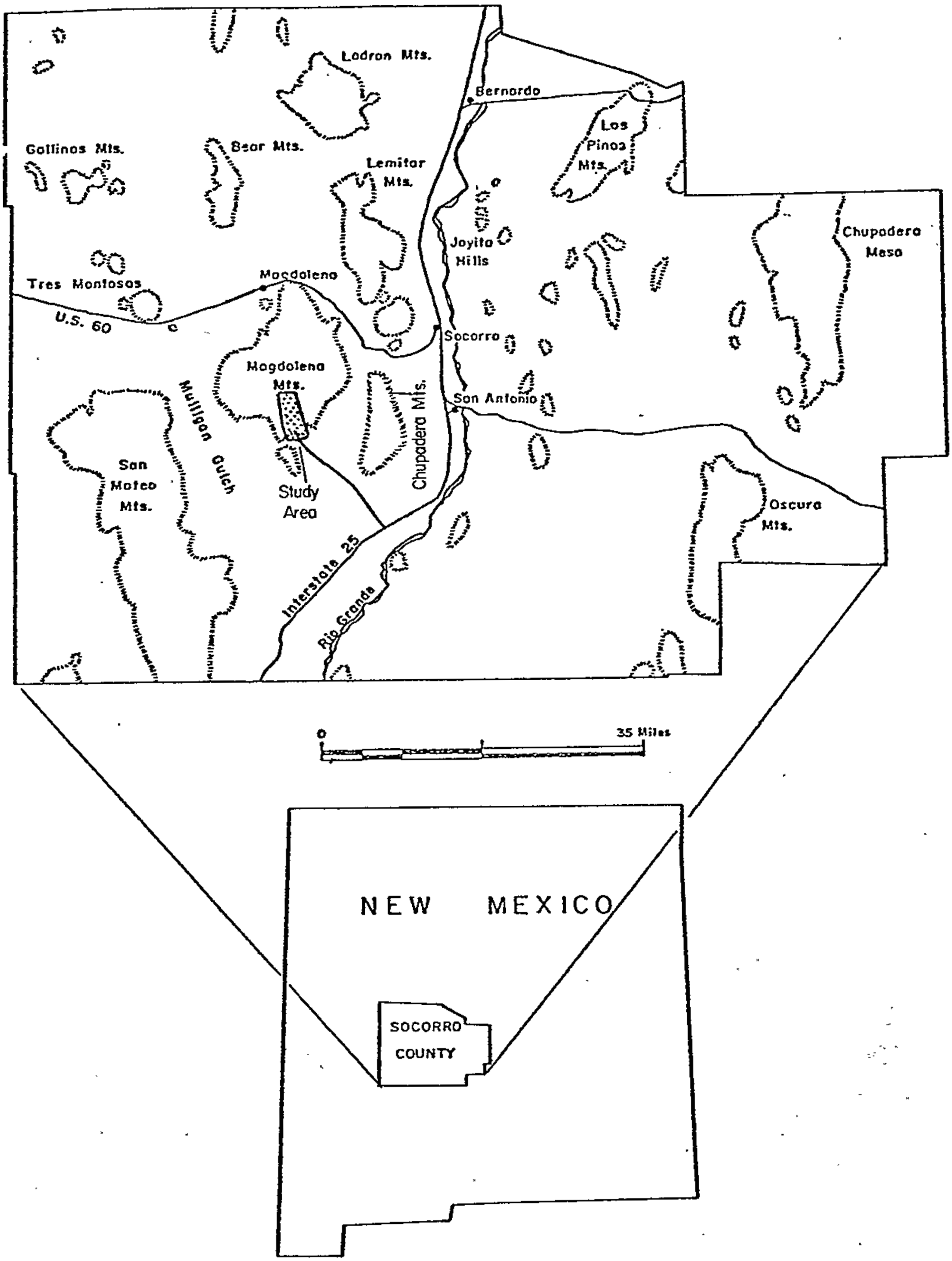

Figure 1. General location map showing relationship of the study area to major physiographic features and routes of access in Socorro County.

Figure 2. Aerial photograph, looking north, of the southern Magdalena Mountains and the head of the San Marcial alluvial fan. V-L Ranch is shown by the white spots in the center of the photograph. The thesis area begins just south of the V-L Ranch and covers most of the area in the photograph north of the ranch. The high, bare peak in the upper right-hand corner is South Baldy Peak to the north of this study area. The long ridge to the west is Hardy Ridge.

Figure 3. Aerial photograph, looking north, of the northern half of the thesis area. The high peak is South Baldy Peak and the ridge to the west is Hardy Ridge. Sawmill Canyon forks at Sawmill Ridge in the center of the photograph. White rhyolite dikes are prominent in the center of the photograph west of Sawmill Ridge. The northern boundary of the thesis area is just north of these dikes.

Puertecito Gap, and Cienega Ranch quadrangles of the U.S. Geological Survey 7 1/2-minute series (1:24,000). U.S. Forest Service aerial photographs (4-10-71 and 4-13-71) at a scale of 1:12,000 were used to aid in structural interpretation and location of outcrops. Forty-seven thin sections of rocks from within the study area were analyzed in order to describe and correlate units. Most of the thin sections were stained with sodium cobaltinitrite using the procedure described by Deer, Howie, and Zussman (1966, p. 311) to help distinguish potassium feldspars from quartz and to evaluate possible potassium metasomatism of plagioclase feldspar and the groundmass. Etching time was increased to 30 seconds. Petrographic rock names are according to Lipman (1975, Figure 3); colors are from the Geological Society of America Rock Color Chart.

A sample for radiometric dating was collected from a tuff interbedded in the sedimentary interval of the unit of Sixmile Canyon.

Previous Work

This study is the first detailed geologic mapping carried out in the southern Sawmill Canyon area, although several mapping projects have been completed in adjacent areas of the southern Magdalena Mountains. Figure 4 shows the relationship of the study area to previous studies in surrounding areas. Most of these, including the present

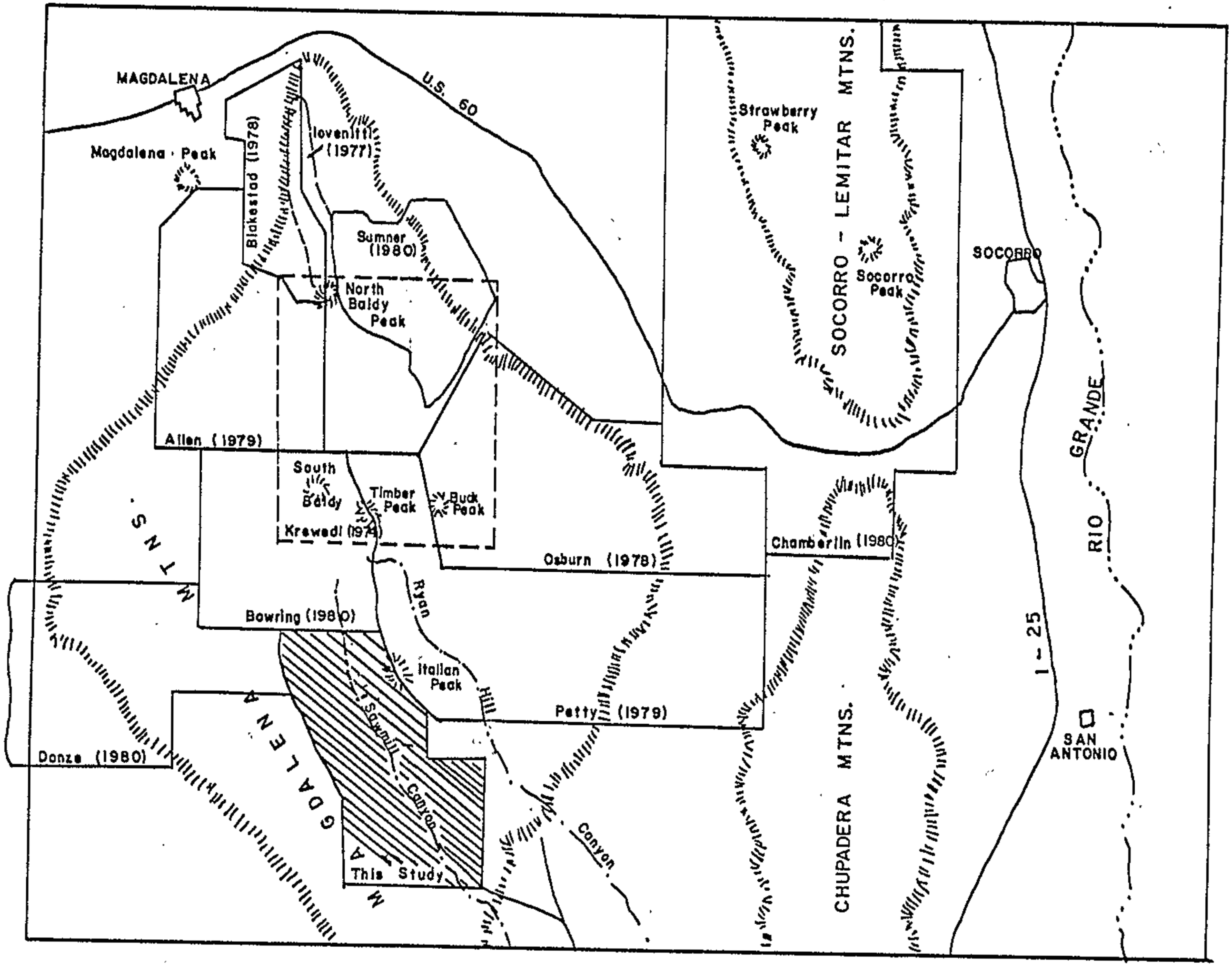

Figure 4. Relationship of this study area to previous studies in the Socorro-Magdalena area.

study, are part of the "Magdalena Project" that is being conducted by the New Mexico Bureau of Mines and Mineral Resources.

Establishment of the volcanic stratigraphy in the Magdalena Mountains is a result of the integration of many studies, including those in surrounding mountain ranges in Socorro County. The entire Tertiary sequence was originally named the Datil Formation by Winchester (1920) after the Datil Mountains; the type section was located at the northern end of the Bear Mountains. The first detailed mapping in the Magdalena Mountains was carried out in the northern part of the range by Loughlin and Koschmann (1942) in their study of the Kelly mining district. Tonking (1957) mapped the Puertecito quadrangle north of Magdalena and divided the Datil Formation into three members; from oldest to youngest these are the Spears, Hells Mesa, and La Jara Peak Members. Weber (1971) later suggested raising the Datil Formation to group status; the Spears, Hells Mesa, and La Jara Peak Members were elevated to formation status by Chapin (1971b). Brown (1972) mapped the southern Bear Mountains and subdivided the Hells Mesa Formation into two informal units--the tuff of Goat Springs and the tuff of Bear Springs. The Hells Mesa Formation has since been restricted to the tuff of Goat Springs of Brown (Chapin, 1974; Deal and Rhodes, 1976); the tuff of Bear Springs was renamed the A-L Peak Rhyolite by Deal and Rhodes (1976). Present workers have agreed to abandon the term Datil Formation.

Further subdivisions of these formations have been made by subsequent workers and will be discussed in individual sections. A chronologic development of the stratigraphy is shown in Figure 5.

Acknowledgements

The author gratefully acknowledges the many individuals who contributed to the completion of this study. Larry Smith allowed access to his private property. Robert G. Osburn contributed many useful suggestions in the field and office and critically read the manuscript. John W. Hawley aided in field classification of the Santa Fe Group and Quaternary deposits. Drs. Antonius J. Budding and David L. Norman served on my thesis committee and critically read the manuscript.

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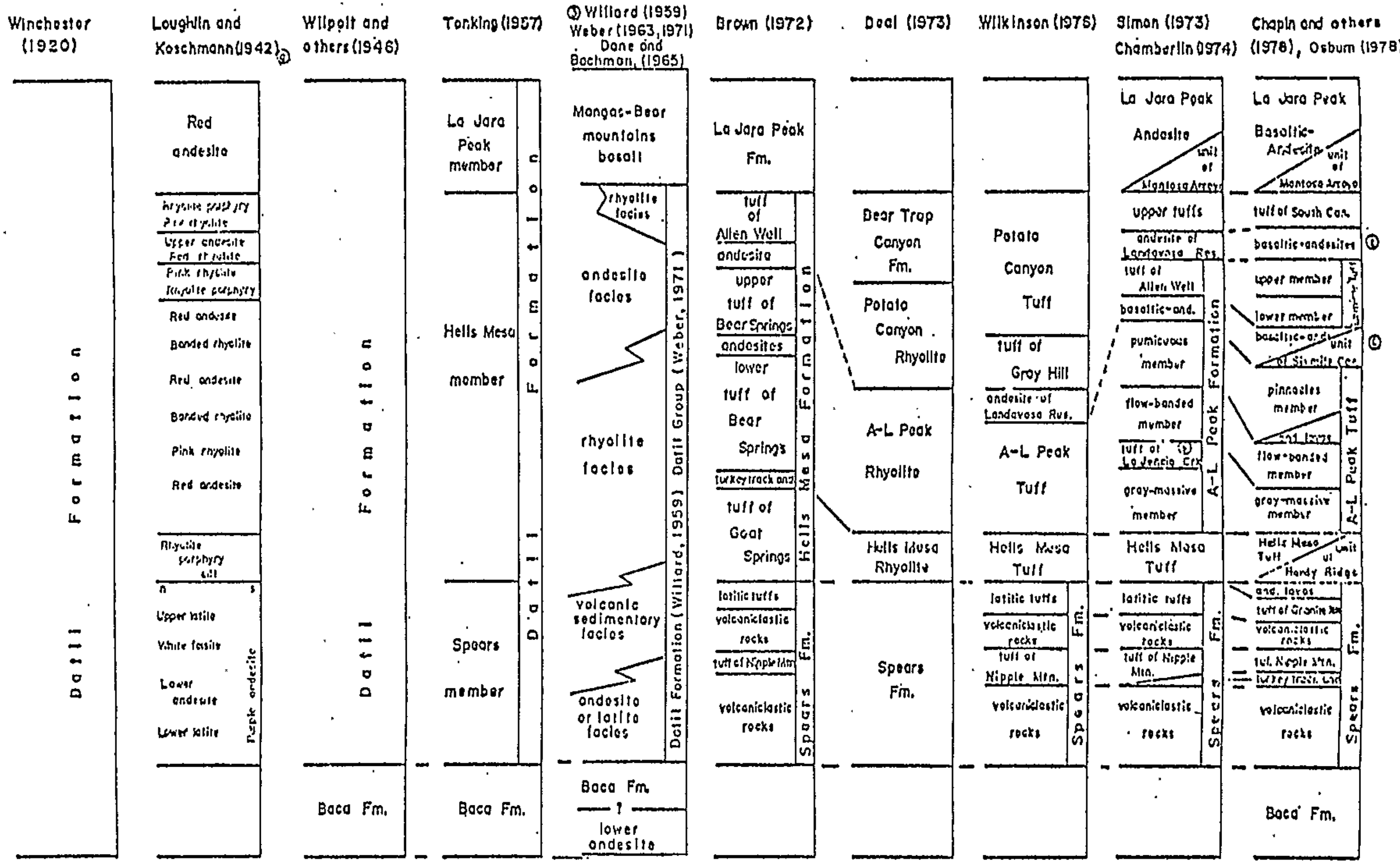


a) no straight-forward correlation of present units with Loughlin and Koschmanns volcanic stratigraphy is possible. This column is after Blakestad, 1977 where the reader will find more detailed information.

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

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

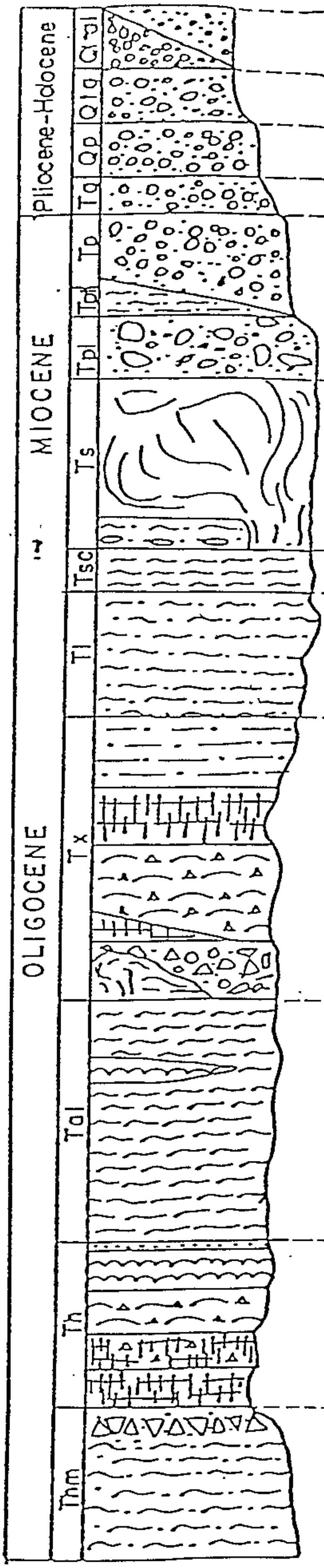
Figure 5. Correlation diagram showing the relationship of units defined in previous stratigraphic studies (after Osburn, 1978).

STRATIGRAPHY AND PETROGRAPHY

Regional Stratigraphy

During the late Eocene, the area of Socorro County was eroded to a surface of low relief (Epis and Chapin, 1975). Resting upon this surface are rocks of the Oligocene Spears Formation, composed of latitic-andesitic volcaniclastic sedimentary rocks and minor ash-flow tuffs. The Spears represents the alluvial apron which surrounded the Datil-Mogollon volcanic field prior to its ignimbrite climax (Chapin and others, 1978). Overlying the Spears are thick and extensive ash-flow tuff sheets formed by pyroclastic eruptions from successive, overlapping cauldrons. Thick piles of lavas, tuffs, and sediments accumulated within these cauldrons. During the late stages of this volcanism, rift-related extension formed basins that were filled with sediments of the Santa Fe Group and basaltic and rhyolitic lavas.

Rocks exposed in the study area consist of ash-flow tuffs, lavas, and sedimentary rocks of Oligocene and early Miocene age overlain by fanglomerate and mudflow deposits. The map units are shown graphically on Figure 6.



Alluvium: (0-20 ft, 6.1 m) ALLUVIUM: deposits of sand and gravel along stream channels.

Talus and Colluvium: (0-50 ft, 15 m) TALUS AND COLLUVIUM: masses of rock fragments deposited on steep slopes. Colluvium is gradational with talus and is present on more moderate slopes.

Terrace gravels: (0-50 ft, 15 m) TERRACE GRAVELS: deposits of gravel and sand along stream terraces.

Piedmont gravels: (0-200 ft, 61 m) PIEDMENT GRAVELS: gravel and sand derived from high areas and deposited as coalescing alluvial fans.

Tertiary gravels: (0-200 ft, 61 m) GRAVEL AND SAND: moderately consolidated gravel and sand that crops out poorly in this area.

Upper Popotosa Fm.: (0-200 ft, 61 m) CONGLOMERATES AND SANDSTONES: buff to brn., moderately to poorly indurated, heterolithic cgl. and cgl. ss.

Tuff: (0-100 ft, 30.5 m) ASH-FLOW TUFF: poorly to moderately welded rhy. to qtz. latite ash-flow tuff; lithic rich; moderately crystal rich.

Lower Popotosa Fm.: (0-200 ft, 61 m) MUDFLOW DEPOSITS AND CONGLOMERATES: red-brn., very well indurated, heterolithic mudflow deposits with abundant clasts of underlying volcani units; grades upward into conglomerates.

Unit of Sawmill Canyon: (0-1000 ft, 305 m) RHYOLITE DOME COMPLE RHYOLITE LAVA FLOWS, ASH-FLOW TUFFS: white to pink, dense, often flow-banded rhy.; float blocks rare. Crystal-poor ash-flow tuffs and vent breccias underlie rhyolite.

Tuff of South Canyon: 26 m.y. (0-65 ft, 20 m) ASH-FLOW TUFFS: multiple-flow, simple cooling unit of rhyolite ash-flow tuff. Dk. gray, moderately to densely welded, moderately xl-rich tuff w/ chatoyant sanidine and euhedral quartz.

Tuff of Lemitar Mountains: 27.9 m.y. (1000 ft, 305 m) ASH-FLOW TUFFS: multiple-flow, compositionally zoned, simple to compound cooling unit of densely welded tuff. Lt.-gray to pale-red, xl-poor lower member; md.-red, xl-rich, qtz.- and biotite-rich, 2 feld. upper member.

Unit of Sixmile Canyon: (2500 ft, 762 m) RHYOLITE DOME COMPLEX, RHYOLITE LAVA FLOWS, ASH-FLOW TUFFS, ANDESITE LAVAS, AND VOLCANICLASTIC SEDIMENTARY ROCKS: rhyolite dome complex—pink, aph., flow-banded rhy. and overlying debris-flow deposits; sanidine rhy. lava flow; brown, vesicular andesite lavas; and tuff of Caronita Canyon: 29.4 m.y.; multiple-flow, simple cooling unit of densely welded ash-flow tuff; red, xl-poor lower member; white to gray, xl-rich upper member.

A-L Peak Tuff: 32-28 m.y. (0-3000+ ft, 914 m) ASH-FLOW TUFFS: rhy., densely welded, 1-feld, xl-poor tuffs; gray to red brn.; flow banded. Gray to pink, xl-poor rhy. lavas interbedded in upper part.

Unit of Hardy Ridge: (1000 ft, 305 m) RHYOLITE AND ANDESITE LAVA FLOWS: dk.-brn., aph. andesite; brn. porph. andesite; pink to gray, xl-poor rhy. One rhy. has a trace of biotite and plagioclase phenocrysts.

Hells Mesa Tuff: 32 m.y. (1500+ ft, 457 m) ASH-FLOW TUFFS: rhy., mult.-flow, simple cooling unit of densely welded, xl-rich qtz.-rich, 2-feld., massive tuffs. Pink to red brn. Mesobreccia found in south-central part of study area.

Figure 6. Stratigraphic column of this study area.

Hells Mesa Tuff

The oldest unit exposed in the study area is the Hells Mesa Tuff. The Hells Mesa is a multiple-flow, simple cooling unit of densely welded, crystal-rich ash-flow tuff (Chapin and others, 1978). Tonking (1957) named the Hells Mesa Member of the Datil Formation after a prominent landform in the eastern Bear Mountains. Chapin (1974) and Deal and Rhodes (1976) restricted the term Hells Mesa to the lower, crystal-rich interval of the Hells Mesa Member. The tuff is correlative with the rhyolite porphyry sill of Loughlin and Koschmann (1942) and the tuff of Goat Springs of Brown (1972). K-Ar dates obtained for the Hells Mesa Tuff are 30.6 +/- 2.8 m.y. (Weber and Basset, 1963) and 32.1 +/- 1.5 m.y. and 32.4 +/- 1.5 m.y. (Burke and others, 1963).

Outflow thickness of the Hells Mesa Tuff is normally 600 ft (183 m) or less. Krewedl (1974) mapped a thickness of 3850 ft (1173 m) in the central Magdalena Mountains where it fills the North Baldy cauldron (Chapin and others, 1978). Exposures of the unit in the study area are all within the proposed North Baldy cauldron. The Hells Mesa outcrops are bounded by fault and intrusive contacts. The lower contact is not exposed, but a minimum thickness of 1500 ft (457 m) is present. In the southwestern part of the study area (portions of Secs. 9, 15, and 16, T.5S., R.3W.), outcrops of the Hells Mesa cover about one square mi (2.6 square km) in a roughly triangular pattern. Here, the Hells

Mesa is typically reddish brown to grayish red and weathers along joint planes to form blocky outcrops. Columnar jointing is present in some outcrops. Pumice is inconspicuous in most outcrops; strike and dip readings are inaccurate due to poorly defined foliation. Lithic fragments usually make up less than 10% of the rock; however, a mesobreccia (Lipman, 1976) is present in the southeast quarter of Sec. 9 (T.5S., R.3W.). Here, the lithic fragments are as large as 3 ft (0.9 m) in diameter and comprise as much as 75% of the rock. Common lithologies are porphyritic andesite, crystal-rich tuff, rhyolite lava, and biotite schist, each of which is locally abundant. Figure 7 is a photograph that shows the typical appearance of Hells Mesa mesobreccia.

In the southeastern part of the study area (S 1/2, Sec. 14, T.5S., R.3W.), small scattered outcrops of Hells Mesa Tuff are found. Here, the Hells Mesa is conformably overlain by a porphyritic basaltic andesite lava flow of the unit of Hardy Ridge (Thal). The tuff is very light gray to pale red and weathers to rounded boulders. Locally, pale red, subangular to rounded fragments with the same mineralogy as the matrix are found within the very-light-gray portion of the tuff. Lithic fragments are sparse. The Hells Mesa Tuff in this study area is consistently crystal rich, containing 25 to 45% phenocrysts of quartz, sanidine, plagioclase, biotite, and magnetite. Relatively large (up to 5 mm),

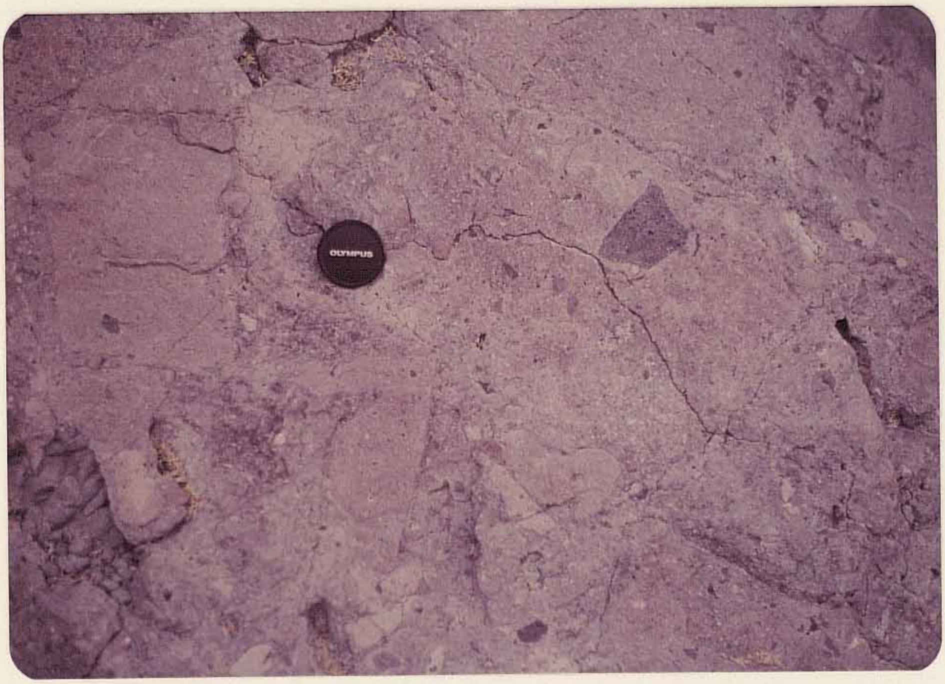


Figure 7. Photograph of mesobreccia in the Hells Mesa Tuff. Lens cap is 4 cm in diameter. Breccia fragments consist of andesite (dark clasts) and crystal-rich ash-flow tuff. (E 1/2, Sec. 9, T.5S., R.3W.).

anhedral to subhedral, often deeply embayed quartz comprises about 40% of the phenocrysts. Subequal amounts of subhedral sanidine and plagioclase make up another 40% of the phenocrysts; the plagioclase crystals are often highly altered. Biotite and magnetite make up the remainder of phenocrysts; about 10% of each is present. Magnetite is often found replacing biotite.

A pale-pink ash-fall tuff that is about 6 in. (15 cm) thick is interbedded in the Hells Mesa in the southwest quarter of Sec. 14 (T.5S., R.3W.). A thin sandstone interval (1 ft, 0.3 m) is interbedded in the Hells Mesa at one location (center, NE 1/4, SW 1/4, Sec. 9, T.5S., R.3W.).

Detailed petrographic work has been done on the Hells Mesa Tuff by Brown (1972), Chamberlin (1974), and Spradlin (1976); the interested reader is referred to their works for further information.

Unit of Hardy Ridge

The unit of Hardy Ridge was informally named by Bowring (1980) for exposures just north of this study area. The unit represents cauldron-fill deposits of the North Baldy cauldron and consists of several andesite flows and dikes, a thick sequence of rhyolite lavas, and minor volcaniclastic sedimentary rocks and interbedded ash-flow tuffs. A complete section in not exposed within the study area, but here the unit is not less than 1000 ft (305 m) thick. Bowring (1980) reports a thickness of 800 ft (244 m) on Hardy Ridge to the north of this study area.

The unit of Hardy Ridge overlies the Hells Mesa Tuff and crops out at scattered locations throughout the study area. Where exposed within the Sawmill Canyon cauldron (Secs. 32 and 33 (unsurveyed), T.4S., R.3W., and Secs. 4 and 5, T.5S., R.3W.) and to the south of the southern topographic margin of the Sawmill Canyon cauldron (S 1/2, Sec. 14 and N 1/2, Sec. 23, T.5S., R.3W.), the unit is unconformably overlain by A-L Peak Tuff. To the west of the western margin of the Sawmill Canyon cauldron (Sec. 30 (unsurveyed), T.4S., R.3W.), the unit of Hardy Ridge is directly overlain by the unit of Sawmill Canyon.

<u>andesites and sedimentary rocks</u>. Conformably overlying the Hells Mesa Tuff is a series of thin andesite flows. The andesites crop out at scattered sites throughout the study area. One distinctive flow (Tha2) was mapped separately; the rest were mapped as Tha1. Tha1 is the basal member of the unit of Hardy Ridge in this study area. Thickness of the andesite varies from 10 ft (3 m) to more than 100 ft (30 m). Outcrops are relatively non-resistant, often marked by grassy slopes. The rock is pale brown to light brownish gray when fresh and various shades of green when altered. Vesicles, often filled with a dark-yellowish-orange clay mineral, are common locally. Phenocryst mineralogy of the andesites varies locally. In the northern part of the study area (NE

1/4, Sec. 30, T.4S., R.3W.), the andesite is dense and aphanitic. In the south (S 1/2, Sec. 14, T.5S., R.3W.), the andesite lava contains about 10% phenocrysts of plagioclase, clinopyroxene, and biotite. Five percent of the phenocrysts are plagioclase, about 0.5 mm long, some of which have a "honeycomb" texture. Four percent of the phenocrysts are clinopyroxene euhedra that are about 0.4 mm in diameter. The remaining 1% of the phenocrysts are subhedral biotite crystals that appear to be altered; these are about 0.3 mm long. One or 2% magnetite is present, some as replacement products of the pyroxene and biotite. Plagioclase microlites are present in the groundmass. A coarse mosaic of calcite has filled irregular pore spaces.

A distinctive porphyritic andesite flow (Tha2) conformably overlies Thal in the southern part of the study area (S 1/2, Sec. 14, T.5S., R.3W.). This andesite is about 400 ft (122 m) thick and is relatively resistant; it forms cliffy outcrops and weathers to hackly, angular talus fragments. The rock is grayish red to various shades of green and characteristically contains 15 to 20% large plagioclase phenocrysts (as much as 1 cm in long dimension). About 5% phenocrysts of clinopyroxene, biotite, and hornblende are present. Euhedral clinopyroxene averaging 1 mm in diameter makes up nearly 5% of the rock. Traces of biotite and hornblende occur as phenocrysts. Biotite and magnetite commonly replace clinopyroxene. The groundmass consists of elongate plagioclase microlites and euhedral clinopyroxene. Both phenocrysts and groundmass minerals have a strongly preferred orientation.

rhyolite lavas. A rhyolite lava overlies the andesites in scattered outcrops in the south part of the area (S 1/2, Sec. 14, and NW 1/4, Sec. 24, T.5S., R.3W.). This rhyolite (Thr1) is distinguished from Thr2 by the presence of traces of biotite and plagioclase phenocrysts. The biotite- and plagioclase-bearing rhyolite is relatively resistant and weathers to blocky fragments. The presence of spherulites and alternating dark-gray and moderate-red flow bands makes the rock colorfully distinctive in outcrop and hand specimen. In thin section, about 1% phenocrysts of biotite and plagioclase are present in subequal amounts. Biotite is elongate and averages 1 mm in long dimension. Subhedral plagioclase phenocrysts range in length up to 3 mm. The groundmass is spherulitically devitrified to radiating aggregates of quartz and feldspar.

A second rhyolite lava (Thr2) underlies the A-L Peak Tuff in the north half of the study area (Secs. 32 and 33 (unsurveyed), T.4S., R.3W., and Secs. 4 and 5, T.5S., R.3W.). This rhyolite is dense and aphanitic and ranges in color from light gray or pale pink to grayish blue. The rock is often fractured and silicified. Locally the rhyolites are flow banded, and spherulites are common within and aligned with the flow banding. A distinctive devitrification texture, consisting of subspherical, overlapping masses of rhyolite through which the flow banding is continuous, is common in the rhyolites (Fig. 8). These masses are surrounded by a rind about which they weather out. For a more detailed description of this texture, the reader is referred to Bowring (1980). In thin section, the rhyolites are very crystal poor; some contain a trace of magnetite.

A sedimentary interval that is as much as 50 ft (15 m) thick overlies Thr2 (Figs. 9 and 10). It consists of pale-red, fine- to coarse-grained thinly laminated sandstones that are locally cross bedded. A thin light-gray ash-flow tuff is interbedded with the sandstones. It contains 5 to 10% phenocrysts of quartz, sanidine, and biotite. Lithic fragments of rhyolite and andesite make up about 5% of the rock.

A-L Peak Tuff

The A-L Peak Tuff was first named A-L Peak Rhyolite by Deal (1973a) for exposures in the San Mateo Mountains; the name has since been modified to A-L Peak Tuff (Chapin and others, 1978). The tuff is correlative with the banded rhyolite of Loughlin and Koschmann (1942), the upper part of Tonking's (1957) Hells Mesa Member, and the tuff of Bear Springs of Brown (1972). The A-L Peak has been dated by Smith and others (1976) at 31.8 +/- 1.7 m.y. by the fission-track method.

Figure 8. Photograph of botryoidal masses of coalescing spherulites, a devitrification texture found in the crystal-poor rhyolite lavas in this study area.

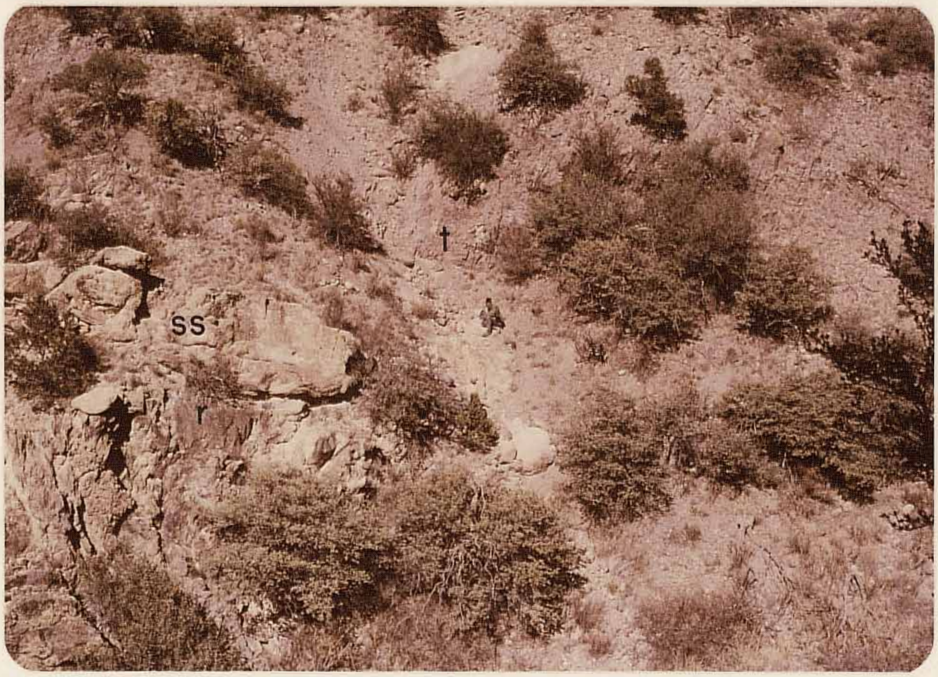


Figure 9. Photograph of the contact between the unit of Hardy Ridge and the A-L Peak Tuff. All contacts are depositional. (r=rhyolite, ss=sandstone, t=tuff) (SW 1/4, Sec. 33 (unsurveyed), T.4S., R.3W.).

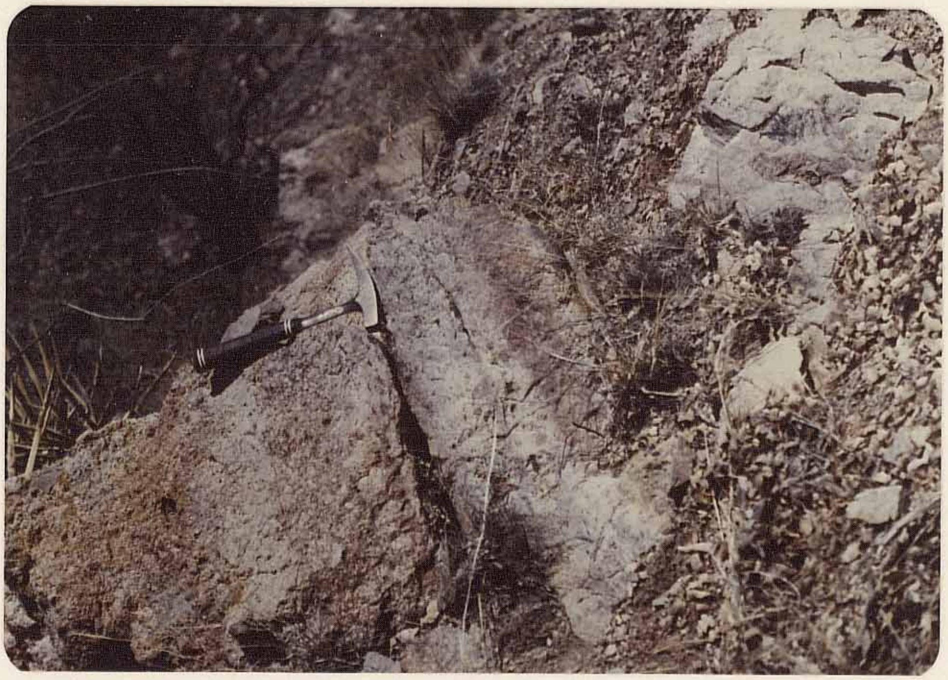


Figure 10. Photograph of sedimentary rocks underlying the A-L Peak Tuff in the north-central part of the study area (SW 1/4, Sec. 33 (unsurveyed), T.4S., R.3W.).

The A-L Peak Tuff has three recognized members within its outflow sheet--the gray-massive, flow-banded, and pinnacles members. All of the members are crystal-poor, densely welded, one-feldspar, rhyolite ash-flow tuffs (Chapin and others, 1978). The middle, pumice-rich, flow-banded member is usually welded to the lower, pumice-poor gray-massive member and these two members are normally mapped together. In the Lemitar and Bear Mountains, the upper, pumice-rich pinnacles member is separated from the underlying flow-banded member by basaltic-andesite lava flows (Chapin and others, 1978).

The source areas for members of the A-L Peak Tuff are poorly understood at this time. Deal (1973a) originally proposed the Mount Withington cauldron in the San Mateo Mountains as a source for the A-L Peak; however, it is currently believed that all members of the tuff were erupted from the Magdalena and Sawmill Canyon cauldrons.

Thickness of the A-L Peak in the Socorro-Magdalena area usually varies from 0 to 700 ft (213 m). Thickness estimates in the study area and vicinity are generally unreliable due to lack of an exposed base, strike and dip variations caused by secondary folding, and unrecognized faulting within a lithologically uniform unit with no marker horizons. The unit is extremely thick, however. Bowring (1980) estimates a minimum thickness of 2000 ft (610 m) to the north of this study area, and Petty (1979) reports a similar thickness in Ryan Hill Canyon; both of these areas are within the Sawmill Canyon cauldron. In this study area, the A-L Peak is at least 3000 ft (914 m) thick within the Sawmill Canyon cauldron, but it thins abruptly and becomes laterally discontinuous outside the main ring fracture. West of the main ring fracture, the A-L Peak Tuff is absent and the unit of Hardy Ridge is unconformably overlain by the tuff of Lemitar Mountains. Outside the southern topographic margin of the Sawmill Canyon cauldron (S 1/2, Sec. 14, T.5S., R.3W.), the A-L Peak is about 200 ft (61 m) thick.

Outcrops of A-L Peak cover almost 2 sq mi (5.2 sq km) in the north part of the study area, where the unit attains its maximum thickness (Secs. 28, 29, 32, and 33 (unsurveyed), T.4S., R.3W.). Outside the main ring fracture of the Sawmill Canyon cauldron, the tuff crops out at scattered localities throughout the area, mainly to the east of Sawmill Canyon. Where the basal contact is exposed, the A-L Peak unconformably overlies the unit of Hardy Ridge. The presence of an irregular contact of the A-L Peak with the underlying rhyolite lava (Sec. 33 (unsurveyed), T.4S., R.3W., and Sec. 4, T.5S., R.3W.) suggests the presence of an irregular erosion surface upon which the A-L Peak was deposited. The A-L Peak is overlain by cauldron-fill deposits of the unit of Sixmile Canyon.

In the northern part of the study area, the A-L Peak Tuff is separated into two intervals by a rhyolite lava flow (Talr). The portion of the tuff that overlies the lava varies somewhat in appearance, phenocryst content, and degree of welding from the portion below the lava and will be discussed separately. Bowring (1980) reports a similarly variable upper part of the A-L Peak immediately to the north of this study area.

lower member. The lower A-L Peak Tuff is well exposed in the northern part of the study area and forms extensive outcrops along the east side of Sawmill Canyon. The presence of closely spaced sheet joints normal to the foliation (Fig. 11) causes the tuff to weather to small platelets that form extensive talus slopes. The rock is typically light brownish gray with grayish-red pumice. Coatings of reddish-brown iron oxide and black manganese oxide are common on joint surfaces. The pumice, in amounts up to 20%, are highly flattened and often strongly lineated (Fig. 12). In some areas, coarse vapor-phase minerals have filled elongate gas cavities. Phenocrysts, in amounts of 2 to 10%, consist of sanidine and quartz. Subhedral sanidine, about 1.0 mm long, is generally 4 to 5 times as abundant as quartz, which is small (about 0.25 mm) and anhedral (often rounded). Anhedral magnetite phenocrysts are about 0.25 mm in diameter. Plagioclase and magnetite are present in trace amounts. One to five percent andesite lithic fragments, often too small to be observed in hand specimen, are present. Shard structure is well preserved in some thin sections; in others, devitrification has obscured primary textures.

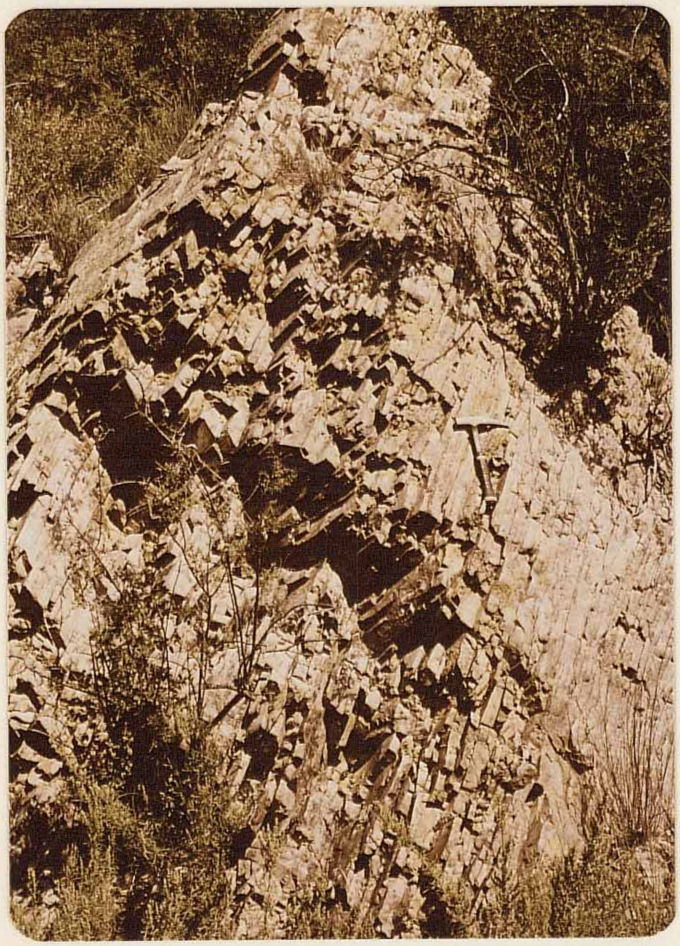


Figure 11. Well-developed sheet joints in the A-L Peak Tuff near the northern boundary of the study area (SE 1/4, Sec. 29 (unsurveyed), T.4S., R.3W.). Foliation in the tuff is nearly perpendicular to the joint planes.

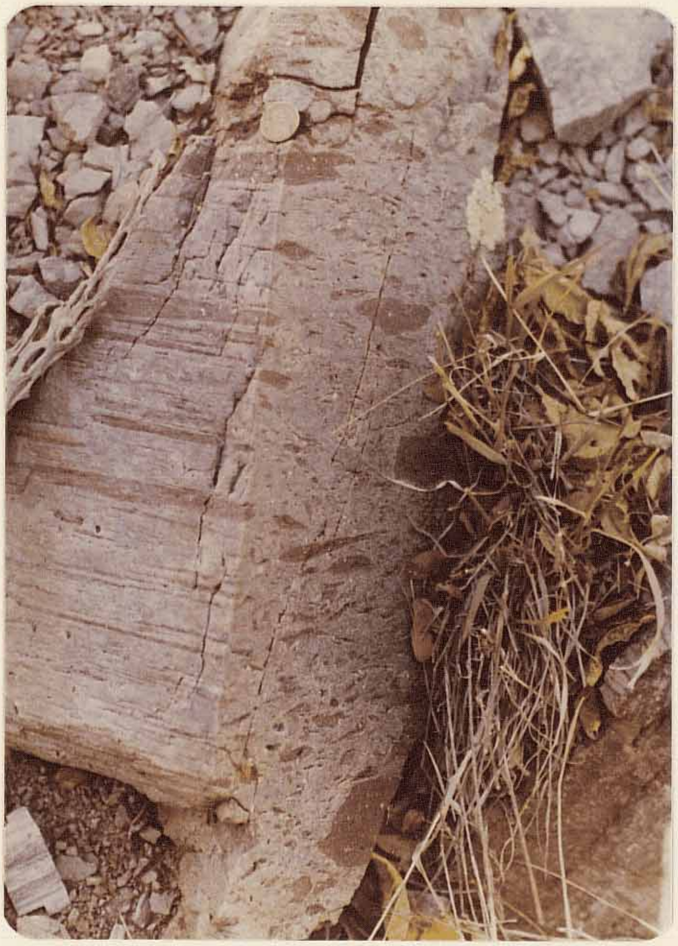


Figure 12. Photograph of lineated pumice in the A-L Peak Tuff. The thickness-to-length ratio of the pumice is often as much as 1:100. (SW 1/4, Sec. 33 (unsurveyed), T.4S., R.3W.).

The upper 10 to 20 ft (3 to 6 m) of the lower A-L Peak is usually non-lineated and grayish red in color with pinkish-gray disc-shaped pumice. At one location (NW 1/4, Sec. 33 (unsurveyed), T.4S., R.3W.), the top of the tuff is blackish red and extremely dense due to silicification. In another outcrop (NW 1/4, Sec. 28 (unsurveyed), T.4S., R.3W.), the top of the lower A-L Peak is moderately crystal-rich, containing about 12% phenocrysts of sanidine, quartz, and magnetite. Nine percent euhedral to subhedral sanidine laths, about 1 mm long, and 1% small (about 0.25 mm), anhedral, often deeply embayed quartz make up most of the phenocrysts at this locality. One to 2% anhedral to subhedral magnetite about 0.25 mm in diameter is also present. Andesite lithic fragments comprise as much as 5% of the rock and are sometimes too small to be visible in hand specimen. Pumice constitutes about 15% of the rock and contains sanidine and quartz. In one thin section, concentric rings of sericite within the pumice are probably caused by perlitic cracks being filled with alteration products. Shard structure is well preserved in the groundmass.

Primary laminar flow structures are common in the lower A-L Peak in this study area; these include 1) lineated pumice and gas cavities, 2) rotated lithic fragments and phenocrysts, 3) folded and lineated foliation planes, and 4) dips too steep to have been caused by secondary compaction.

Primary laminar flow structures have been recognized in other tuffs (Schmincke and Swanson, 1967; Walker and Swanson, 1968; Parker, 1972; Lowell and Chapin, 1972; Deal, 1973a, 1973b; Chapin and Deal, 1976; Coats, 1976; Ekren and others, 1978; Chapin and Lowell, 1979). Chapin and Lowell (1979, p. 152) attribute the presence of the primary flow features to high temperatures during transport and deposition: "If the temperature of the glassy particles is well above the softening point, the particles will agglutinate, collapse, and weld in the laminar boundary layer to form a viscous fluid with the rheological properties of a rhyolite lava. . . . if . . . below . . ., the glassy particles will fail to adhere and deposition will occur as loose ash. . ."

The trend of lineations is approximately east-west in this and adjacent study areas (Petty, 1979; Bowring, 1980). Folds range in scale from microscopic to macroscopic. Often the A-L Peak that immediately overlies a fold is undisturbed, although the entire thickness is welded together without any cooling breaks (Fig. 13). Ramp-like structures (Fig. 14) and crenulations in laminae adjacent to rotated lithic fragments and phenocrysts reflect the viscous nature of the A-L Peak ash flows.

Dip angles of the A-L Peak within the Sawmill Canyon cauldron generally range from 40 to 60 degrees compared with dips of less than 40 degrees in the other units. The consistently steeper dips of the A-L Peak

Figure 13. Photograph of a primary fold in the A-L Peak Tuff. The axial plane of this fold is perpendicular to the lineation and to the plane of this photograph.
(SW 1/4, Sec. 33 (unsurveyed), T.4S., R.3W.).

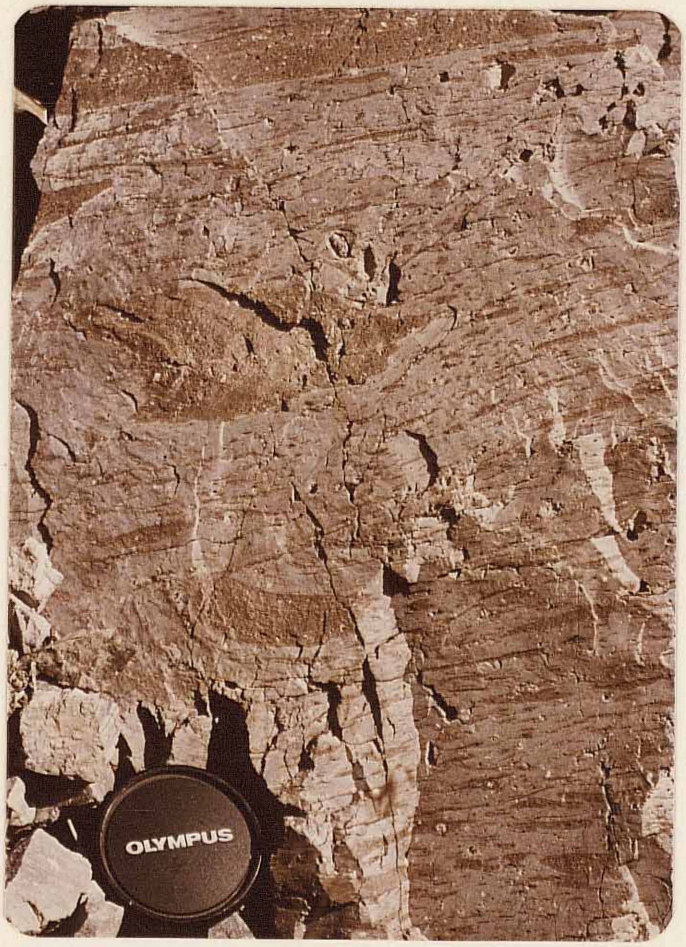


Figure 14. Photograph of the A-L Peak Tuff showing pumice that have been deformed and truncated by an overlying ash flow. Movement of the flow was left to right. Lens cap is 4 cm in diameter.
(SW 1.4, Sec. 33 (unsurveyed), T.4S., R.3W.).

probably reflect contemporaneous deposition and downwarping along the cauldron margin during subsidence. In other words, the A-L Peak was deposited on a surface dipping 5 to 25 degrees northeastward towards the center of the Sawmill Canyon cauldron. Chapin and Lowell (1979) report steep primary dips in ash-flow tuffs deposited along the margins of paleovalleys in Colorado. Some of the steep dips in the A-L Peak may have been enhanced by local folds induced by inward slumping of tuff.

rhyolite lava. The rhyolite lava interval within the A-L Peak crops out as a 2.5 mi- (4.0 km-) long strip along the east side of Sawmill Canyon. It is 700 ft (213 m) thick at its center and pinches out laterally to the north and south. The rhyolite is typically aphanitic, gray to pink in color, and weathers to platy fragments. Strikes and dips are difficult to obtain on this lava due to lack of distinct flow foliation. A flow breccia is often present at the top, where exposed.

upper member. The upper A-L Peak crops out discontinuously above the rhyolite lava interval along the east side of Sawmill Canyon for a distance of 2.5 mi (4.0 km). Its maximum thickness is 500 ft (152 m). Good exposures are found in the northeast quarter of Sec. 4 (T.5S., R.3W.). The upper A-L Peak is usually densely welded, although in places a poorly welded zone about 15 ft (4.6 m) thick is exposed at its base. The poorly welded interval is light gray with grayish-green pumice and weathers easily to clay. The basal 10 to 20 ft (3 to 6 m) of the densely welded zone is crystal poor and lithic rich; this interval is pale red and weathers to blocky talus. In thin section, 1 to 2% phenocrysts of sanidine (largely plucked out during preparation) and quartz are present. As much as 15% angular lithic fragments of andesite and flow-banded rhyolite are present and range in size up to 5 cm. The upper portion of the densely welded zone is pale purple to pale red purple and contains 12 to 15% crystals of sanidine and quartz and a trace of biotite and magnetite. Euhedral sanidine about 1 mm long is 4 times as abundant as quartz, which is small, anhedral, and deeply embayed. Pumice average 1.5 cm in length and are often spherulitic. A trace of angular rhyolite lithic fragments is present.

Outcrops of A-L Peak Tuff that are present beyond the outcrop area of the rhyolite lava vary in appearance and will be described separately. Outcrops in sections 3 and 10 (T.5S., R.3W.) are poor due to the abundance of talus from the overlying units. Some of these A-L Peak outcrops occur as float blocks in the rhyolite dome complex of the unit of Sixmile Canyon. Where outcrops are present, the base of the A-L Peak consists of a thin, (about 15 ft (4.6 m) thick) moderate-brown vitrophyre that contains dark-reddish-brown (often spherulitic) pumice. The unit tends to crumble when broken. Overlying the vitrophyre is a densely welded zone of moderate-red tuff containing dark reddish-brown pumice. In one outcrop (NW 1/4, Sec. 10, T.5S., R.3W.), the tuff contains subspherical devitrification masses similar to those found in the rhyolite of the unit of Hardy Ridge (p. 19; Fig. 6).

The A-L Peak Tuff in Secs. 14, 22, and 23 is moderately to densely welded and weathers to angular blocks. The tuff here is pale red purple or grayish red with very-light-gray pumice that are typically 10 cm by 0.5 cm in size and contain spherulitic and axiolitic structures. Two to 5% phenocrysts of sanidine, biotite, and quartz are present. Sanidine is 3 to 4 times as abundant as quartz. A trace of biotite is present. Magnetite commonly replaces biotite. These outcrops are outside the topographic margin of the Sawmill Canyon cauldron and represent outflow-facies A-L Peak.

Outside the major ring fracture of the Sawmill Canyon cauldron, lineation is strongly defined in some outcrops, while in others it is poorly defined or absent. When present, the general trend of the lineations is north-south in contrast to the general easterly or northeasterly trends within the cauldron. The lateral and vertical variation in primary flow structures is probably due largely to temperature variations during eruption.

At the present time, the gray-massive member of the A-L Peak Tuff is believed to have been erupted from the Magdalena cauldron. The flow-banded and pinnacles members are considered to have been erupted from the Magdalena and Sawmill Canyon cauldrons, respectively. However, the presence of flow banding in the A-L Peak within both of these cauldrons makes this correlation uncertain. Alternatively, the Sawmill Canyon and Magdalena cauldrons may have subsided concurrently, in part, with the flow-banded A-L Peak having been erupted from both cauldrons.

Unit of Sixmile Canyon

Overlying the A-L Peak Tuff are moat deposits of the Sawmill Canyon cauldron, first named the Sixmile Canyon Andesite by Krewedl (1974) after exposures in the eastern Magdalena Mountains. Osburn (1977) changed the name to unit of Sixmile Canyon to indicate its heterolithic nature. The unit consists of rhyolite lava flows and domes, andesite lava flows, sedimentary rocks, and thin, local tuffs and is capped by a distinctive ash-flow tuff interval informally named tuff of Caronita Canyon.

The unit of Sixmile Canyon crops out continuously along the eastern border of the study area and intrudes and overlies the A-L Peak Tuff and the unit of Hardy Ridge. The upper interval of the unit is repeated in the southwestern portion of this study area by a large down-to-the-west normal fault.

The unit of Sixmile Canyon is at least 2500 ft (762 m) thick for much of its extent; Petty (1979) reports a similar thickness in Ryan Hill Canyon. Bowring (1980) has informally subdivided the unit into two members based upon the degree of lateral variability of lithologies and thicknesses; his method of division will be used in this study. The lower member of the unit of Sixmile Canyon is characteristically variable in rock type and thickness. The upper member is a laterally continuous sequence composed of an andesite lava flow and the overlying tuff of Caronita Canyon.

lower member. The lower member of the unit of Sixmile Canyon consists of an intrusive rhyolite complex, rhyolite lava flows, volcaniclastic sedimentary rocks, and minor ash-flow tuffs.

rhyolite dome complex (Txrl). A rhyolite dome complex (Txrl) is located in the central part of the study area. It is intrusive into the Hells Mesa Tuff, the unit of Hardy Ridge, and the A-L Peak Tuff and is overlain by cauldron-fill deposits of the Sawmill Canyon cauldron. Within the rhyolite are float blocks that range in outcrop area from several sq ft to 0.08 sq mi (0.21 sq km). The float blocks are composed of a crystal-poor ash-flow tuff, a porphyritic andesite, Hells Mesa mesobreccia, A-L Peak Tuff, and A-L Peak mesobreccia.

The rhyolites are very resistant and often form steep cliffs and pinnacles. Closely spaced sheet joints and highly contorted flow banding are common features in the rhyolites. Spherulites and devitrification textures similar to those found in the rhyolites of the unit of Hardy Ridge (p. 19; Fig. 8) are also present. The rhyolites are pale red in color and dense and aphanitic to sugary in texture. Phenocrysts are usually absent, but a trace of quartz is locally present.

volcaniclastic sedimentary rocks and tuffs (Txs). A sedimentary interval consisting of debris-flow deposits, interbedded sandstones, and a thin ash-flow tuff crops out at scattered locations in the southeastern part of this study area. The sedimentary interval overlies the rhyolite dome complex (Txrl) and consists largely of blocks of rhyolite that were eroded from the domes; the contact between the rhyolite and debris-flow deposits is gradational.

Outcrops of the debris-flow deposits are well indurated and form cliffy outcrops at the base of the canyon near Sawmill Canyon Windmill (Sec. 15, T.5S., R.3W.). The clasts are generally grain-supported with little matrix, poorly sorted, and range up to 1 m in diameter. At the base of the unit, the clasts consist entirely of crystal-poor rhyolite (Fig. 15). Fragments of andesite increase in abundance upward, and a trace of clasts of A-L Peak Tuff is present. The matrix is usually dark reddish brown but is

Figure 15. Photograph of debris-flow deposits (Txs) found in the unit of Sixmile Canyon. Clasts are crystal-poor rhyolite lava. (SE 1/4, Sec. 10, T.5S., R.3W.).

dusky yellow green where propylitized. Interbedded sandstones are usually less than 20 ft (6 m) thick and are grayish yellow green in color.

An interbedded water-laid (?) tuff, about 10 ft (3 m) thick, crops out in the southeast quarter of Sec. 10 (T.5S., R.3W.). This tuff is white in color and contains about 5% biotite, 10% feldspars and a trace of quartz phenocrysts. Small (less than 1 mm) lithic fragments make up a large portion of the groundmass. A sample of the tuff was collected for radiometric dating.

ash-flow tuff (Txt). One outcrop of Txt is present within this study area. The tuff is pale yellow and contains about 20% phenocrysts of sanidine and a trace of quartz. The tuff is believed to be correlative with the tuff (Txt) mapped to the north by Bowring (1980).

sanidine rhyolite (Txr2). At the top of the lower member of the unit of Sixmile Canyon is a sanidine-bearing rhyolite (Txr2) that crops out for a distance of almost 4 mi (6.4 km). This rhyolite is approximately 1000 ft (305 m) thick at its southern extremity (N 1/2, Sec. 10, T.5S., R.3W.) and thins to less than 20 ft (6 m) at the northern boundary of this study area. Outcrops of sanidine rhyolite form steep cliffs and weather to large boulders that form impressive talus slopes that obscure underlying units. The rhyolite is light brownish gray to grayish red purple when fresh. A moderate-reddish-brown vitrophyre that is 10 to 20 ft (3 to 6 m) thick is present at its upper contact at one location (SW 1/4, SE 1/4, Sec. 28 (unsurveyed), T.4S., R.3W.). Just north of the vitrophyric zone, the rhyolite is propylitized to a grayish-green color. Five to 15% phenocrysts of sanidine and quartz are present in subequal amounts. In thin section, sanidine euhedra as much as 1 cm in length are highly altered to fine-grained phyllosilicates. Anhedral to subhedral quartz phenocrysts that range in size from 0.2 mm to 1.0 mm are often deeply embayed. Magnetite is finely disseminated throughout the devitrified groundmass.

Upper member. The upper member of the unit of Sixmile Canyon crops out continuously from the northern boundary of the study area to the southern topographic margin of the Sawmill Canyon cauldron (Sec. 14, T.5S., R.3W.). It consists of 1) a basal andesite lava interval that contains interbedded sandstones and 2) an ash-flow tuff interval known as the tuff of Caronita Canyon.

andesite lavas. The andesite lava interval in the upper member of the unit of Sixmile Canyon interfingers with the sanidine rhyolite of the lower member in the north part of the study area (Sec. 28 (unsurveyed), T.4S., R.3W.). Sedimentary rocks (usually sandstones) that are interbedded with the andesite lavas are relatively abundant in the northern part of the study area, making up more than 50% of the thickness of the unit. Toward the south, the andesite-to-sandstone ratio gradually increases to where the andesite makes up at least 90% of the thickness of the unit. Outcrops of andesite are very non-resistant and usually weather to grassy slopes. The andesite is dense, aphanitic, and brownish gray in color. Vesicles are common and are usually filled with chalcedony or drusy and mosaic quartz, although coarse calcite and a fibrous zeolite (probably natrolite) are found locally. The andesite weathers preferentially with respect to the quartz amygdules, which are more resistant and are found as ellipsoidal bodies. Often these bodies are coated with a thin, grayish-green layer that is probably celadonite. Phenocrysts consist of a trace of plagioclase that averages about 1.5 mm long. Plagioclase euhedra, averaging 0.4 mm in length, comprise about 25% of the groundmass; clinopyroxene anhedra less than 0.1 mm in diameter make up about 5%. The remaining groundmass is cryptocrystalline and intensely hematite-stained.

Tuff of Caronita Canyon. Overlying the andesite interval is the tuff of Caronita Canyon, a multiple-flow, simple cooling unit which was informally named for exposures in the southeastern Magdalena Mountains by Petty (1979). Petty (1979) reports a range in thickness of 200 to 1000 ft (61 to 305 m). However, his estimated thickness of 1000 ft (305 m) on Italian Peak is somewhat low, as the lower member there is at least 750 ft (229 m) thick. Osburn (1978) mapped a thin tuff interval in Sixmile Canyon that is equivalent to part of the tuff of Caronita Canyon; Bowring (1980) mapped a tuff unit 350 ft (107 m) thick on Timber Ridge to the north of this study area. Biotite from a sample of the tuff of Caronita Canyon collected on Molino Peak has been dated at 29.4 +/-1.1 m.y. by the K-Ar method (C.E. Chapin, unpub. date).

The tuff of Caronita Canyon crops out continuously along the eastern boundary of the study area for a distance of 4 mi (6.4 km) and continues southeastward in scattered outcrops for 1.5 mi (2.4 km). Here, in the southern portion of Sec. 14, T.5S., R.3W., the tuff of Caronita Canyon pinches out against older units along the east-trending southern topographic margin of the Sawmill Canyon cauldron. Exposures are also found in the southwestern part of the study area (Secs. 16 and 21, T.5S, R.3W.), where the unit is repeated by several down-to-the-west faults that will be discussed later.

The tuff of Caronita Canyon is the youngest member of the unit of Sixmile Canyon. The tuff normally overlies andesite lavas (Txa2) except near the southern topographic margin of the Sawmill Canyon cauldron. Here, the unit overlies a rhyolite lava flow (Txr5) and pinches out against the older unit of Hardy Ridge. The tuff is conformably overlain by the tuff of Lemitar Mountains or unconformably overlain by the Lower Popotosa Formation. However, a thin lens of sandstone overlies the tuff in one local area (NE 1/4, Sec. 11, T.5S., R.3W.).

<u>lower member</u>. The lower member of the tuff of Caronita Canyon is rhyolitic to quartz latitic in composition. Three to 20% phenocrysts of plagioclase, biotite, and magnetite are present. The phenocryst content increases upward in the section with plagioclase comprising about 75% of the phenocrysts. Some plagioclase phenocrysts show a marked zonation. Subhedral biotite makes up about 15% of the phenocrysts. Anhedral to subhedral magnetite constitutes about 10% of the phenocrysts and is sometimes found replacing biotite. Sanidine, quartz, clinopyroxene, and hornblende are present in trace amounts. Pumice contain phenocrysts of plagioclase, biotite, and magnetite and are usually spherulitic.

Petty (1979) has divided the lower member into three zones based on the degree of welding, phenocryst content, and color; detailed descriptions can be found in his thesis. These zones, in addition to a vitrophyric zone, are present in the study area and will be described briefly here. The zonation becomes less distinct to the south as the unit becomes thinner.

Where exposed, the base of the unit consists of a grayish-pink, poorly welded zone 10 to 20 ft (3 to 6 m) thick overlain by a black vitrophyre exhibiting eutaxitic structure. Good outcrops of these zones are found in the south-central part of the study area (NW 1/4, SW 1/4, Sec. 11, T.5S., R.3W). Overlying the vitrophyre is a light to moderate brown, lithic-rich, crystal-poor, densely welded interval. Lithic fragments in this interval are largely flow-banded rhyolite.

The upper, crystal-rich zone of the lower member is typically moderate red to grayish red and densely welded. It is relatively resistant and breaks along joint planes to form angular talus fragments. This zone often displays prominent eutaxitic foliation.

upper member. The contact between the upper and lower members of the tuff of Caronita Canyon was mapped at a sharply gradational change from andesitic to rhyolitic mineralogy. An increase from 20% to 30 or 40% phenocrysts also occurs across this break. The upper member weathers to rounded boulders; it is white to medium gray except for the basal few feet, which are sometimes pale red. The upper member is moderately to densely welded and contains 30 to 45% phenocrysts of sanidine, quartz, and biotite. Subhedral sanidine and large, often dipyramidal, quartz crystals are present in subequal amounts and constitute 90% of the phenocrysts. Small, subhedral biotite crystals make up about 10% of the phenocrysts. Plagioclase is present in trace amounts. Pumice contain only traces of phenocrysts and are often spherultic.

The upper tuff of Caronita Canyon varies from 0 to as much as 1100 ft (335 m) thick in the study area, although thicker sections may be exaggerated by unrecognized faulting. Many outcrops suggest a thickness of at least 500 ft (152 m).

Tuff of Lemitar Mountains

The tuff of Lemitar Mountains is a multiple-flow, compositionally zoned, simple to compound cooling unit of densely welded tuff (Chapin and others, 1978). Chamberlin (1980) described a section in the Lemitar Mountains, after which the tuff is named. Using the K-Ar method on biotite, samples of the tuff of Lemitar Mountains from the 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 (C.E. Chapin, unpub. date). Three dates from the same outcrop in the Joyita Hills yielded ages of 28.8 +/-0.7 m.y., 27.6 +/-1.1 m.y., and 28.1 +/- 1.2 m.y. (C.E. Chapin, oral commun.). The 26.3 m.y. date can be eliminated due to potassium metasomatism; the remaining dates average 27.9 m.y. Chapin and others (1978) proposed that the Socorro cauldron was the source of the tuff of Lemitar Mountains, but this assignment is now in question.

The tuff of Lemitar Mountains crops out along the west side of Sawmill Canyon where it forms extensive dip slopes; it also crops out in a few scattered patches to the east of the canyon. The tuff is divisible into two members based upon phenocryst content--a lower, moderately crystal-poor member and an upper, crystal-rich member. The contact between the two members is gradational over 5 to 50 ft (1.5 to 15 m) and was mapped at the abrupt increase in crystal content. Relative thickness of the members is highly variable, as is the total thickness of the unit. However, the tuff of Lemitar Mountains is very thick in this study area--as much as 1000 ft (305 m) where a complete section is exposed (Sec. 21, T.5S., R.3W.). Petty (1979) reports thicknesses up to 1800 ft (549 m) in Ryan Hill Canyon. The occurrence of these thick sections of outflow-facies tuff of Lemitar Mountains is probably due to ponding of the tuff in a depression left by collapse of the Sawmill Canyon cauldron. Donze (1980) reports a thickness of 2000 ft (600 m) of Lemitar and interbedded mesobreccias and megabreccias to the west of this study area. He suggests that the source cauldron for the tuff of Lemitar Mountains may be located in that area, but unequivocal proof has not been documented. Within the Sawmill Canyon cauldron, the tuff of Lemitar Mountains overlies the tuff of Caronita Canyon. Elsewhere, the lower contact is not exposed and the tuff is in intrusive contact with the younger rhyolites of the unit of Sawmill Canyon.

Osburn (1978) measured and described a stratigraphic section of the lower member of the tuff of Lemitar Mountains in Sixmile Canyon; see his thesis for a detailed description of zonation and petrographic characteristics. Donze (1980) described a 1500-ft (450-m) thick intermediate zone that has not been recognized in this study area.

lower member. The lower member of the tuff of Lemitar Mountains is densely welded and often breaks with a hackly fracture. The rock is usually pale red in color, although the basal few feet are moderate orange pink where exposed. The lower member is moderately crystal poor, containing 10 to 15% phenocrysts. Quartz anhedra that are 1 to 2 mm in diameter and sometimes embayed make up about 25% of the phenocrysts; another 75% are sanidine euhedra that are 0.5 to 2.5 mm long. A trace of biotite and euhedral sphene are present as phenocrysts. Lithic fragments of various compositions comprise 2 to 5% of the rock. Shard structure is well preserved in the groundmass.

upper member. The upper member of the tuff of Lemitar Mountains is densely welded and weathers to slabs or rounded boulders. Near its lower contact, the rock is usually grayish red purple with wispy white streaks of pumice. The rest of the section is usually moderate red to grayish red. Near the top of the section, the tuff contains angular to lenticular dark-reddish-brown cognate fragments similar to those found in the Hells Mesa Tuff; however, the fragments in the upper tuff of Lemitar Mountains are quartz-free. Figure

16 is a photograph of an outcrop of the tuff of Lemitar Mountains that contains these fragments. The lenticular masses may be pumice; they are small and usually in alignment. The angular blocks, however, range in diameter up to 3 ft (1 m) and are probably lithic fragments. Good exposures of outcrops that contain these fragments can be found along the west side of Sawmill Canyon (Sec. 32 (unsurveyed), T.4S., R.3W.).

The upper tuff of Lemitar Mountains is consistently crystal-rich and contains 20 to ~~35~~ 50% phenocrysts. Quartz phenocrysts are unusually large and may be as much as 5 mm in diameter, although the average size is 1.5 mm. The quartz is anhedral to euhedral, often embayed, and makes up 30 to 50% of the phenocrysts. Sanidine and plagioclase euhedra that are 1 to 2 mm long comprise 50 to 70% of the phenocrysts. All of the feldspar phenocrysts have been altered to a varying degree. In some thin sections, plagioclase has been altered almost entirely to fine-grained phyllosilicates or has been plucked out during preparation. The high degree of feldspar alteration within the tuff of Lemitar Mountains makes the plagioclase-to-sanidine ratio difficult to estimate; however, it is approximately 3:1. Biotite euhedra comprise 2 to 5% of the rock; all are partially altered to magnetite. Traces of sphene and clinopyroxene (?) are present in some samples.

Figure 16. Photograph of angular and lenticular cognate fragments in the tuff of Lemitar Mountains.
(NE 1/4, Sec. 32 (unsurveyed), T.4S., R.3W.).

Tuff of South Canyon

The tuff of South Canyon is a multiple-flow, simple cooling unit of rhyolite ash-flow tuff (Chapin and others, 1978). The tuff was named after a measured stratigraphic section at the mouth of South Canyon (Osburn, 1978). The tuff of South Canyon is correlative with the upper Potato Canyon Tuff of Spradlin (1976). Chapin and others (1978) have suggested that the tuff of South Canyon was erupted from the Hop Canyon cauldron (see Chapin and others, 1978, Fig. 2). The tuff of South Canyon has been dated at 26.2 +/- 1.0 m.y. using the K-Ar method on biotite from rocks collected in the Joyita Hills (C.E. Chapin, unpub. date). 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).

Only three small outcrops of the tuff of South Canyon are present in this study area; these outcrops are at the southern boundary of the area, in Secs. 21 and 22 (T.5S., R.3W.). Here, the tuff attains a maximum thickness of 65 ft (20 m). Petty (1979) reports thicknesses up to 750 ft (229 m) in Ryan Hill Canyon, and Donze (1980) reports that the tuff is 425 ft (130 m) thick to the west of this study area. The absence of a thicker section of the tuff of South Canyon in this study area is probably due to an erosional hiatus after its deposition. In this study area, the tuff of South Canyon overlies the upper tuff of Lemitar Mountains and is unconformably overlain by the Popotosa Formation.

The tuff of South Canyon is moderately welded and weathers to crumbly blocks. The rock is pinkish gray with light-brownish-gray pumice that contain axiolitic and spherulitic structures and make up 3 to 5% of the rock. Quartz and sanidine each comprise about 10% of the tuff. Quartz is anhedral to euhedral and averages 1 mm in diameter. Sanidine euhedra are about 1.5 mm long. Traces of biotite euhedra occur as phenocrysts and are partially replaced by magnetite. A trace of hornblende was observed in thin section. The groundmass is extensively altered to phyllosilicates and contains finely disseminated magnetite. For a detailed description of zonation and petrographic characteristics, see Osburn (1978).

Unit of Sawmill Canyon

A rhyolite intrusive complex and associated pyroclastic deposits intrude and overlie the tuff of Lemitar Mountains in the northwestern part of the study area. The unit is younger than the Lemitar, but a minimum age cannot be determined from field relationships.

<u>pyroclastic deposits (Tst)</u>. The basal pyroclastic deposits of the unit of Sawmill Canyon directly overlie the unit of Hardy Ridge in the northwestern part of this study area; Donze (1980) reports that the same relationship exists on the west flank of Hardy Ridge. The pyroclastic deposits consist of ash-flow tuffs, andesites, volcaniclastic sedimentary

rocks, and vent breccias. The pyroclastic unit is as much as 450 ft (137 m) thick in this study area. In Sec. 5 (T.5S., R.3W.) the outcrops consist of poorly to densely welded tuffs that weather to blocky or platy talus. The tuff is less than 50 ft (15 m) thick and appears to have filled topographic depressions on the surface of the underlying tuff of Lemitar Mountains. The rocks range in color from light gray to moderate red and contain as much as 10% pumice that weather easily to clay. The tuff is consistently very crystal poor and contains a trace of small quartz anhedra. Lithic fragments are usually absent but make up 20% of the tuff's basal zone. The remaining outcrops of Tst contain similar crystal-poor tuff and a variety of other rock types that will be described later. Lithic fragments of rhyolite and andesite are abundant in some units and constitute as much as 50% of the rock; lithic fragments of crystal-rich ash-flow tuff, as large as 25 cm, are common locally.

Several distinctive units are found within the ash-flow tuff interval in the northernmost part of the study area (Sec. 30, T.4S., R.3W.). A rhyolite lapilli breccia (Macdonald, 1972, p.131) crops out in the northeast quarter of Sec. 30 and weathers to blocky talus. The unit consists of 50% very-pale-orange pumice that appear ragged in thin section and about 5% angular lithic fragments of rhyolite.

A moderately crystal-rich ash-flow tuff unit crops out just south of the rhyolite lapilli breccia (SE 1/4, NE

1/4, Sec. 30, T.4S., R.3W.). The tuff is densely welded and weathers to blocky talus. The rock is grayish red and contains 15% phenocrysts. Sanidine, partially resorbed and largely altered to sericite, comprises about 10% of the phenocrysts. Subequal amounts of small anhedral quartz and biotite make up about 5% of the rock. A trace of anhedral magnetite is present. Lithic fragments of rhyolite and andesite make up about 2% of the rock.

An andesite lava crops out at one location (Sec. 32 (unsurveyed), T.4S., R.3W.). It is dense, aphanitic, and medium gray in color.

A vent breccia is exposed in the southwest quarter of Sec. 32 (T.4S., R.3W.). It contains clasts of andesite and the tuff of Lemitar Mountains that are as large as 3 ft (1 m) in diameter. The clasts are enclosed in a fragmental rhyolite matrix.

rhyolite lavas. A crystal-poor rhyolite intrudes and overlies the Hells Mesa Tuff, the unit of Hardy Ridge, the tuff of Lemitar Mountains, and the pyroclastic rocks of the unit of Sawmill Canyon. Good exposures of intrusive contacts can be seen in the northeast quarter of Sec. 30 and in the southeast quarter of Sec. 32 (unsurveyed), T.5S., R.3W.).

Thickness estimates are probably unreliable due to unrecognized faulting within the rhyolites, but as much as 100 ft (305 m) of lavas are present. The lavas cover more than 2 sq mi (5.2 sq km) on the east flank of Hardy Ridge.

The rhyolites are dense and aphanitic and sometimes weather to platy fragments. They are extremely resistant and usually form steep cliffs (Fig. 17). The lavas are often flow-banded and spherulitically devitrified and commonly contain the devitrification texture that is found in the crystal-poor rhyolites of the unit of Hardy Ridge (p. 19, Fig. 8).

Popotosa Formation

The Popotosa Formation was named by Denny (1940) for exposures in Arroyo Popotosa southeast of the Ladron Mountains. The Popotosa consists of mudflow deposits, conglomerates, sandstones, siltstones, and mudstones that represent alluvial fan/playa deposition in an arid to semi-arid climate (Bruning, 1973). In this study area, the unit consists of basal mudflow deposits (Tpl) and upper conglomerates and sandstones (Tp); all of the deposits in this area are in the fanglomerate facies of Bruning (1973). A laterally discontinuous ash-flow tuff (Tpt) is interbedded in Sec. 12 (T.5S., R.3W.).

The Popotosa Formation crops out at scattered sites in the southern part of this study area. It was deposited on an erosional unconformity and is in depositional contact with units of different ages; the youngest of these is the tuff of South Canyon and the oldest is the A-L Peak Tuff. The Popotosa beds were beveled by a pediment surface and are now

Figure 17. Photograph of cliff-forming rhyolite lavas in the unit of Sawmill Canyon. (NW 1/4, Sec. 32 (unsurveyed), T.4S., R.3W.).

in contact with younger Quaternary units. An estimated thickness for the Popotosa Formation in this study area is 400 ft (122 m), although the lack of continuous exposures makes it difficult to obtain an accurate thickness.

lower member. The lower Popotosa Formation in this study area consists of mudflow deposits that grade upward into coarse conglomerates. The rock is well indurated and weathers to narrow ledges. The lower Popotosa is pervasively altered to moderate red or reddish brown. Chapin and others (1978) suggested that the red color and degree of induration are anomalous and are related to an ancient geothermal system.

The mudflow deposits are unsorted, matrix-supported, and usually unstratified, although crude bedding is locally present. Clasts that range in size up to several meters are mainly fragments of the tuff of Lemitar Mountains. The rock becomes increasingly heterolithic upward in the section as stratification becomes more pronounced. Sedimentary structures that were observed include channels and minor cross-bedding.

ash-flow tuff. A local ash-flow tuff that is rhyolitic to quartz latitic in composition overlies the lower Popotosa Formation with angular unconformity in Sec. 12 (T.5S., R.3W.). Here, the tuff is less than 100 ft (305 m) thick. G.R. Osburn (oral commun.) reports that a similar tuff crops out just outside this study area. Deposition of this tuff occurred after the geothermal event that pervasively altered the lower Popotosa Formation.

The tuff is poorly to moderately welded and weathers to rounded boulders. The rock is pinkish gray and contains grayish-yellow, disc-shaped pumice that weather out easily. Lithic fragments of various compositions comprise up to 20% of the rock. Phenocrysts of quartz, plagioclase, and sanidine make up about 10% of the rock. Quartz anhedra about 0.3 mm in diameter comprise 70% of the phenocrysts, and plagioclase anhedra, 0.3 mm long, make up 20% of the phenocrysts. Ten percent of the phenocrysts are sanidine anhedra about 0.3 mm long. Traces of biotite and hornblende are found as phenocrysts.

upper member. The upper Popotosa Formation in this study area was deposited on an erosion surface that formed after deposition of the lower member. The rock is poorly to moderately indurated and very non-resistant; exposures are confined to the sides of arroyos. The upper Popotosa consists of very-light-gray conglomerates and interbedded sandstones. Clasts consist largely of fragments of the tuff of Lemitar Mountains and crystal-poor rhyolite lavas, although other lithologies are present in subordinate amounts. The particles in the conglomerates range from clay-size to boulder-size, with boulders locally as large as several meters in diameter. The most common particle size is less that 1 cm.

Channels and cross-bedding are common structures in the upper Popotosa. Imbricated pebbles are abundant and were used to obtain transport directions. Measurements were usually made on sets of 2 or 3 pebbles in contact with each other. Five to 10 measurements were made at each outcrop and were averaged to yield one value for that outcrop. The results are plotted on Plate 1 and indicate a general direction of transport to the southwest.

Santa Fe Group (undifferentiated)

The low, rounded northwest-trending hills that are found at the mouth of Sawmill Canyon contain no outcrops. However, their location and the lack of outcrops suggest that they are made up of poorly indurated Tertiary gravels, probably the upper Popotosa and lower Sierra Ladrones Formations.

The Sierra Ladrones Formation was named by Machette (1978) for the low foothills of the Ladron Mountains. The type section is early Pliocene to middle Pleistocene in age and contains alluvial-fan, piedmont-slope, alluvial-flat, flood-plain, and axial stream deposits (Machette, 1978).

Tertiary intrusive rocks

Dikes and plugs of Tertiary age are found at scattered locations throughout the study area. In general, their trend is in a north-northwesterly direction where they intrude extensional faults that are associated with the Rio Grande rift. The intrusives can be classified into 5 groups: andesite dikes, a latite dike, porphyritic rhyolite intrusives, flow-banded rhyolites, and white rhyolite dikes and dome.

andesite dikes. Andesite dikes are intrusive into the Hells Mesa Tuff in the southwest quarter of Sec. 9 (T.5S., R.3W.). They contain about 3% phenocrysts of euhedral plagioclase, most of which have been partially altered to phyllosilicates. The groundmass contains randomly oriented plagioclase microlites and finely disseminated magnetite.

latite dikes. One small latite dike was found on the northern boundary of section 32 (unsurveyed) (T.4S., R.3W.). This rock has a light-bluish-gray groundmass and contains 15 to 20% large potassium-feldspar phenocrysts that are as long as 1.5 cm. A trace of small quartz phenocrysts was also observed.

porphyritic rhyolite dikes. Several crystal-rich rhyolite dikes (Trl) are found in the north-central part of the study area. These dikes are light brownish gray to light red in color and are very dense; they weather to blocky talus. Phenocrysts make up 15 to 20% of the rock and characteristically contain large quartz (as much as 5 mm in diameter). Sanidine and biotite are also present. The quartz-to-sanidine ratio is about 3:1 and only a trace of biotite was observed.

Another porphyritic rhyolite intrusive (Tr2) crops out at one location in the southern half of the study area (NW 1/4, Sec. 11, T.5S., R.3W.). This rhyolite is very resistant and forms steep cliffs. The cliff-forming rhyolite is light brownish gray to light red and contains 10 to 15% phenocrysts of sanidine, quartz, and biotite. Subhedral sanidine is about 1 mm long and deeply embayed quartz averages about 1.5 mm long; the sanidine-to-quartz ratio is 1:1. A trace of small, anhedral biotite is present. Silicification in the form of small quartz veins was seen in thin section.

flow-banded rhyolites. Flow-banded, crystal-poor rhyolite intrusives are abundant in the southern two-thirds of the study area. These rhyolites are intrusive into units as young as the tuff of Lemitar Mountains. Some of the intrusives contain float blocks of a crystal-poor ash-flow tuff (Trf) that are as long as 2000 ft (610 m).

Outcrops of Tr3 are very dense and form bold outcrops near the base of Sawmill Canyon. Distorted flow banding is common in this intrusive. A trace of quartz is present.

Tr4 is intrusive into Tr3. Outcrops of Tr4 are very resistant and weather to blocky talus. Flow-banding in Tr4 has a distinctive appearance and contains alternating color bands of brownish gray and light gray. Each band is about 5 mm thick. Quartz phenocrysts, in amounts less than

2%, are subhedral, often deeply embayed, and average 0.5 mm in diameter. Finely disseminated magnetite is present in most samples. A trace of subhedral biotite averaging 0.2 mm long was observed in a sample from the northeast quarter of Sec. 14 (T.5S., R.3W.). The groundmass is spherulitically devitrified in alignment with the flow banding. A mosaic of quartz and sanidine and a trace of biotite and magnetite fill irregular pore spaces.

White rhyolite dikes and dome. White rhyolite dikes and a dome are located at the north end of the study area, mainly along the Sawmill Canyon Fault. The dikes are arranged in a roughly radial pattern outward from the dome. The white color of the dikes makes them very conspicuous. The white rhyolite dikes have been tilted to the east (Fig. 18) and, therefore, predate some of the rift faulting.

Outcrops of white rhyolite are moderately resistant and weather to platy talus. The country rocks are usually highly silicified. In hand specimen, the rhyolite is sometimes flow-banded and usually crystal poor but may contain a trace of sanidine and quartz. One specimen contained 2% iron-stained casts that probably represent oxidized pyrite crystals.

Figure 18. Photograph of a white rhyolite dike that has been rotated to a subhorizontal position. The dike was intruded into the A-L Peak Tuff, rotated to its present position, and overlain by Quaternary terrace gravels. (NW 1/4, Sec. 29 (unsurveyed), T.4S., R.3W.).

Quaternary-Tertiary deposits

alluvial-fan gravels. Poorly consolidated gravels and sands that accumulated as alluvial fan deposits and are now stranded high above the present stream levels at the mouth of Sawmill Canyon were mapped as Quaternary-Tertiary gravels (Q-Tg). These deposits may be equivalent to part of the Sierra Ladrones Formation (J.W. Hawley, 1980, oral commun.). Refer to p. 59 for further information about the Sierra Ladrones Formation. These deposits are found as isolated patches where they have been dissected by stream erosion.

Quaternary deposits

piedmont gravels. Poorly consolidated gravels and sands that accumulated by coalescence of alluvial fans at the base of the Magdalena Mountains were mapped as piedmont gravels. These gravels are the most extensive Quaternary deposits and have been dissected to some degree by subsequent stream erosion.

terrace gravels. Terrace gravels in this study area consist of poorly consolidated sand and gravel deposits located on benches that are usually parallel to present streams. These deposits are found at scattered sites along Sawmill Canyon and can be seen at elevations as high as 7600 ft (2316 m) in the northern part of the study area. Figure 18 is a photograph of a particularly good exposure of terrace gravels on the northern boundary of this study area.

talus and colluvium. Talus and colluvium are gradational and were mapped together as one unit. Talus occurs on oversteepened slopes throughout the study area and consists of loose rock fragments that were deposited by mass wasting. Colluvium covers more moderate slopes and generally contains more soil than does talus.

slump block. A large slump block of tuff of Lemitar Mountains is found in the northwest quarter of Sec. 9 (T.5S., R.3W.). The block is surrounded by talus and no contacts were observed. The slump block appears to have been derived from the steep cliffs of Lemitar that are found directly above the block.

alluvium. Alluvium in this study area is Holocene in age and consists largely of poorly sorted sand and gravel, although in one stream bed the deposits are mainly boulder-size clasts.

valley alluvium. Holocene alluvium that is confined to valleys and consists largely of debris shed from the valley walls was mapped as valley alluvium. These deposits usually are not restricted to narrow stream beds. Valley alluvial deposits grade upslope into colluvium.

STRUCTURE

The Magdalena Mountains are located at the intersection of the Rio Grande rift and the northeastern corner of the Datil-Mogollon volcanic field. The west-trending Capitan and the northeast-trending Morenci lineaments intersect near Socorro, and a transverse shear zone of the Morenci lineament passes through the central Magdalena Range (see Chapin and others, 1978, Fig. 1). These structural elements are superimposed upon several overlapping cauldron structures to produce a complex geologic setting in the Socorro-Magdalena area.

Regional Structure

Several episodes of deformation preceded volcanic activity in the Socorro-Magdalena area. The ancestral Rocky Mountains were formed during late Mississippian to Permian time. Folding and reverse faulting of Paleozoic and Mesozoic rocks in west-central New Mexico occurred during the Laramide orogeny (Late Cretaceous to Middle Eocene time). The Magdalena Mountains area was on the flank of a broad Laramide uplift (Chapin and others, 1978). In the late Eocene, the area was eroded to a surface of low relief (Epis and Chapin, 1975). Detritus from erosion of the Laramide uplift in the Magdalena Mountains area was shed northward into the Baca basin and incorporated into the Eocene (?) Baca Formation. No pre-Oligocene rocks are exposed in this thesis area.

Volcanic activity in the Socorro-Magdalena area began in early Oligocene time with deposition of the Spears Formation unconformably upon rocks ranging in age from Precambrian to late Eocene (Chapin and others, 1978). Major pyroclastic activity began about 32 m.y. ago in the Magdalena Mountains area with the eruption of the Hells Mesa Tuff and subsequent collapse of the North Baldy cauldron. Several overlapping cauldron structures were formed during the period from 32 to 26 m.y. ago; this study area is located within the North Baldy and Sawmill Canyon cauldrons.

The Rio Grande rift began developing about 32 m.y. ago along preexisting crustal weaknesses (Chapin, 1978). Chamberlin (1978) has documented the existence of high-angle normal faults in the Lemitar Mountains that developed between 32 and 23 m.y. ago. He suggests that the period of 32 to 28 m.y. ago was a time of high heat flow and rapid crustal extension. The Rio Grande Rift is represented by a series of north-trending basins that begin in central Colorado and widen in the Socorro-Magdalena area to produce several parallel basins that are separated by intrarift horsts (Chapin, 1971a and 1978).

The Capitan and Morenci lineaments intersect in the Socorro-Magdalena area, and a transverse shear zone of the Morenci lineament divides the Magdalena Range into two structural fields. To the north of the shear zone, movement along faults is down to the east and the strata dip to the west. South of the shear zone, down-to-the-west faults and eastward-dipping strata predominate. Formation of the transverse shear zone was concurrent with the development of an extensional stress field in the area. Chapin (1978) suggests that the shear zone follows an earlier zone of weakness in the Precambrian basement.

By 26 m.y. ago, a shallow basin in the Socorro-Magdalena area had begun accumulating sediments of the Popotosa Formation. Uplift of the ancestral Magdalena Mountains in the early to middle Miocene provided a source for some of these sediments. The ancestral Magdalenas were largely buried in their own debris by middle Miocene time (Bruning, 1974).

Between 7 and 4 m.y. ago, the Popotosa basin was broken into a series of narrow, parallel basins and ranges that reflect the present topography in the southern Rio Grande rift (Chapin and others, 1978). Sediments of the upper Santa Fe Group were deposited with angular unconformity upon the moderately to steeply tilted Popotosa Formation.

Local Structure

This study area is located south of the transverse shear zone of the Morenci lineament and is characterized by down-to-the-west normal faults and eastward-dipping Tertiary rocks. The area mapped is entirely within the North Baldy cauldron (Fig. 19). The southwestern margin of the Sawmill

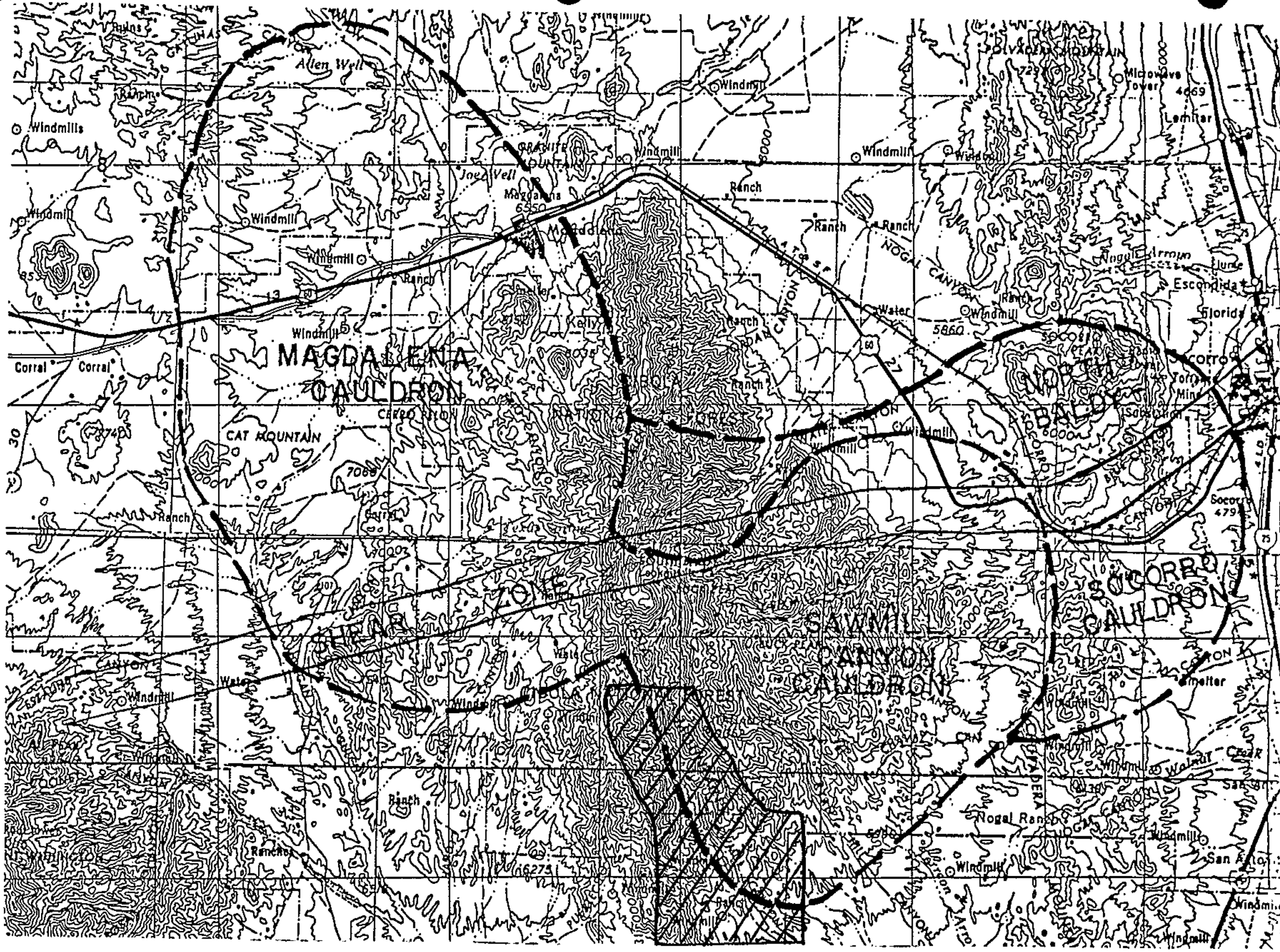


Figure 19: Map showing relationship between cauldron structures in the Magdalena Mountains and the transverse shear zone. (Modified after Allen, 1979). The Socorro cauldron of Chapin and others (1978) and Chamberlin (1980) is now thought to be part of the North Baldy cauldron. The shaded region is the area of this study.

Canyon cauldron is located within the study area and greatly influences the local structure.

North Baldy cauldron. The oldest documented cauldron in the Magdalena Mountains is the North Baldy cauldron. The northern margin of this cauldron is located just south of North Baldy Peak and the southern margin crosses the Devils Backbone to the south of this study area. The southern margin is unmapped and its exact location is uncertain. The eastern and western margins are buried under younger rocks.

Eruption of the Hells Mesa Tuff initiated the collapse of the North Baldy cauldron. The Hells Mesa is as much as 3850 ft (1173 m) thick within the cauldron (Krewedl, 1974). Evidence that this study area is within the North Baldy cauldron are:

1) The Hells Mesa Tuff is unusually thick here (1500 ft, 457 m) as compared with outflow-facies Hells Mesa, which is usually 600 ft (183 m) thick;

2) Cauldron-fill deposits are recognized in the area and are known as the unit of Hardy Ridge. Scattered outcrops of the unit of Hardy Ridge occur throughout this study area but are largely buried beneath younger rocks; and

3) A mesobreccia (Lipman, 1976) is found in the Hells Mesa Tuff in the southwestern part of the study area (SE 1/4, Sec. 9, T.5S., R.3W.).

Sawmill Canyon cauldron. The southwestern margin of the Sawmill Canyon cauldron is located within this study area and continues north into the area mapped by Bowring (1980). The northern margin of the cauldron has been mapped north of Timber Peak by Petty (1979). The eastern margin is largely buried beneath younger rocks.

In this study area, the ring-fracture zone of the Sawmill Canyon cauldron trends north-northwest and is located, for much of its length, along and just west of the bottom of Sawmill Canyon (Fig. 19). In the southern half of the area, the trend becomes east-west. The ring-fracture zone is narrow in the north and is characterized by recurrent normal faulting and later intrusive activity. The structural margin of the cauldron widens in the central part of the study area. This wide zone was intruded by a rhyolite dome complex (Txrl) during the early stages of cauldron-fill activity in the Sawmill Canyon cauldron. The ring-fracture zone was at least 1 mi (1.6 km) in width along the southwestern edge of the Sawmill Canyon cauldron, as outcrops of the dome complex are of this magnitude. As the rhyolite intrusives die out to the south, the ring fracture zone is marked by a complex fault zone and the presence of later rhyolite intrusives (southeastern quarter of this study area).

Osburn (1979, unpub. maps) has documented the remnants of the southern topographic rim of the Sawmill

Canyon cauldron just east of the southern part of this study area. Relationships similar to those mapped by Osburn are found in the southern half of this study area. Here, however, contacts are not exposed well enough to make a definite correlation.

The eruption of the pinnacles and flow-banded members of the A-L Peak Tuff caused the simultaneous collapse of the Sawmill Canyon and Magdalena cauldrons to form a dumbbell-shaped depression (Allen, 1979). This depression was filled with moat deposits of the unit of Sixmile Canyon that crop out extensively throughout this study area. Allen (1979) reports that similar deposits overlie the A-L Peak Tuff in the Magdalena cauldron and may have interfingered with the Sixmile Canyon deposits.

Block faulting. Normal faulting during the middle to late Cenozoic has dominated the structural style in the southern Magdalena Range. This study area is south of the transverse shear zone and in the field dominated by down-to-the-west faults and eastward-dipping strata. In general, the trend of these faults is north-northwest. Faulting in this study area, however, has been greatly influenced by preexisting structures produced by collapse of the Sawmill Canyon cauldron. For example, the Sawmill Canyon fault marks the approximate boundary of the ring-fracture zone of the Sawmill Canyon cauldron in the northern part of the canyon. The collapse of the cauldron was downward to the east along this fault. Recurrent movement along this ring fracture due to regional extension was down to the west with the amount of displacement in excess of 6000 ft (1829 m). The trend of the Sawmill Canyon fault is north-northwest in the northern part of the thesis area and makes a rather sharp bend in the south (Sec. 16, T.5S., R.3W.) to follow the trend of the ring-fracture zone. Other faults with less displacement than the Sawmill Canyon fault also show this trend, for example, the fault that offsets the andesite of the unit of Sixmile Canyon (Txa2) in sections 14 and 15 (T.5S., R.3W.). This fault appears to follow the topographic margin of the Sawmill Canyon cauldron (S 1/2, Sec. 14, T.5 R.3W.). Displacement along this fault has been down to the south. However, cauldron-fill deposits of the unit of Sixmile Canyon were deposited against older rocks along the topographic cauldron margin. In map view (Plate 1), the down-to-the-south movement along this unconformity gives the false appearance of down-to-the-north displacement.

A fault in section 33 (unsurveyed) (T.4S., R.3W.) with several hundred feet of displacement strikes nearly perpendicular to the regional structural trend and probably represents recurrent movement along preexisting ring fractures of the Sawmill Canyon cauldron. Complex faulting has occurred within the ring fracture zone in the southern half of the study area. Within the ring fracture zone, faults often make right-angle turns and produce isolated horsts and grabens that are atypical of the block-faulting usually found in the Magdalena Range. Examples of this complex faulting can be found in Secs. 11 and 12 (T.5S., R.3W.).

One small block of westward-dipping tuff of Lemitar Mountains was found in Secs. 15 and 22 (T.5S., R.3W.). The block probably slumped off the large outcrops of tuff of Lemitar Mountains to the west and was later buried by sediments of the upper Popotosa Formation. Evidence for this origin include 1) chaotic attitudes within this block and 2) undisturbed overlying Popotosa Formation.

Dips of most of the fault planes in this study area are usually about 60 degrees to the west but may be as steep as 70 degrees in the west or as shallow as 45 degrees in the east. Shallow dips of 10 to 30 degrees as reported by Chamberlin (1978) in the Lemitar Mountains have not been documented in this study area.

ALTERATION AND MINERALIZATION

Alteration

Regional potassium metasomatism has affected the rocks in the Sawmill Canyon area and in surrounding areas. The effects of the metasomatism were a net increase in the amount of potassium in the rocks and a corresponding decrease in the amount of sodium (Chapin and others, 1978). Rocks altered in this manner usually have plagioclase, and sometimes sanidine, phenocrysts altered to fine-grained phyllosilicates. Treatment with sodium cobaltinitrite (refer to p. 6) of thin sections of potassium-metasomatized rocks reveals a strong yellow stain. The intense yellow stain indicates the presence of excess potassium in the groundmass of the rock.

This event is believed to have been caused by an ancient geothermal system (Chapin and others, 1978). The extent of the potassium anomaly is not known, but it is present from at least the southern Magdalena Range to the Ladron Mountains to the north. In this and other study areas, the tuff of Lemitar Mountains seems to have been more susceptible to potassium metasomatism than the other units.

Extensive hematite staining is present along the ring-fracture zone of the Sawmill Canyon cauldron. This hematite staining causes a conspicuous color anomaly from the air (Fig. 3). The hematite is a result of the oxidation of pyrite that is disseminated along fracture surfaces in the rhyolite dome complex and the A-L Peak Tuff. As much as 5% very small (less than 1 mm) oxidized pyrite cubes can be found along these fracture surfaces. The pyrite was, therefore, deposited after intrusion of the rhyolite dome complex.

The areas of most abundant pyrite and most intense hematite stain are 1) in the A-L Peak Tuff at its depositional contact with the underlying rhyolite of Hardy Ridge (Thr2) and 2) in the rhyolite dome complex in the unit of Sixmile Canyon (Txr1), especially near its intrusive contacts (Fig. 20). The platy, sheet-jointed A-L Peak Tuff and the brecciated intrusive contacts of the rhyolite dome complex were very permeable. This permeability was favorable for later passage of hydrothermal solutions.

However, the age and source of these solutions is unknown. The pyrite is limited to the vicinity of the ring-fracture zone of the Sawmill Canyon cauldron. Possible origins of the hydrothermal solutions that deposited the pyrite are 1) late-stage emanations from a cooling magma associated with the Sawmill Canyon cauldron or 2) heated solutions, from a later thermal event, that circulated along conduits provided by the Sawmill Canyon cauldron ring-fracture zone.

Figure 20. Intensely hematite-stained outcrop of the rhyolite dome complex in the unit of Sixmile Canyon.
(SE 1/4, NE 1/4, Sec. 9, T.5S., R.3W.).

Mineralization

Mineralization in the Sawmill Canyon area of the Magdalena Mountains is sporadic and consists entirely of low-grade manganese deposits. Most of the prospects in the study area are bulldozed cuts. Some of these prospects were cut in andesites that contain celadonite-stained chalcedony amygdules and joint faces, probably in search for copper deposits. In others, no mineralization was evident in outcrop. However, ore has been removed from two locations in this study area.

The greatest amount of ore has been removed from the prospect in the Haunted Spring area (Sec. 17, T.5S., R.3W.). Here, at the intersection of two major faults, the rocks are brecciated and sheared and the fragments are cemented with botryoidal psilomelane. The adjacent andesite (Txa2) is altered and celadonite is abundant on joint faces and calcite amygdules. A visual estimate shows the pit's dimensions to be approximately 25 x 50 x 100 ft.

Evidence of mining activity is also present in sections 11 and 12, T.5S., R.3W. Here, manganese oxides have formed a cement for fault-breccia fragments of the lower Popotosa Formation. According to Farnham (1961), these are the Burris unpatented claims, owned by B.O. Burris of Socorro. Farnham goes on to state:

> The claims were located in the early 1950's by B.O. Burris, and shortly thereafter considerable exploratory work was completed. The only known

> production was a few tens of tons of hand-sorted ore that was sold to Socorro Manganese Co. by lessee M.V. Dempsey.
>
> The work consisted of 12 or more scattered bulldozer trenches and open-cuts. . . The openings ranged from 25 to 200 feet in length, and from a few feet to 8 feet in depth. The ore produced reportedly contained about 20 percent manganese, and was hand sorted from the dumps of some of the excavations.

The manganese deposits in this study area are small and low grade and do not constitute an economic deposit at present prices.

CONCLUSIONS

Several important conclusions can be made from this study of the southern Magdalena Range. These are divided into three sections--stratigraphy, structure, and alteration and mineralization.

Stratigraphy

Rocks in this thesis area are all Tertiary in age and are mainly volcanic in origin, although minor sedimentary units are also present. In general, the rocks within the southern Magdalena Mountains correlate well with the regional stratigraphy defined by Chapin and others (1978). Important contributions to the regional stratigraphy that have been made by this study are:

1) Outcrops of cauldron-facies Hells Mesa Tuff are present at several localities wtihin the study area and are as much as 1500 ft (457 m) thick. A mesobreccia, as defined by Lipman (1976), is present in the Hells Mesa Tuff. Moat deposits of the North Baldy cauldron overlie the Hells Mesa Tuff in this thesis area.

2) The A-L Peak Tuff is at least 3000 ft (914 m) thick in Sawmill Canyon and is usually flow-banded. The unit of Sixmile Canyon, cauldron-fill unit of the Sawmill Canyon cauldron, is at least 2500 ft (762 m) thick. A rhyolite dome complex (Txrl) is intrusive along the ring fracture of the

Sawmill Canyon cauldron, and complex fault patterns are present along the ring fracture zone.

3) The tuff of Lemitar Mountains is unusually thick in this area and may have filled the depression left after collapse of the Sawmill Canyon cauldron.

4) A large rhyolite dome complex post-dating the tuff of Lemitar Mountains covers more than 2 sq mi (5.2 sq km) along Hardy Ridge in the northwestern part of the study area. This rhyolite and associated pyroclastic deposits are herein designated as the unit of Sawmill Canyon; they are believed to have been extruded along conduits provided by the ring fracture of the Sawmill Canyon cauldron.

5) The lower Popotosa Formation was deposited upon an extensive erosion surface in the southern Magdalena Mountains.

6) Volcanic activity continued after initiation of Popotosa deposition as indicated by the presence of an interbedded ash-flow tuff.

7) Flow directions in the upper Popotosa Formation indicate that a highland source was previously located to the northeast of the mouth of Sawmill Canyon.

Structure

Major structural features of the Sawmill Canyon area are north-northwest trending normal faults that are related to the Rio Grande rift and strongly controlled by the

ring-fracture zone of the Sawmill Canyon cauldron.
Structural elements in this thesis area are:

1) The study area is entirely within the North Baldy cauldron and contains the Hells Mesa Tuff and associated cauldron-fill deposits.

2) The southwestern margin of the Sawmill Canyon cauldron is located within this study area. The ring fracture zone dominates the structural style in the Sawmill Canyon area and largely controls later extensional fault patterns.

3) Extensional faults generally trend north-northwest except where deflected by the ring-fracture zone of the Sawmill Canyon cauldron. Fault blocks are usually down to the west and strata is tilted to the east.

Alteration and Mineralization

Conclusions regarding alteration and mineralization in Sawmill Canyon are:

1) This study area is located within the regional potassium anomaly,

2) Intense hematite staining is the result of the oxidation of pyrite that is disseminated along fracture surfaces in rhyolite and A-L Peak Tuff. The age and source of this pyrite is unknown.

3) Manganese mineralization is sparse and does not constitute an economic deposit at present prices.

REFERENCES

Allen, P., Geology of the west flank of the Magdalena Mountains south of the Kelly mining district, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 153 p.

Bachman, G.O., and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America Bulletin, v. 89, p. 283-292.

Blakestad, R.B., 1978, Geology of the Kelly mining district, Socorro County, New Mexico [M.S. thesis]: Boulder, University of Colorado, 127 p.

Bowring, S.A., 1980, Geology of the west-central Magdalena Mountains, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 98 p.

Brown, D.M., 1972, Geology of the southern Bear Mountains, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 110 p.

Bruning, J.E., 1973, Origin of the Popotosa Formation, north-central Socorro County, New Mexico [Ph.D. dissertation]: Socorro, New Mexico Institute of Mining and Technology, 132 p.

Burke, W.H., Kenny, G.S., Otto, J.B., and others, 1963, Potassium-argon dates, Socorro and Sierra Counties, New Mexico: Guidebook of the Socorro region, New Mexico Geological Society, 14th Field Conference , p. 224.

Chamberlin, R.M., 1974, Geology of the Council Rock district, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 130 p.

Chamberlin, R.M., 1978, Structural development of the Lemitar Mountains, an intrarift tilted fault-block uplift, central New Mexico [abs.], in Program with Abstracts, 1978 International Symposium on the Rio Grande rift: Los Alamos Scientific Laboratory, University of California, p. 22-24.

Chamberlin, R.M., 1980, Geologic framework of the Socorro Peak geothermal area, Socorro County, New Mexico

[Ph.D. dissertation]: Golden, Colorado School of Mines, 500 p.

Chapin, C.E., 1971a, The Rio Grande rift, part 1: modifications and additions: Guidebook of the San Luis Basin, Colorado, New Mexico Geological Society, 22nd Annual Field Conference, p. 191-201.

Chapin, C.E., 1971b, K-Ar age of the La Jara Peak Andesite and its possible significance to mineral exploration in the Magdalena mining district, New Mexico: Isochron/West, v. 1, no. 2, p. 43-44.

Chapin, C.E., 1974, Composite stratigraphic column of the Magdalena area: New Mexico Bureau of Mines and Mineral Resources Open-File Report 46.

Chapin, C.E., 1978, Evolution of the Rio Grande rift: comparisons between segments and the role of transverse structures [abs.], in 1978 International Symposium on the Rio Grande Rift: Los Alamos Scientific Laboratory, University of California, p. 24-27.

Chapin, C.E., Chamberlin, R.M., Osburn, G.R., and others, 1978, Exploration framework of the Socorro geothermal area, New Mexico, in Chapin, C.E., and Elston, W.E., eds., Field guide to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication 7, p. 115-129.

Chapin, C.E., and Deal, E.G., 1976, The A-L Peak Tuff, New Mexico: a composite ash-flow sheet: Geological Society of America Abstracts with Programs, v. 8, no. 5, p. 575.

Chapin, C.E., and Lowell, G.R., 1979, Primary and secondary flow structures in ash-flow tuffs of the Gribbles Run paleovalley, central Colorado: Geological Society of America Special Paper 180, p. 137-154.

Coats, R.R., 1976, Pyroclastic dike feeders of welded tuffs and primary surficial deformation in welded tuffs on the south margin of the Owyhee Plateau, Elko County, Nevada: Geological Society of America Abstracts with Programs, v. 8, no. 5, p. 578.

Dane, C.H., and Bachman, G.O., compilers, 1965, Geologic map of New Mexico: U.S. Geological Survey, scale 1:500,000, 2 sheets.

Deal, E.G., 1973a, Geology of the northern part of the San Mateo Mountains, Socorro County, New Mexico: a study of a rhyolite ash-flow tuff cauldron and the role of laminar flow in ash-flow tuffs [Ph.D. dissertation]: Albuquerque, University of New Mexico, 136 p.

Deal, E.G., 1973b, Primary laminar flow structures in the rhyolite ash-flow tuff of A-L Peak, San Mateo Mountains, New Mexico: Geological Society of America Abstracts with Programs, v. 5, no. 6, p. 475.

Deal, E.G., and Rhodes, R.C., 1976, Volcano-tectonic structures in the San Mateo Mountains, Socorro County, New Mexico, in Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico, New Mexico Geological Society Special Publication no. 5, p. 51-56.

Deer, W.A., Howie, R.A., and Zussman, J., 1966, An introduction to the rock-forming minerals: New York, John Wiley and Sons, 528 p.

Denny, C.S., 1940, Tertiary geology of the San Acacia area, New Mexico: Journal of Geology, v. 48, p. 73-106.

Donze, M.A., 1980, Geology of the Squaw Peak area, Magdalena Mountains, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 123 p.

Ekren, E.B., McIntyre, D.H., and Bennett, E.H., 1978, Welded ash-flow sheets that reverted to high-viscosity liquids, Owyhee County, Idaho: Geological Society of America Abstracts with Programs, v. 10, no. 5, p. 215.

Epis, R.C., and Chapin, C.E., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the southern Rocky Mountains, in: Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45-74

Farnham, L.L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Information Circular 8030, p. 27-28.

Iovenitti, J. 1977, A reconnaissance study of jasperoid in the Kelly Limestone, Kelly mining district, New Mexico: Socorro, New Mexico Institute of Mining and Technology, 200 p.

Krewedl, D.A., 1974, Geology of the central Magdalena Mountains, Socorro County, New Mexico [Ph.D. dissertation]: Tucson, University of Arizona, 128 p.

Lipman, P.W., 1975, Evolution of the Platoro caldera complex and related volcanic rocks, southeastern San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 852, 128 p.

Lipman, P.W., 1976, Caldera-collapse breccias in the western San Juan Mountains, Colorado: Geological Society of America Bulletin, v. 87, p. 1397-1410.

Loughlin, G.F., and Koschmann, A.H., 1942, Geology and ore deposits of the Magdalena mining district, New Mexico: U.S. Geological Survey Professional Paper 200.

Lowell, G.R., and Chapin, C.E., 1972, Primary compaction and flow-foliation in ash-flow tuffs of the Gribbles Run paleovalley, central Colorado: Geological Society of America Abstracts with Programs, v. 4, no. 7, p. 725-726.

Macdonald, G.A., 1972, Volcanoes: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 510 p.

Machette, M.N., 1978, Geologic map of the San Acacia quadrangle, Socorro County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1415.

Osburn, G.R., 1977, Geology of the eastern Magdalena Mountains, Water Canyon to Pound Ranch, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 136 p.

Parker, D.F., 1972, Laminar flow in a peralkaline ash-flow sheet, Davis Mountains, Texas: Geological Society of America Abstracts with Programs, v. 4, no. 4, p. 288.

Petty, D.M., 1979, Geology of the southeastern Magdalena Mountains, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 163 p.

Schmincke, H., and Swanson, D.A., 1967, Laminar viscous flowage structures in ash-flow tuffs from Gran Canaria, Canary Islands: Journal of Geology, v. 75, p. 641-664

Simon, D.B., 1973, Geology of the Silver Hill area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 101 p.

Smith, E.I., Aldrich, M.J., Jr., Deal, E.G., and others, 1976, Fission-track ages of Tertiary volcanic and plutonic rocks, Mogollon Plateau, southwestern New Mexico, in Elston, W.E., and Northrup, S.A., eds., Cenozoic volcanism in southwestern New Mexico, New Mexico Geological Society Special Publication no. 5, p. 117-118.

Spradlin, E.J., 1976, Stratigraphy of Tertiary volcanic rocks, Joyita Hills area, Socorro County, New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 73 p.

Sumner, W., 1980, Geology of the Water Canyon--Jordan Canyon area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 150 p.

Tonking, W.H., 1957, Geology of Puertecito quadrangle, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 41, 67 p.

Walker, G.W., and Swanson, D.A., 1968, Laminar flowage in a Pleistocene soda rhyolite ash-flow tuff, Lake and Harney Counties, Oregon: U.S. Geological Survey Professional Paper 600B, p. B37-B47.

Weber, 1971, K-Ar ages of Tertiary igneous rocks in central and western New Mexico: Isochron/West, no. 1, p. 33-45.

Weber, R.H., and Bassett, W.A., 1963, K-Ar ages of Tertiary volcanic and intrusive rocks in Socorro, Catron, and Grant Counties, New Mexico: Guidebook of the Socorro region, New Mexico Geological Society, 14th Field Conference, p. 220-223.

Willard, M.E., 1959, Tertiary stratigraphy of northern Catron County, New Mexico: Guidebook of west-central New Mexico: New Mexico Geological Society, 10th Field Conference, p. 92-99.

Wilkinson, W.H., Jr., 1976, Geology of the Tres Montosas--Cat Mountain area, Socorro County, New Mexico [M.S. thesis]: Socorro, New Mexico Institute of Mining and Technology, 158 p.

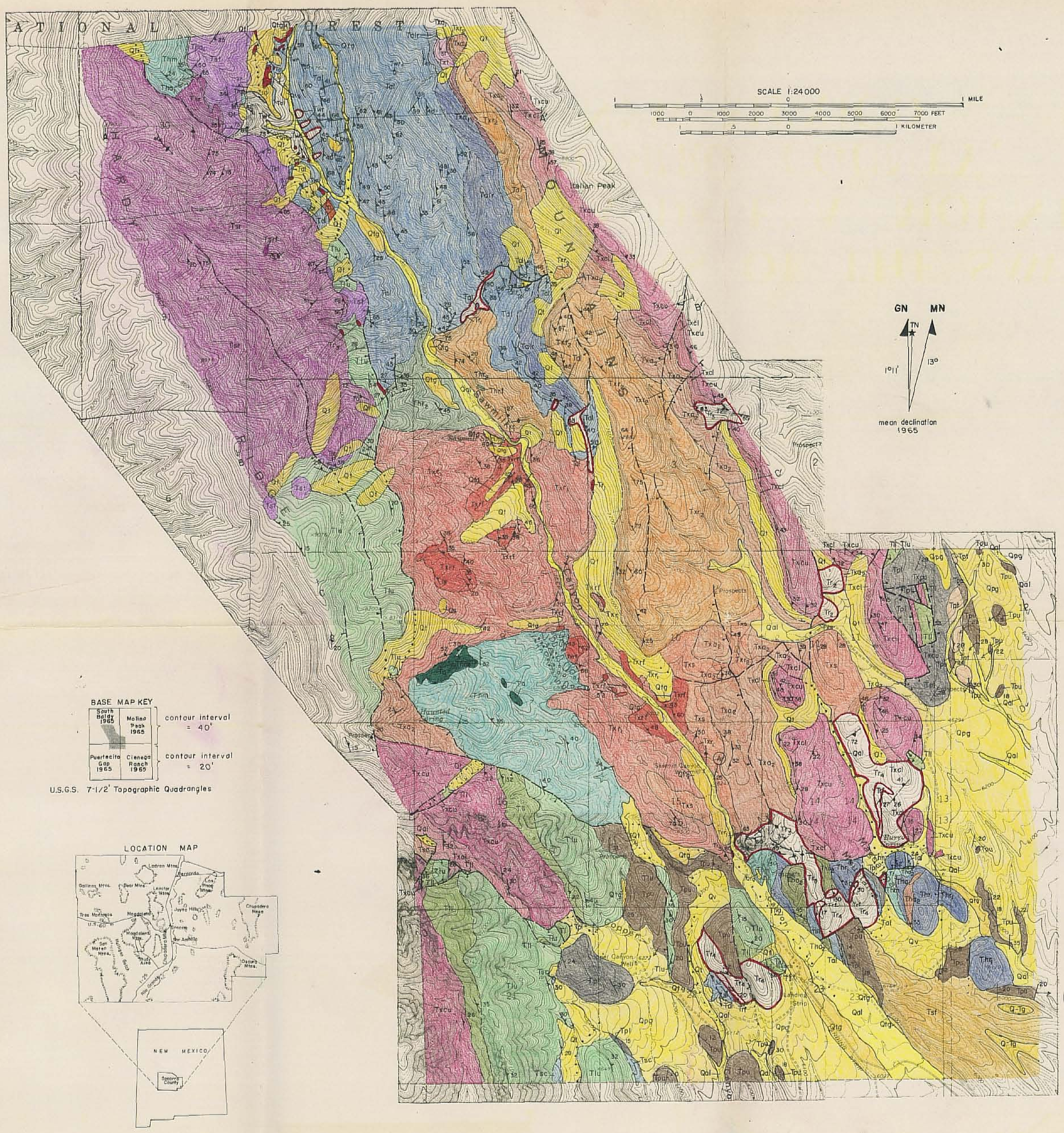
Wilpolt, R.H., and others, 1946, Geologic map and stratigraphic sections of Paleozoic rocks of the Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations, Preliminary Map 61.

Winchester, D.E., 1920, Geology of Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U.S. Geological Survey Bulletin 716-A.

GEOLOGIC MAP AND SECTIONS OF THE SAWMILL CANYON AREA OF THE MAGDALENA MOUNTAINS SOCORRO COUNTY, NEW MEXICO

by

SUSAN J. ROTH
1980



EXPLANATION

QUATERNARY
- Qal alluvium
- Qv valley alluvium
- Qs slump block
- Qt talus and colluvium
- Qpg piedmont gravels
- Qtg terrace gravels

Pliocene
- Q-Tg alluvial fan gravels

Miocene — Santa Fe Group
- Tsf Santa Fe Group (undifferentiated)
- Tpu upper Popotosa Formation
- Tpt lithic-rich tuff
- Tpl lower Popotosa Formation

Oligocene

unit of Sawmill Canyon
- Tsr crystal-poor rhyolite lavas (Tsrf = float block)
- Tst tuffs, vent breccias, and sedimentary rocks

- Tsc tuff of South Canyon
- Tlu, Tll tuff of Lemitar Mountains (upper and lower members)

unit of Sixmile Canyon
- Txcu, Txcl tuff of Caronita Canyon (upper and lower members)
- Txa2 andesite lavas
- Txr2 sanidine rhyolite lavas
- Txs sedimentary rocks (debris-flow deposits and sandstones) and tuffs
- Txrf, Txr1 rhyolite intrusive complex (Txrf = float block)
- Txa1 andesite lava
- Txt ash-flow tuff

- Talr, Tal A-L Peak Tuff (Talr = rhyolite lava)

unit of Hardy Ridge
- Thr1 rhyolite lava
- Thrf, Thr2 rhyolite lava (Thrf = float block)
- Tha2 porphyritic andesite lava
- Tha1 andesite lava
- mesobreccia
- Thm Hells Mesa Tuff

Intrusives
- Twr white rhyolite dikes
- Trf, Tr4 flow-banded, crystal-poor rhyolite intrusives (Trf = float block)
- Tr3 crystal-poor rhyolite intrusives
- Tr2 crystal-rich rhyolite intrusive
- Tr1 quartz-rich rhyolite dikes
- Tl latite dike
- Ta andesite intrusives

Contact — Dashed where approximate, Dotted where covered

Normal Fault — Dashed where approximate, Dotted where covered, Ball and bar on downthrown block

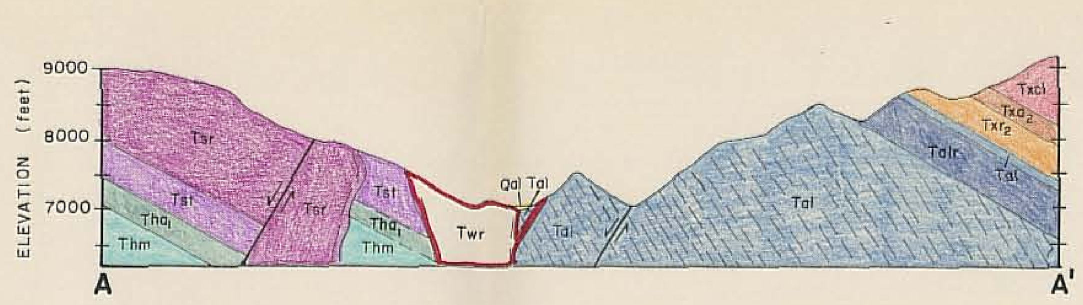
Strike and dip of foliation — Vertical foliation

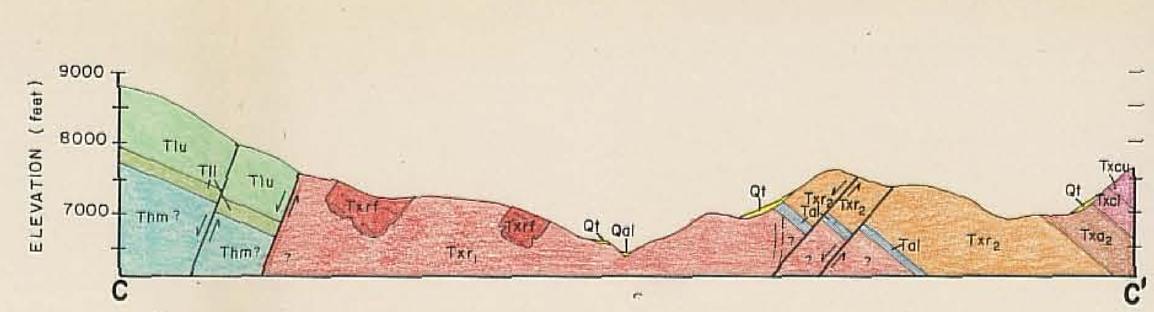
Strike and dip of bedding

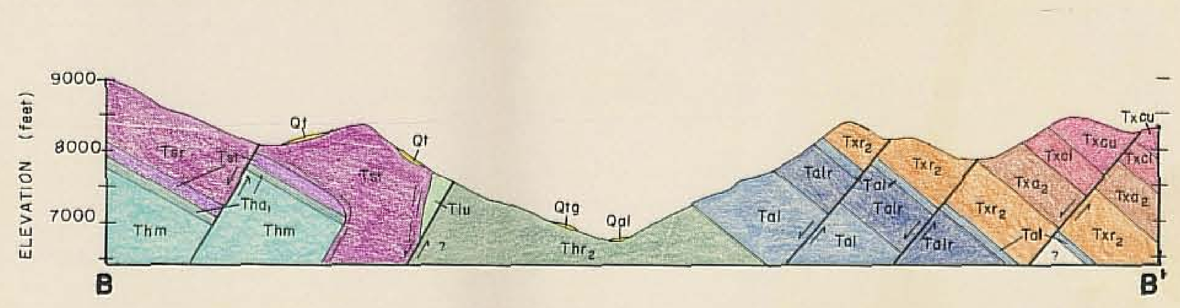
Trend of lineation

Transport direction

Ⓐ Sample location for K/Ar date







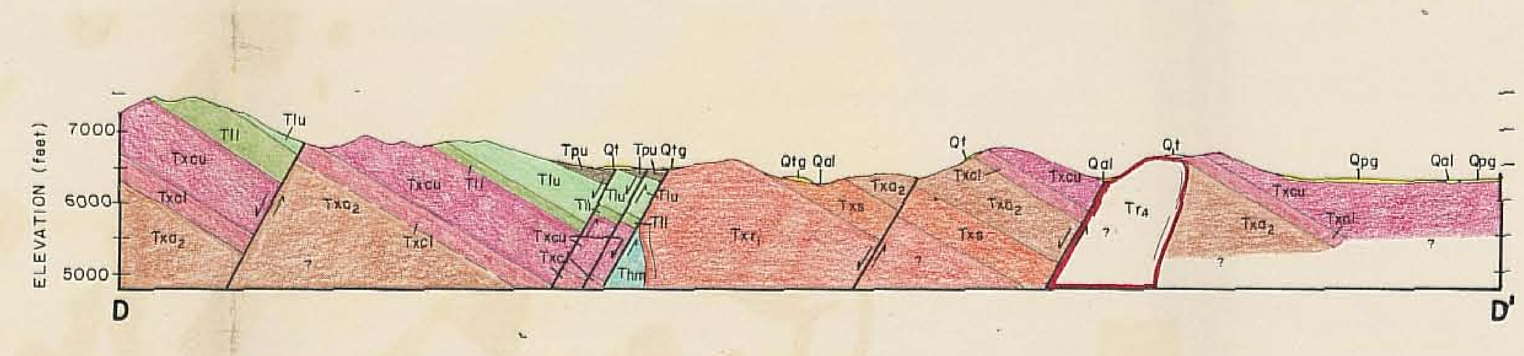


PLATE 2

STRUCTURAL GEOLOGY OF THE SAWMILL CANYON AREA

by

SUSAN J ROTH

1980