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GEOLOGY OF THE SOUTHEASTERN MAGDALENA MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The southeastern Magdalena Mountains have a complex middle to late Tertiary geologic history. This study area is located entirely within the North Baldy cauldron, from which the Hells Mesa Tuff erupted about 32 to 33 m.y. ago. The Hells Mesa Tuff is at least 2000 feet thick in the study area. The unit of Hardy Ridge (rhyolite lavas and domes, and volcaniclastic sedimentary rocks) filled the North Baldy cauldron after the Hells Mesa Tuff was erupted.

The A-L Peak Tuff (pinnacles member ?) erupted from the Sawmill Canyon cauldron about 32 m.y. ago. This tuff is at least 3000 feet thick in the southeastern Magdalena Mountains. The unit of Sixmile Canyon (as much as 2500 feet thick) is a heterogeneous assemblage of rhyolite and andesite lavas, tuffs, and volcaniclastic sedimentary rocks that filled the Sawmill Canyon cauldron after the A-L Peak Tuff was erupted.

The part of the Sawmill Canyon cauldron that has been delineated so far is roughly elongate in an east-northeast direction. The east-northeast trending Morenci lineament may have influenced the shape of the Sawmill Canyon cauldron. The northern cauldron margin transects the northwestern portion of this study area; part of this margin is the ring fracture and part of it is the topographic rim of the cauldron. The southern ring fracture of the Sawmill Canyon cauldron

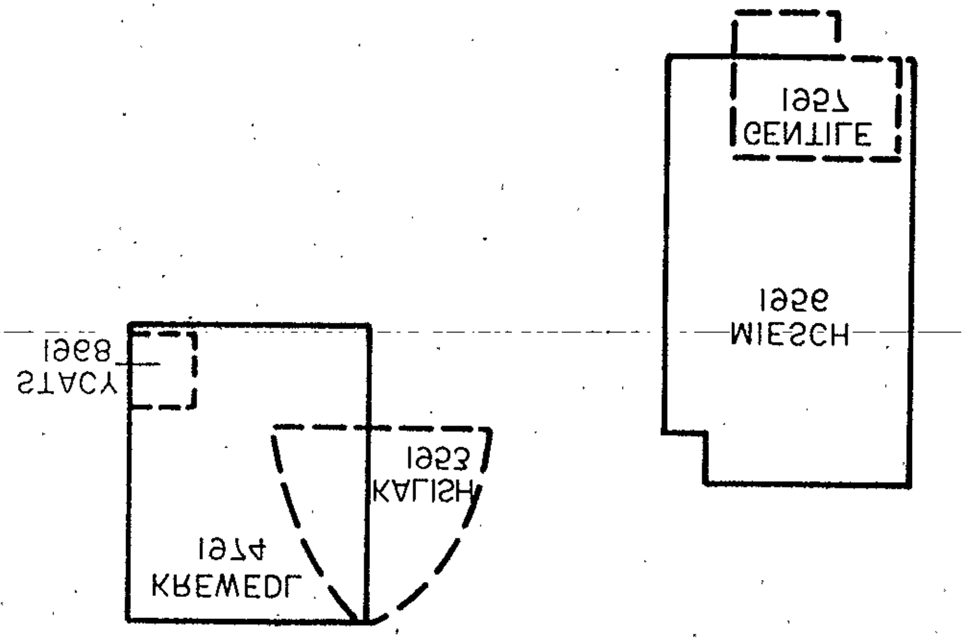
is exposed in Ryan Hill Canyon; elsewhere, it is covered with younger rocks. A portion of the southern topographic rim has been mapped south of this study area. A wide zone between the southern ring fracture and the southern topographic rim indicates that considerable slumping and caving of the cauldron wall took place. Apparently, little or no slumping occurred along the northern cauldron margin in this study area.

The tuff of Lemitar Mountains erupted from the Socorro cauldron about 27 m.y. ago. The western margin of this cauldron may pass through this study area. If it does, it is a hinge zone on a trap-door cauldron. The tuff of Lemitar Mountains thickens slightly across this cauldron margin, but it is unusually thick outside the cauldron. This may be because the tuff of Lemitar Mountains partially filled a depression remaining in the Sawmill Canyon cauldron.

Sedimentary rocks and interbedded lava flows in the Santa Fe Group cover several square miles in the eastern portion of the study area. A number of regional and local unconformities exist between the youngest rocks of the Santa Fe Group and the Oligocene rocks.

Numerous faults associated with extension of the Rio Grande rift occur in the study area. The transverse shear zone, which transects the northwestern portion of this study area, separates fields of oppositely tilted fault blocks. Most of this study area is south of the transverse shear zone, where the strata dip to the east and most of the faults dip to the west. However, some of the strata in the northwestern portion of the study area (on the transverse shear zone) dip to the west. The structural deformation that produces the tilted strata has been called "domino-style" faulting. This style involves progressive tilting of both the strata and the faults. New faults form when the older faults become too shallow for movement to occur on them.

The Sawmill Canyon cauldron was the major structural control for most of the mineralization in this study area. Gold and silver mineralization occurs along the northern cauldron margin. This mineralization is closely associated with white rhyolite dikes that intruded north-trending faults and the east-trending ring fracture of the Sawmill Canyon cauldron. Manganese mineralization occurs in a wide zone between the southern ring fracture and the southern topographic rim of the Sawmill Canyon cauldron. It is especially intense at the intersection of the ring fracture of the Sawmill Canyon cauldron with the hinge zone of the Socorro cauldron. A regional potassium metasomatism has affected some of the rocks in the study area.


STACY
1968
KREWEDL
1974
KALISH
1953
MIESCH
1956
GENTILE
1957

INTRODUCTION

Purpose of the Investigation

The objectives of this study are: 1) to define the volcanic and sedimentary stratigraphy of the southeastern Magdalena Mountains and to fit it into the known stratigraphic section in the Socorro-Magdalena region, 2) to map and interpret the geology of overlapping cauldrons located within the thesis area, 3) to map and interpret extensional structures within the thesis area that may be related to the Rio Grande rift, and 4) to evaluate the mineral potential of this area.

Location and Accessibility

The study area covers about 35 square miles in the southeastern Magdalena Mountains, Socorro County, New Mexico. The area shown in Figure 1 is bounded on the northwest by Timber Peak, on the southwest by Italian Peak, and on the east by the Chupadera Mountains. Figure 2 shows the general physiographic features of the area, surrounding studies, and access routes. About one-half of the study area is in the Cibola National Forest. The study area can be reached from U.S. Highway 60 by following Forest Route 235 to the Water Canyon Campground. An unpaved portion of Forest Route 235 continues beyond the campground to the Langmuir Laboratory on South Baldy. This road passes through the northwestern portion of the

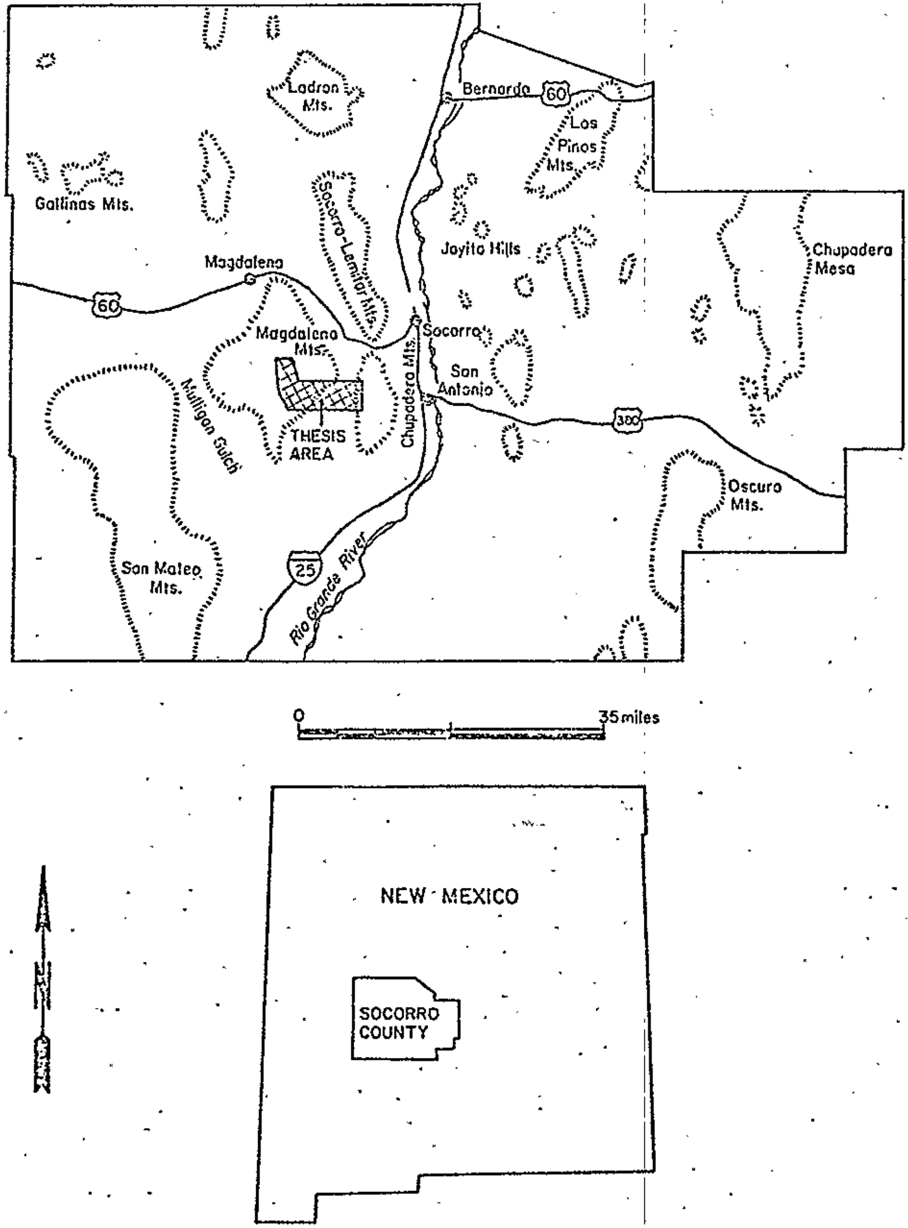


Figure 1: Location map of study area.

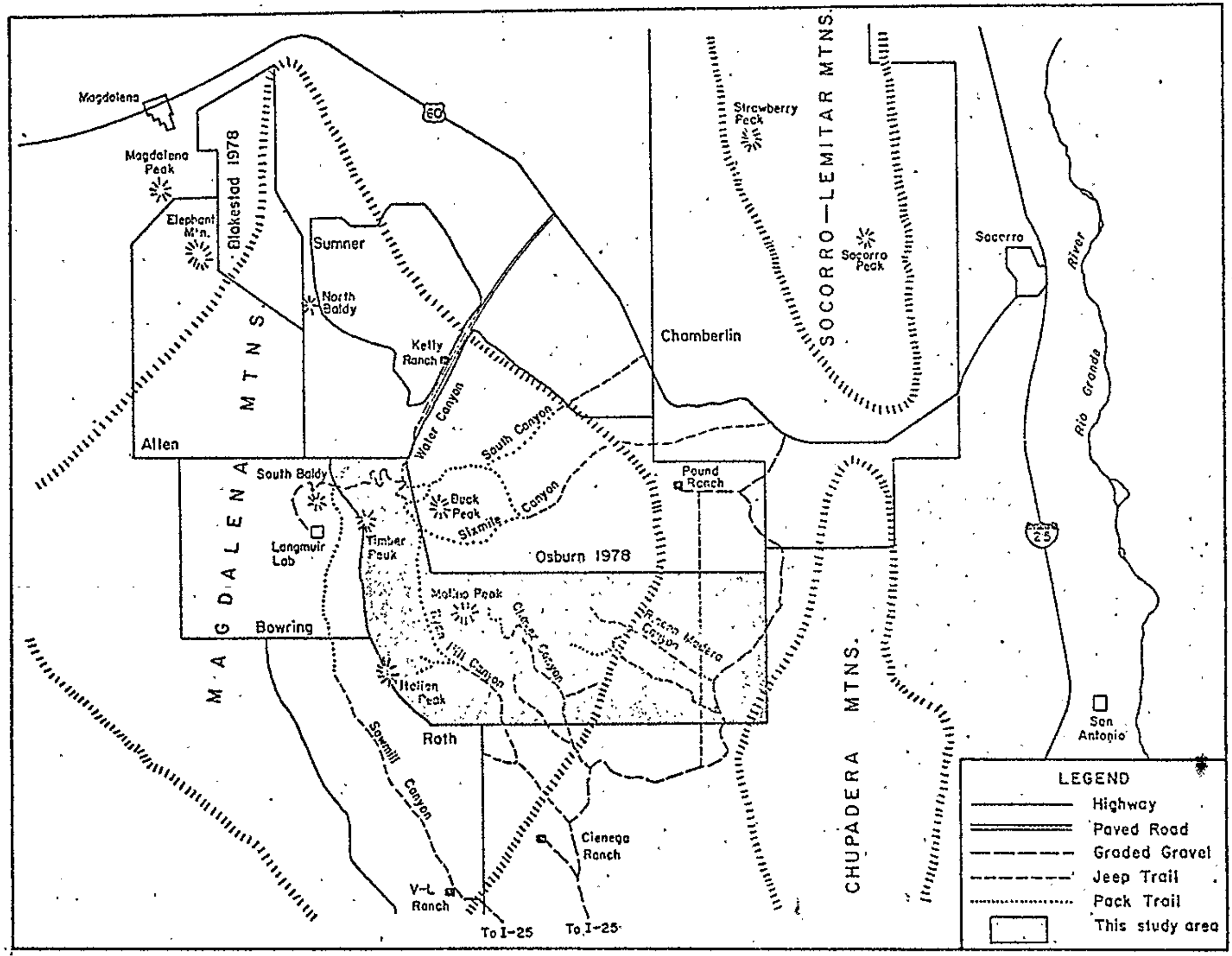


Figure 2. Location map showing physiographic features of the study area, surrounding studies and access routes.

study area (secs. 3, 4, and 5, T. 4 S., R. 3 W., unsurveyed, and sec. 34, T. 3 S., R. 3 W.). The eastern portion can be reached by following an unpaved road which leaves U.S. Highway 60 about 6.5 miles west of Socorro. This road passes the Pound Ranch and continues south-southwest until it connects with Forest Route 472. The eastern portion can also be reached by following Interstate Highway 25 to the San Marcial exit, then following Forest Route 472 northwest.

Physiographic Setting

A high, north-trending ridge connecting Timber Peak (10,510 feet) and Italian Peak (9,052 feet) forms the western boundary of the study area. South Canyon and Sixmile Canyon drain northeastward from the north end of this ridge; Ryan Hill Canyon, the largest canyon in the study area, drains southeastward along the east side of this ridge. About 2500 feet of topographic relief exists between Timber Peak and the floor of Sixmile Canyon, 1.1 miles to the east. The lowest elevations (5600-6200 feet) are found in the north-trending graben that separates the Magdalena and Chupadera Mountains. Figure 3 is a panoramic view which shows some of the features mentioned above.

Most of the southeastern Magdalena Mountains are dominated by east-tilted fault blocks, some of which form prominent hogbacks. A transverse shear zone (Chapin and others, 1978) transects the northwestern portion of the

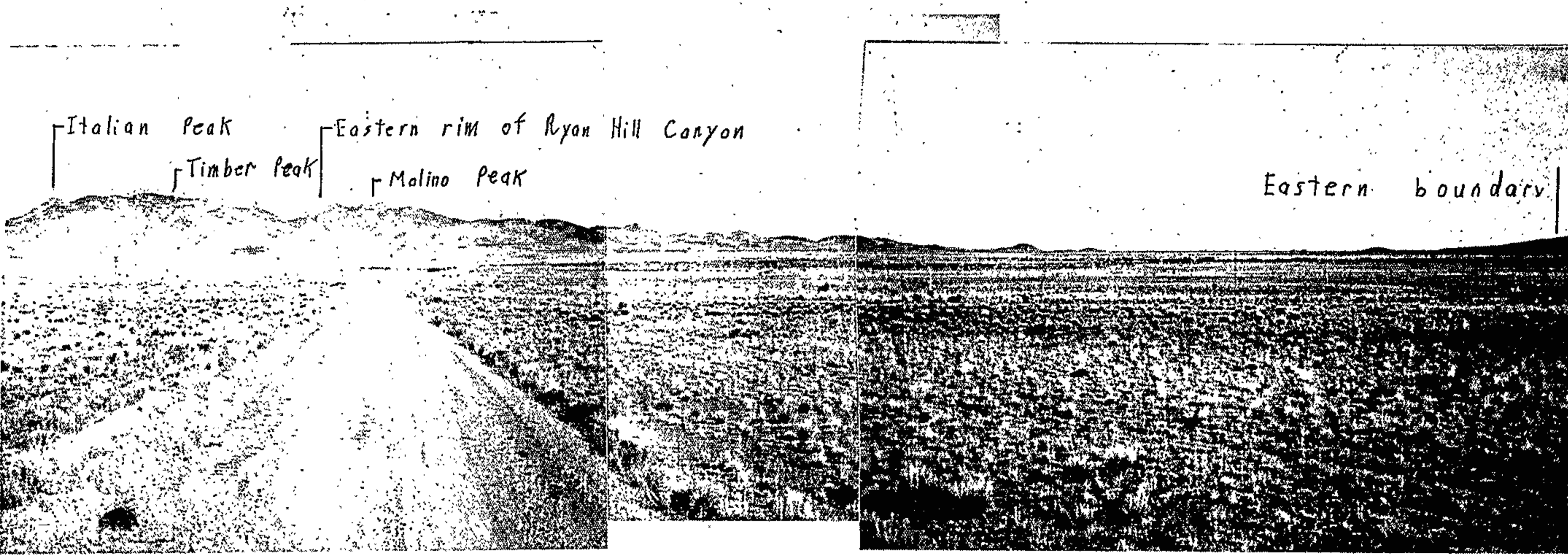


Figure 3. Panoramic view of the thesis area from the southeast. The north-trending ridge connecting Timber Peak (10,510 feet) and Italian Peak (9,052 feet) forms the western boundary of the thesis area. Molino Peak (8,902 feet) is the highest summit east of Ryan Hill Canyon. The eastern boundary of the thesis area is located in the western Chupadera Mountains. A better view of the Chupadera Mountains can be seen in Figure 18. The distance between Italian Peak and the eastern boundary is about 8.5 miles.

area. North of this transverse shear zone, the strata dip to the west. Five overlapping cauldrons have been found in the Magdalena Mountains; the study area includes portions of three of these cauldrons. In the easternmost portion of the study area, nearly flat-lying Pliocene (?) basalts cap older sediments of the Santa Fe Group.

Previous Work

Winchester (1920) examined the volcanic rocks along the northern edge of the Datil-Mogollon volcanic field and named them the Datil Formation after the Datil Mountains. His type section, however, is at the north end of the Bear Mountains. Laughlin and Koschmann (1942) published a detailed study of the geology and ore deposits of the Kelly mining district. Kalish (1953) studied the geology of the Water Canyon area northeast of this study area. Miesch (1956) mapped the Luis Lopez manganese district and the northern Chupadera Mountains.

Tonking (1957) published the first detailed study of the volcanic rocks in the Datil Formation north of Magdalena. He mapped the Puertecito quadrangle and divided the Datil Formation into three members; from oldest to youngest these are the Spears, Hells Mesa, and La Jara Peak Members. Givens (1957) mapped the Dog Spring Quadrangle and divided the Hells Mesa Member into seven mappable units. Weber (1963) excluded the La Jara Peak Member from the Datil

Formation. Later, Weber (1971) elevated the Datil Formation to group status. The Spears, Hells Mesa, and La Jara Peak Members were raised to formational status by Chapin (1971a). 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 quartz-rich, crystal-rich ash-flow tuffs that are the basal unit of Tonking's Hells Mesa Member and 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). Elston (1976) recommended that the term Datil Group be abandoned.

Recently, a number of theses and dissertations have been completed in the Socorro-Magdalena area which have further defined the volcanic and sedimentary stratigraphy. Figure 2 shows the location of published maps and maps in preparation in the Magdalena and Chupadera Mountains. Krewedl (1974) studied the geology of the central Magdalena Mountains in order to evaluate the economic potential of that area. A portion of the southern part of Krewedl's area was remapped for this study. Blakestad (1978) mapped and described the geology of the Kelly mining district in the northwestern Magdalena Mountains while Osburn (1978) studied the geology of the southeastern Magdalena Mountains just north of this thesis area. Bowring (in preparation) mapped the upper Sawmill Canyon area concurrently with this study and shared a common boundary along the crest of Timber Peak. Roth (in progress) is mapping the lower portion of Sawmill Canyon, west-southwest of this study area. Other recent studies in the Socorro-Magdalena area include those by Park (1971), Bruning (1973), Deal (1973), Simon (1973), Woodward (1973), Chamberlin (1974), Siemers (1974, 1978), Deal and Rhodes (1976), Spradlin (1976), Wilkinson (1976), and Iovenitti (1977). The contributions of these and other authors will be discussed in more detail in the sections on stratigraphy and structure. This study area is located in the Rio Grande rift; summary papers on this continental rift have been published by Chapin (1971b), Chapin and Seager (1975), and Cordell (1978).

Methods of Investigation

Detailed geologic mapping was done at a scale of 1:24,000 on a base map consisting of parts of the Molino Peak and South Baldy 7 1/2-minute quadrangles. Aerial photographs of the GS-VAVL series (8-6-64; scale, 1:34,682 and 1:8,276) and the GS-VMA series (3-7-56; scale, 1:9,317) were used as an aid in locating outcrops and making structural interpretations. Approximately nine to ten months of field work were done between June, 1977 and November, 1978.

Ninety-three thin sections were made from samples collected throughout the study area. Most of the thin sections were stained for potassium with sodium cobaltinitrite (after Deer, Howie and Zussman, 1966, p. 311). Petrographic analyses were done on a Zeiss binocular microscope. All samples were described using the petrographic classification of Travis (1955). Visual estimates were used to determine the mineral abundances.

Acknowledgements

The author would like to thank the many individuals who made suggestions and provided information for this project. Graduate students conducting geologic studies in the Socorro-Magdalena area were very helpful, especially G.R. Osburn who provided valuable aid in the field and in office discussions. He also took the photomicrographs presented in this thesis. Dr. A.J. Budding and Dr. K.C. Condie served on my thesis committee and critically read the manuscript.

The author would like to extend special thanks to Dr. Charles E. Chapin, who originally suggested this problem and then served as thesis advisor for this study. Financial support and field transportation were provided by the New Mexico Bureau of Mines and Mineral Resources, to whom the author is grateful.

STRATIGRAPHY AND PETROGRAPHY

Pre-Tertiary Rocks

Pre-Tertiary rocks are not exposed in the study area, but they do crop out about one-half mile north of the study area. The pre-Tertiary rocks in the central Magdalena Mountains have been described recently by Krewedl (1974), Siemers (1974, 1978), and Osburn (1978).

The closest Precambrian rocks crop out along Water Canyon about 1.5 miles northeast of the study area. These rocks are metasedimentary rocks mapped as argillite by Krewedl (1974). Further north, Krewedl also mapped Precambrian granite intruding the argillite. Sumner (in preparation) has mapped the Precambrian rocks in the north-central Magdalena Mountains.

The Paleozoic rocks in the Magdalena Mountains have been discussed by Laughlin and Koschmann (1942), Armstrong (1958, 1963), Kottlowski (1960, 1963), Krewedl (1974), Siemers (1974, 1978), Blakestad (1978), and Osburn (1978). Krewedl (1974) divided the Paleozoic rocks in the central Magdalena Mountains into five map units. The oldest of these is the Mississippian Kelly Limestone, which is a light-bluish-gray, medium- to coarse-grained, crinoidal biosparrite and is approximately 80-100 feet thick in the Water Canyon area. Above this is the Sandia Formation of Pennsylvanian age, which Krewedl (1974) divided into a lower quartzite member and an upper shale member. The

Sandia Formation is approximately 550 feet thick in the Water Canyon area. The thickest Paleozoic unit in the Water Canyon area is the Pennsylvanian Madera Limestone, which is as much as 1800 feet thick in the central Magdalena Mountains (Siemers, 1978). The Madera Limestone is mostly a thick, homogeneous sequence of gray to black micritic limestone, although the lower part contains some interbedded quartzose sandstones. The contact between the Madera Limestone and the underlying Sandia sandstones and shales is gradational; Krewedl placed the base of the Madera Limestone at the horizon above which limestone predominates over sandstone and shale. In the Water Canyon area, Krewedl (1974) reports that the Madera Limestone is overlain by the Spears Formation of Oligocene age; further north in the Magdalena Mountains, the Permian Abo Formation separates the Madera and Spears Formations (Laughlin and Koschmann, 1942).

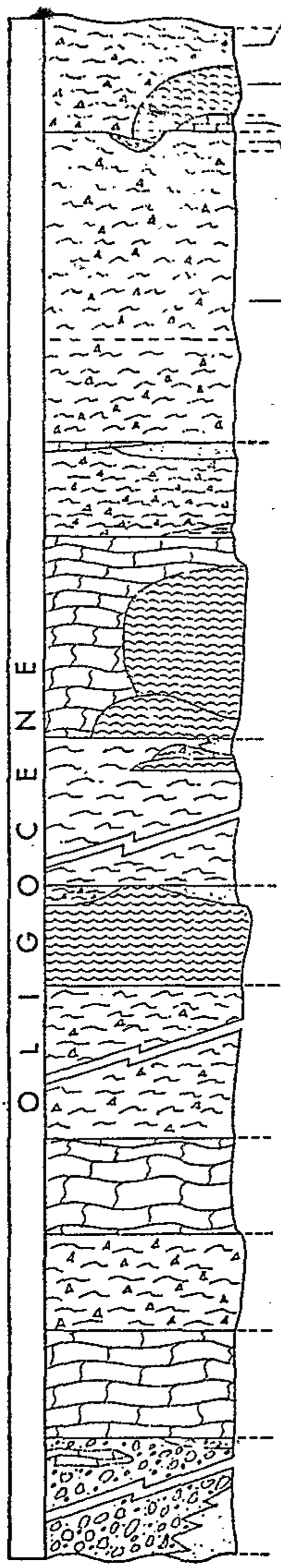
Tertiary Volcanic and Sedimentary Rocks

During the late Eocene, central New Mexico was eroded to a surface of low relief (Epis and Chapin, 1975). Because of this erosion surface, Oligocene volcanic rocks were able to spread over large areas in central New Mexico. The basal Oligocene rocks in the Magdalena area are andesitic and latitic conglomerates, laharic breccias, and sandstones of the Spears Formation. Lavas and ash-flow tuffs of similar composition are abundant in the upper

Spears Formation. The Spears is typical of the andesitic-latitic aprons of volcanic and volcaniclastic rocks found at the base of the foreland volcanic fields of the western United States (Lipman and others, 1970). After deposition of about 2000 feet of the Spears Formation, extensive ash-flow tuff sheets were formed by pyroclastic eruptions from cauldrons in south-central and southwestern New Mexico. In the Magdalena Mountains, several of these cauldrons overlap one another (Fig. 20); thick piles of lavas, tuffs, and volcaniclastic sediments usually fill each cauldron. Beginning in late Oligocene-early Miocene time, basins formed along the Rio Grande rift and were filled with clastic sediments of the Santa Fe Group. Basaltic and rhyolitic lavas are interbedded with these sediments in the study area. All of the rocks exposed in the area mapped are Cenozoic in age. Stratigraphic columns depict the Oligocene units in Figure 4 and Miocene-Pliocene units in Figure 13.

Spears Formation

The Spears Formation is a group of interbedded volcaniclastic sedimentary rocks, lava flows, and ash-flow tuffs which represent the beginning of Oligocene volcanism in the Socorro-Magdalena area. Tonking (1957) measured a thick section of these rocks on the Guy Spears ranch in the Puertecito Quadrangle and named them the Spears Member of the Datil Formation. Chapin (1971a) raised the Spears



Tuff of South Canyon: 26 m.y. (0-700 ft.) ASH-FLOW TUFFS: multiple-flow, simple cooling unit of rhyolite ash-flow tuffs. Lower zone of lt.-gry., poorly to densely welded, xl.-poor tuff w/"botryoidal" pumice and lithic-rich lenses. Upper zone of med.-gry. to prpl.-gry., mod. to densely welded, mod. xl.-rich tuff w/chatoyant sanidine and euhedral qtz.

Dome and lava flows: (0-700 ft.) RHYOLITE: xl.-poor, spherulitic, rhyolite dome and lava flows, gry.-pk. to gry.

Lava Flows: (0-50 ft.) BASALTIC ANDESITE: Most are La Jara Peak like; gry., dense, basaltic andesites with abun. small, rd., hematized ferromag. phen. and no feld. phen. Some have abundant olivine and some feld. phen.

Tuffs: (0-300 ft.) ASH-FLOW TUFFS and minor SANDSTONES: thin, poorly welded, ash-flow tuffs and volcaniclastic ss. beneath rhyolite lava in Ryan Hill Canyon.

Tuff of Lemitar Mountains: 27 m.y. (1000-2000 ft.) ASH-FLOW TUFFS: rhyolite, multiple-flow, comp. zoned, simple to compound cooling unit. Lt.-gry. to pale-rd., 1-feld., xl.-poor, lower member 200-800 ft. thk. Med.-rd., xl.-rich, qtz.-and biotite-rich, 2-feld., upper member 800-1200 ft. thk. Source is Socorro cauldron.

Unit of Sixmile Canyon: (1000-2000 ft.) ANDESITE to BASALTIC ANDESITE LAVAS, RHYOLITE LAVAS, ASH-FLOW TUFFS, LAHARIC BRECCIAS and SANDSTONES: cauldron fill of Sawmill Canyon cauldron; lower interval of xl.-poor, pk. to lt.-gry., rhyolite lavas, tuffs and lithic-rich ss. overlain by dense, gry. to gry.-prpl., andesite lavas interbedded with pale-rd. to pk.-gry. rhyolite lavas and minor dk.-gry. to prpl., heterolithic, laharic breccias. Thin ss. and siltst. overlie the lavas in places. TUFF OF CARONITA CANYON (in upper part of unit) is a multiple-flow, simple cooling unit of ash-flow tuff consisting of a lower member of brick-rd. to gry., xl.-poor, andesite ash-flow tuff and an upper member of gry. xl-rich, qtz.-rich, rhyolite ash-flow tuff; qtz.- and feld.-rich ss. occurs near top of unit. "La Jara Peak like" basaltic andesites overlie these and underlie the tuff of Lemitar Mountains.

A-L Peak Tuff - pinnacles member(?): 32 m.y. (3000+ ft.) ASH-FLOW TUFFS: rhyolite, densely welded, 1-feld., xl.-poor, pumiceous, tuffs; gry. to rd.-brn. with gry.-rd. to brn. pumice. Weathers to small, platy talus; pumice lineated. Unit believed erupted from Sawmill Canyon cauldron; probably correlative with pinnacles member. Base not known, but unit is minimally several thousand ft. thick. Gry. to pnk. rhyolite lavas with 10-15% phen. of sanidine and qtz., lithic-rich ss. and thin, poorly welded tuffs interbedded in upper part of unit.

Unit of Hardy Ridge: (400-900(?) ft.) RHYOLITE LAVAS and DOMES, ASH-FLOW TUFFS and SANDSTONES: cauldron fill of North Baldy cauldron. Mostly pk. to gry., xl.-poor rhyolite lavas and domes. Thin, poorly welded, ash-flow tuffs and med.-crs.-gnd., lithic-rich ss. overlie the rhyolite lava.

Hells Mesa Tuff: 32-33 m. y. (2000+ ft.) ASH-FLOW TUFFS: rhyolite, multiple-flow, simple cooling unit, densely welded, xl.-rich, qtz.-rich, 2-feld., mass. tuffs. Pk. to rd.-brn. when fresh, gry. when propyl. altered. Weathers to blocky bldrs. Basal tuffs similiar to tuff f Granite Mtn.; abrupt increase in qtz. 10-25 ft. above base. Source is North Baldy cauldron.

Spears Formation - upper lavas and breccias: (500 ft.) ANDESITE to LATITE LAVAS and minor MUD-FLOW DEPOSITS: mostly dense, latite to andesite lavas, prpl. to dk.-gry. One type is aphanitic latite; other type is porphyritic andesite. Contains minor interbedded andesitic to latitic mud-flow breccias.

Spears Formation - tuff of Granite Mountain: (400-500 ft.) ASH-FLOW TUFFS: latite, multiple-flow, simple cooling unit, densely welded, xl.-rich, lithic-rich, qtz.-poor, mass. tuffs; rd.-brn when fresh, dk.-grn.-gry. when propyl. altered.

Spears Formation - "turkey track" andesite: (500 ft.) ANDESITE LAVAS: gry.-rd. to prpl. porphyritic andesite with crudely flow-aligned plag. phen. Underlies tuff of Nipple Mtn. in northern Magdalena Mts.; tuff not recognized here.

Spears Formation - lower volcaniclastic unit: 37-33 m. y. (1200 ft.) CONGLOMERATES, MUD-FLOW DEPOSITS, SANDSTONES, LAVAS, and ASH-FLOW TUFFS: volcaniclastic apron of latite to andesite comp.; deposits coarsen and contain more volcanic units upwards and to the south of the Socorro-Magdalena area.

Figure 4. Oligocene stratigraphic section for focks in the eastern Magdalena Mountains. Graphic sections and descriptions modified after Chapin and others, 1978, and Osburn, 1978.

to formational status; however, the terms Datil Formation and Datil Group (Weber, 1971) have been abandoned (Elston, 1976, p. 134). Burke and others (1963) reported a K-Ar date of 37.1 m.y. from biotite in a boulder from the upper part of the Spears.

The Spears Formation is found only in the northwestern portion of the study area (secs. 3 and 4, T. 4 S., R. 3 W., unsurveyed, and secs. 33 and 34, T. 3 S., R. 3 W.) along the road to Langmuir Laboratory. It covers about three quarters of a square mile. According to Krewedl (1974), the Spears Formation unconformably overlies the Madera Limestone in most places; however at the head of Patterson Canyon, it overlies the Abo Formation. The base of the Spears Formation is not exposed in this study area.

The Spears Formation has several different rock types which may undergo marked facies changes from one area to another. Brown (1972), Chamberlin (1974), Spradlin (1976) and Wilkinson (1976), divided the Spears Formation into upper and lower members. In general, the lower member consists of andesitic-latitic volcaniclastic conglomerates and sandstones with minor lava flows; while the upper member consists of latitic ash-flow tuffs, andesitic to latitic lava flows, laharic breccias and other sedimentary rocks. Usually the boundary between the two members is placed at the base of a "turkey track" andesite that underlies the tuff of Nipple Mountain.

The Spears Formation has recently been mapped in the Magdalena Mountains by Krewedl (1974), Blakestad (1978) and Osburn (1978). In the central Magdalena Mountains, the tuff of Nipple Mountain is not present. Here, Krewedl (1974) divided the Spears Formation into three mappable units, with a "turkey track" andesite (middle member) separating an upper member from a lower member. According to Krewedl, the "turkey track" andesite he mapped is equivalent to the "turkey track" andesite mapped by Brown (1972). If this correlation is correct, then Krewedl's middle and upper members are equivalent to Brown's upper member. Krewedl's lower member is not exposed in this thesis area, but his middle and upper members are. For this study, the Spears Formation was divided into three mappable units, which from oldest to youngest are the "turkey track" andesite, the tuff of Granite Mountain, and an upper unit of andesitic-latitic lavas and laharic breccias. The tuff of Granite Mountain and the upper unit of andesitic-latitic lavas and laharic breccias were mapped together by Krewedl as his upper member.

"Turkey Track" Andesite. A distinctive series of porphyritic lava flows, which exhibit a "turkey track" texture imparted by a subparallel alignment of plagioclase phenocrysts, covers about one quarter of a square mile in the northwestern portion of the study area. They crop out along the Langmuir Laboratory access road and continue northwestward into the area mapped by Krewedl. The "turkey track" andesite is probably about 550 feet thick, but faulting makes it difficult to get an accurate estimate. The base of the "turkey track" andesite is not exposed in this thesis area, but it is exposed less than 0.1 mile north of the northern boundary in sec. 34, T. 3 S., R. 3 W.

Outcrops of the "turkey track" andesite are poorly exposed and scattered because it weathers very easily and is often covered by colluvium. Some of the best exposures are found along the road to Langmuir Laboratory; elsewhere, the "turkey track" andesite usually forms isolated, rounded outcrops separated by talus and soil. The joints vary from being roughly planar to highly irregular; consequently, the talus and colluvium blocks vary from angular to somewhat rounded.

The "turkey track" andesite is purple to gray when fresh, but it is frequently altered to a greenish-gray color in the study area. It usually contains 20 to 40 percent plagioclase phenocrysts in an aphanitic matrix. These plagioclase phenocrysts are tabular and vary from 1 mm to about 12 mm in length, but they are fairly uniform in size within any one specimen. The thickness of the unit and the variations in plagioclase size and abundance suggests that there are several flows; however, it was not possible in the field to map individual flows. Amygdules filled with calcite, celadonite, chalcedony, and quartz are common in the "turkey track" andesite.

In thin section, the "turkey track" andesite consists of about 30 percent phenocrysts of euhedral plagioclase (An_{38}; Michel-Levy method, 8 grains) distributed in a subparallel alignment (see Fig. 5). The plagioclase varies from about 0.5 to 5 mm in length and averages about 2.0 mm. These plagioclase phenocrysts are always partially altered to clays, fine-grained quartz, and calcite(?). The rock also contains about 10 percent xenocrysts(?) that have been altered to a porous honeycomb-like structure of fine-grained quartz and clays. The xenocrysts(?) often exhibit eight-sided euhedral outlines that range from 0.4 to 4 mm in diameter and average 1.8 mm. The rock also contains about 2 to 3 percent magnetite and about 1 percent pyroxene (probably hypersthene), which is about 0.5 mm in diameter. The matrix consists mostly of small crystals of plagioclase (average length about 0.1 mm). About 10 percent of the thin section consists of hematite, which occurs as tiny blades and irregular masses replacing the groundmass.

Tuff of Granite Mountain. The tuff of Granite Mountain is a latitic, crystal-rich, quartz-poor, ash-flow tuff which overlies the "turkey track" andesite in the area mapped. It is a densely welded, multiple-flow, simple cooling unit (Chapin and others, 1978). The tuff of Granite Mountain is an informal name proposed by Chapin (1974). The type

Figure 5. Photomicrograph of the "turkey track" andesite. The blocky, euhedral phenocrysts are altered plagioclase. The subparallel alignment of these phenocrysts gives the rock its distinctive "turkey track" texture in hand specimen. The large grain on the right side of the photomicrograph is part of a xenocryst (?). These xenocrysts consist entirely of a fine-grained aggregate of clay minerals and calcite and are too altered to identify. All of the rocks in the northwestern portion of the study area have been intensely altered. The plagioclase phenocrysts in the "turkey track" andesite are always partially altered to clays, fine-grained quartz and calcite. The alteration products seen in this photomicrograph (gray, cloudy material) consists mostly of clay minerals. Most of the opaque minerals in the groundmass are secondary hematite. Crossed nichols, 31.25x.

locality is on Granite Mountain northeast of Magdalena. The tuff of Granite Mountain was included by Krewedl (1974) in his upper member. This tuff has also been described by Brown (1972), Chamberlin (1974), Wilkinson (1976), Blakestad (1978), and Osburn (1978). It covers about one quarter of a square mile, or less, in the northwestern portion of this study area where it is about 500 feet thick. In the Tres Montosas area, the tuff of Granite Mountain is immediately overlain by the Hells Mesa Formation; however, in this study area, the two tuff units are always separated stratigraphically by a series of lava flows and breccias.

In hand specimen, the tuff of Granite Mountain is a moderately to densely welded, crystal-rich, quartz-poor, lithic-rich, latitic ash-flow tuff. Plagioclase, sanidine, and biotite are the predominate phenocrysts. A few percent lithic fragments are usually present; the most common lithic fragments are red-to-gray, fine-grained andesitic fragments that are usually about 0.5 to 3 cm in diameter. Pumice is present in amounts ranging from about 2 to 10 percent. The rock is usually purple when fresh, but it is frequently altered to a green color. The best exposures of this tuff are on the road to the Langmuir Laboratory. Elsewhere, scattered outcrops are usually low, rounded exposures partially covered with colluvium.

In thin section, the tuff of Granite Mountain contains 50 to 60 percent phenocrysts, 5 to 10 percent lithic fragments, and about 5 percent pumice. All the feldspars are highly altered, so it is difficult to estimate abundances. About 80 to 90 percent of the phenocrysts are feldspars, and it appears that plagioclase (andesine) is four to five times as abundant as potash feldspar. However, some of the feldspars are too altered to identify. Previous workers have reported that the plagioclase is only slightly more abundant than the potash feldspar. The feldspars have an average grain size of about 1.1 to 1.2 mm, but some phenocrysts are as much as 2.6 mm long. In thin section, the tuff also contains about 4 to 5 percent biotite, 2 percent magnetite, 1 percent quartz and a trace of pyroxene. The quartz averages about 2.7 mm in diameter and is deeply embayed. The pumice and matrix are devitrified and altered to the point that little vitroclastic texture remains. The pumice is now mostly represented by streaks of vapor-phase quartz and hematite stain.

Upper Unit. In some parts of the Magdalena area, the tuff of Granite Mountain is immediately overlain by the Hells Mesa Tuff (Chamberlin, 1974). In this study area, however, the two tuffs are separated by a group of andesitic to latitic lavas and mud-flow deposits which were mapped as the upper unit of the Spears Formation. These rocks cover about one quarter of a square mile, or less, and are about 500 feet thick.

At least two different lava flows are present. One is a porphyritic andesite with 10 to 20 percent feldspar phenocrysts, that are as much as 1 cm in length. The feldspars are usually altered to a white or light-green color. The other lava flow is a very-fine-grained latite or quartz latite. Both lavas are very dense and gray to grayish-purple when fresh. They usually break along joints to form sharp, angular talus fragments. Occasionally, mudflow conglomerates and breccias are exposed in the upper unit. This rock type consists of unsorted, unstratified, subrounded to angular, andesitic and latitic fragments in a muddy matrix. The porphyritic lava appears to be the most abundant of the three rock types in the upper unit; the crystal-poor lava is next in abundance. The mudflow deposits are exposed in only a few places.

In thin section, the porphyritic lava contains about 10 percent phenocrysts of feldspar, some with a glomeroporphyritic texture. Most of the phenocrysts are subrounded plagioclase (andesine to labradorite); although about 2 to 3 percent of the rock is sanidine phenocrysts. The feldspar phenocrysts average about 3 to 4 mm in diameter, but may be as much as 6 mm in diameter. The feldspars are all partially altered to clays and fine-grained quartz. Five to 6 percent of the rock consists of opaque minerals. About one-half of this (2 to 3 percent of the rock) is probably primary magnetite. The remainder consists of hematite and magnetite which have replaced biotite(?) or other mafic minerals. The groundmass appears to have been holocrystalline, although it has been altered and partially replaced by other minerals. It consists mainly of feldspar microlites (about 0.05 mm long), but also contains larger fragments of feldspar crystals, a few of which range in size up to that of the phenocrysts. Most of the small feldspar crystals are highly altered, but they are probably plagioclase. There is a crude subparallel alignment of the crystals in the groundmass of this rock. About 5 percent of the rock in thin section is secondary quartz; traces of pyroxene are also present.

The fine-grained lava discussed earlier is a latite or quartz latite. The average size of phenocrysts in thin section is about 0.1 mm; the largest phenocryst observed was about 0.3 mm in diameter. This rock appears to be holocrystalline, but it has been partially to completely altered in some places. In thin section, it contains approximately equal amounts of plagioclase (An_{52}) and sanidine. About 5 to 10 percent quartz and 3 to 5 percent magnetite phenocrysts are present in the rock. About 5 percent hematite occurs as a replacement of other minerals.

Hells Mesa Tuff

The Hells Mesa Tuff is a multiple-flow, simple cooling unit of densely welded, crystal-rich, quartz-rich ash-flow tuff (Chapin and others, 1978). Detailed petrographic work by Brown (1972), Chamberlin (1974), and Spradlin (1976) has shown that the Hells Mesa Tuff is a quartz latite to rhyolite in mineralogical composition. Tonking (1957) originally named the Hells Mesa Member of the Datil Formation after Hells Mesa in the eastern Bear Mountains. His type locality was in the Puertecito Quadrangle (sec. 31, T. 2 N., R. 4 W.). The Hells Mesa was elevated to formational status by Chapin (1971a). Brown (1972) conducted a detailed study of the Hells Mesa Formation and divided it into the tuff of Goat Spring and the tuff of Bear Springs. Chapin (1974) and Deal and Rhodes (1976) restricted the Hells Mesa Tuff to the lower, crystal-rich, quartz-rich unit, formerly called the tuff of Goat Spring by Brown (1972). Brown's tuff of Bear Springs was renamed the A-L Peak Rhyolite by Deal and Rhodes (1976). K-Ar dates obtained from the Hells Mesa are 30.6 ± 2.8 m.y. (Weber and Bassett, 1963; Weber, 1971), and 32.1 ± 1.5 and 32.4 ± 1.5 m.y. (Burke and others, 1963).

The Hells Mesa Tuff was first studied in the Kelly mining-district of the Magdalena Mountains by Laughlin and Koschmann (1942), although they mistakenly interpreted it to be a rhyolite porphyry sill. Blakestad (1978) has remapped the Kelly mining district and Krewedl (1974) and Osburn (1978) have mapped some of the Hells Mesa Tuff in the south-central and southeastern parts of the Magdalena Mountains, respectively. Based on their mapping, the source of the Hells Mesa Tuff has been determined to be the North Baldy cauldron (see Fig. 20, and Chapin and others, 1978). The Hells Mesa Tuff mapped for this thesis is entirely within the North Baldy cauldron. Exposures of Hells Mesa are cut off to the south by the younger Sawmill Canyon cauldron (see Plates 1 and 2).

The Hells Mesa Tuff is found only in the northwestern portion of this study area (secs. 3, 4, and 5, T. 4 S., R. 3 W., unsurveyed, and secs. 32 and 33, T. 3 S., R. 3 W.) where it covers an area of about 1.5 square miles. Krewedl (1974) reports an angular unconformity between the Hells Mesa Tuff and the Spears Formation in the central Magdalena Mountains, but exposures were inadequate to verify it in this thesis area. The stratigraphic top of the Hells Mesa Tuff is not exposed due to erosion. Other studies outside of the Magdalena Mountains report a thickness of about 600 to 800 feet, but since this study area is within the inferred North Baldy cauldron, the Hells Mesa Tuff may be much thicker. Krewedl (1974) reported a maximum thickness of 3850 feet in the central Magdalena Mountains, but this thickness may be excessive because of unrecognized faulting. Faults are very difficult to recognize in thick, cauldron-facies Hells Mesa Tuff. In this study area, the Hells Mesa probably exceeds 2000 feet in thickness.

The best exposures of the Hells Mesa occur along the road to the Langmuir Laboratory and the gold mine road. Along these roads, the Hells Mesa is usually highly jointed; these joints may be sheet-like in some areas or curved and highly erratic in other areas. The Hells Mesa usually breaks along joints to form sharp, blocky talus. Much of the area is covered by this talus, but occasionally the Hells Mesa forms steep ledges and cliffs.

In hand specimen, the Hells Mesa Tuff is usually white to gray because of strong bleaching and propylitic alteration. Where unaltered, the Hells Mesa is reddish-brown in color (Brown, 1972; Spradlin, 1976). It usually contains 40 to 50 percent phenocrysts of sanidine, plagioclase, quartz and biotite. Quartz often occurs as distinctive "eyes" measuring as much as 4 mm in diameter. the Hells Mesa is usually very pumice poor, although the alteration may make the pumice difficult to see in some areas. In a few places, the Hells Mesa is moderately pumice rich.

Detailed petrographic work on the Hells Mesa has been done by Brown (1972), Chamberlin (1974) and Spradlin (1976). Brown (1972, p. 21-24) reported that the Hells Mesa Tuff (his tuff of Goat Spring) usually contains 40 to 50 percent phenocrysts of broken and partially resorbed crystal fragments. Sanidine varies from 10 to 30 percent of the rock, while plagioclase varies from 10 to 20 percent and averages about 12 percent. Quartz is very scarce in the lower 10 to 20 feet of Brown's Hells Mesa, but it increases to 5 to 15 percent of the rock higher in the section. Biotite comprises about 1 to 4 percent of the rock.

One thin section of the Hells Mesa Tuff was examined from the study area. It contains about 45 percent phenocrysts.

Quartz comprises about 10 to 12 percent of the rock and occurs as subhedral, but deeply embayed phenocrysts ranging in size from 0.3 to 4.0 mm and averaging about 1.8 mm in diameter. Feldspar comprises about 30 percent of the rock. About 65 percent of the feldspar is sanidine, which ranges in size from 0.4 to 4.0 mm in diameter and averages about 0.75 mm in diameter. The rest of the feldspar is plagioclase which has been partially altered to clays and calcite. About 2 to 3 percent biotite occurs as small, euhedral grains, which range from 0.25 to 1.1 mm in diameter. A trace amount of magnetite also occurs in the rock. The matrix has been completely devitrified and altered.

Unit of Hardy Ridge

The unit of Hardy Ridge consists of phenocryst-poor rhyolite lavas; poorly welded, lithic-rich, ash-flow tuffs; and volcaniclastic sedimentary rocks. This unit overlies the Hells Mesa Tuff and is believed to be part of the cauldron fill of the North Baldy cauldron. It was named by Bowring (in preparation) for exposures on Hardy Ridge in the southern Magdalena Mountains. So far, this unit has only been found on Hardy Ridge, and in Sawmill, Ryan Hill and Caronita canyons (all in the southern Magdalena Mountains). These outcrops are probably in the southern portion of the North Baldy cauldron.

In this study area, the unit of Hardy Ridge occurs in southern Ryan Hill Canyon (secs. 25, 26 and 35, T. 4 S., R. 3 W., unsurveyed; and sec. 36, T. 4 S., R. 3 W.). It was mapped as two units: a phenocryst-poor rhyolite lava (Thr), and a group of volcaniclastic sedimentary rocks and welded tuffs (Thrs). The base of this unit is seldom exposed in the study area. However, one small outcrop of Hells Mesa Tuff is exposed in S/2, sec. 36. This outcrop is overlain by the unit of Hardy Ridge. South of this exposure, outcrops of the Hells Mesa Tuff become more abundant as the topographic margin of the Sawmill Canyon cauldron is approached (Osburn, 1979, oral communication).

The unit of Hardy Ridge in this study area (sec. 25, 26, 35 and 36) apparently lies between the topographic rim and the main ring fracture of the Sawmill Canyon cauldron (see Plates 1 and 2). The main ring fracture downfaulted the unit of Hardy Ridge 1000 feet or more, so it is no longer exposed north of that structure. The unit of Hardy Ridge is overlain by the A-L Peak Tuff, which becomes thinner as it approaches the topographic rim of the Sawmill Canyon cauldron.

Rhyolite Lavas (Thr). Most of the unit of Hardy Ridge consists of phenocryst-poor rhyolite lavas. The best exposures of the rhyolite are along the floor of Ryan Hill Canyon. Along the sides of the canyon, the outcrops are poor. There, they usually occur as isolated exposures a few feet in size, which are separated from each other by talus from overlying units. The rhyolite lava has a minimum thickness of about 250 feet, but it may exceed 800 feet in places. Since the base of the rhyolite is not continuously exposed, a maximum thickness cannot be determined. It is overlain by a sequence of sedimentary rocks and welded tuffs (Thrs).

In hand specimen, the rhyolite lava is a pink to gray color. It is usually massive, although occasionally it may be flow banded or brecciated. The rhyolite lava is phenocryst poor; only a few small crystals (secondary quartz ?) can be seen in hand specimens.

In thin section, the rhyolite lava contains about 25 percent spherulitic chalcedony and 10 to 20 percent quartz crystals which are about 0.1 to 1 mm in diameter. These quartz crystals are anhedral and occasionally occur in clusters; part or all of them are probably secondary quartz. The rest of the rock consists of fine-grained (0.02 to 0.1 mm) quartz, chalcedony and sanidine (?).

<u>Sedimentary Rocks and Tuffs (Thrs)</u>. A sequence of volcaniclastic sedimentary rocks and poorly welded tuffs overlies the rhyolite lava in Ryan Hill Canyon. The outcrops of this unit are poor in most places; the best outcrops occur on the east side of Ryan Hill Canyon (SW/4, sec. 25 and sec. 36). There, the better outcrops occur as blocky exposures in ravines where erosion has removed the overlying talus. This unit has an average thickness

of about 50 feet, although the thickness may vary from 0 to 100 feet.

The sedimentary rocks and tuffs are characteristically very thin and discontinuous laterally, so only a general description of the rocks in this unit is given. The sedimentary rocks consist mostly of even, parallel-bedded, poorly sorted, lithic-rich sandstones. Occasionally, conglomerates and breccias occur in this unit. The tuffs are usually gray to green, poorly to moderately welded, and lithic rich. They usually contain about 10 to 20 percent lithic fragments of andesite and rhyolite, 5 to 10 percent quartz phenocrysts, 5 to 10 percent feldspar (mostly sanidine and perthite), and 5 to 20 percent pumice.

A-L Peak Tuff

The A-L Peak Tuff is a composite sheet of densely welded crystal-poor, one-feldspar, rhyolitic ash-flow tuff (Chapin and others, 1978). Deal and Rhodes (1976) named the A-L Peak Rhyolite for a 2000-foot-thick section in the northern San Mateo Mountains. Most workers in the Socorro-Magdalena area now refer to this formation as the A-L Peak Tuff (Chapin and others, 1978). The A-L Peak Tuff is equivalent to the "banded rhyolite" of Laughlin and Koschmann (1942). It is also equivalent to Brown's (1972) tuff of Bear Springs, which is the upper part of Tonking's (1957) Hells Mesa Formation. Brown (1972), Simon (1973), and Spradlin (1976) have presented detailed petrographic descriptions of the A-L Peak Tuff. Chapin and others (1978) divided the A-L Peak Tuff into three members, which from oldest to youngest are the gray-massive member, flow-banded member, and pinnacles member. Smith and others (1976) obtained a fission-track date of 31.8 ± 1.7 m.y. for the A-L Peak Tuff at the type locality.

The A-L Peak Tuff generally contain 2 to 10 percent phenocrysts of sanidine and quartz. The sanidine phenocrysts are usually several times more abundant than the quartz phenocrysts and are found as euhedral to subhedral grains about 1 to 2 mm in length. The quartz phenocrysts are usually small (less than 0.5 mm) and anhedral. The lower gray-massive member of the A-L Peak Tuff is generally light gray and pumice poor. It is overlain by the flow-banded member, which is gray to reddish brown and characterized by abundant, highly welded, lineated pumice. Flow folds are occasionally found in the flow-banded member. The pinnacles member usually contains abundant, non-lineated pumice; however, it may have highly welded, lineated pumice in the Sawmill Canyon cauldron.

Each of the members of the A-L Peak Tuff has been correlated with a major ash-flow tuff eruption associated with cauldron collapse (Chapin and others, 1978). The gray-massive member was previously thought to have caused the initial collapse of the Mt. Withington cauldron (Deal, 1973; Deal and Rhodes, 1976; Chapin and others, 1978). More recent work, however, indicates that the gray-massive member probably came from the Magdalena cauldron (Chapin, 1979, oral communication). The flow-banded member was also erupted from the Magdalena cauldron and is welded to the gray-massive member. The pinnacles member is believed to have erupted from the Sawmill Canyon cauldron. The Sawmill Canyon cauldron contains a section of A-L Peak Tuff which may exceed 3000 feet in thickness, but since the bottom of this tuff is not exposed in most of the cauldron and because of possible concealed faults, this is only an estimate. The pinnacles member is not flow banded in its outflow facies, but the A-L Peak Tuff in the Sawmill Canyon cauldron contains flow-banded, lineated pumice. If the pinnacles member did erupt from the Sawmill Canyon cauldron, then it was hot enough to cause extreme welding and produce flow banding in the cauldron, but not in the outflow facies. The pinnacles and flow-banded members are very similar petrographically, so it is difficult to determine which member filled the Sawmill Canyon cauldron by only examining the rocks in the cauldron.

In this study area, the A-L Peak Tuff is found at the head of Sixmile Canyon (sec. 10, T. 4 S., R. 3 W., unsurveyed) and in Ryan Hill Canyon. Outside the Sawmill Canyon cauldron, the A-L Peak Tuff usually overlies the Hells Mesa Tuff. In this study area, however, the A-L Peak Tuff occurs entirely inside the Sawmill Canyon cauldron, and the base of the A-L Peak Tuff is not exposed except in the southern part of Ryan Hill Canyon (secs. 25, 26 and 36). Here, the A-L Peak Tuff overlies the unit of Hardy Ridge. This area is between the topographic wall and the main ring fracture of the Sawmill Canyon cauldron (see Plates 1 and 2). The A-L Peak Tuff thins as it approaches the topographic margin of the cauldron and is only about 200 to 300 feet thick in section 36. It apparently overlies an unconformity formed inside the topographic wall. Osburn (1979, oral commun.) reports that the unit of Sixmile Canyon (part of the fill of the Sawmill Canyon cauldron) also thins to the south against the topographic wall of the cauldron.

North of the southern ring fracture of the Sawmill Canyon cauldron (Plate 2), the A-L Peak Tuff thickens dramatically. The base of the tuff is not exposed, but the tuff is at least 2000 feet thick less than 1 mile north of the ring fracture. South of the ring fracture, it is usually about 500 feet thick. Further north in Ryan Hill Canyon, the A-L Peak may exceed 3000 feet in thickness.

The A-L Peak Tuff is faulted against younger units on the west side of Ryan Hill Canyon; on the east side, it is overlain stratigraphically by the unit of Sixmile Canyon. The unit of Sixmile Canyon filled the Sawmill Canyon cauldron after the A-L Peak Tuff erupted. Pronounced lateral facies changes occur in the unit of Sixmile Canyon. In the northern part of the canyon, andesite lavas overlie the A-L Peak; whereas further south, rhyolite lavas, sandstones, or thin ash-flow tuffs may overlie it.

At the head of Sixmile Canyon, the A-L Peak Tuff and the unit of Sixmile Canyon are faulted together in a complex manner. This area is on the transverse shear zone (Chapin and others, 1978; Plate 2, this study). It is also close to the northern Sawmill Canyon cauldron margin, so complex structures are likely. Slide blocks emplaced in the Sawmill Canyon cauldron could also account for some of the outcrop complexities. The most likely possibility though, is that these complexities result from complicated normal faulting like that described in the section on structural geology (p. 137). In sixmile Canyon, the A-L Peak Tuff is overlain by a sequence of thin welded tuffs and volcaniclastic sedimentary rocks, which are part of the unit of Sixmile Canyon. These rocks are very similar to the tuffs and sedimentary rocks that overlie the A-L Peak Tuff in Ryan Hill Canyon.

The A-L Peak Tuff is characterized by abundant, closely spaced sheet joints; it is almost impossible to collect a hand specimen free of joints. In the less densely welded zones, the joints are more irregular. In the most densely welded zones, the A-L Peak Tuff commonly breaks both along the foliation and the sheet joints to form small "platelets". In some places, outcrops are largely masked by a covering of these "platelets". The A-L Peak Tuff is exposed moderately well in Sixmile Canyon, but further south in Ryan Hill Canyon, it is often found in isolated, cliffy exposures surrounded by talus.

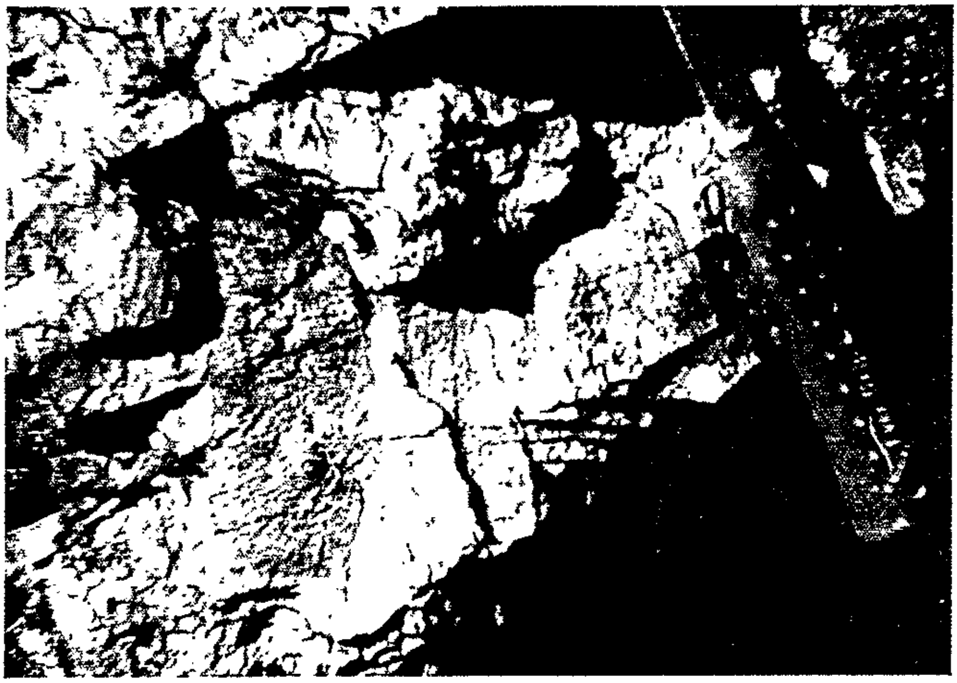
In hand specimen, the A-L Peak Tuff is usually a gray color in northwestern Sixmile Canyon, but it becomes gray to reddish brown further south in Ryan Hill Canyon. The A-L Peak Tuff usually contains about 5 to 6 percent phenocrysts of sanidine and quartz; however, the phenocryst content ranges from 2 to 15 percent. Most of the A-L Peak Tuff contains less than 5 percent lithic fragments, but the upper part of the tuff may contain as much as 10 to 15 percent lithic fragments. These consist mostly of fragments of andesite and rhyolite. The A-L Peak Tuff in Sixmile Canyon is moderately pumice poor, but in the central to southern part of Ryan Hill Canyon, it may contain as much as 25 percent pumice.

In some places, the A-L Peak Tuff is so highly welded that it may resemble a flow-banded rhyolite lava. In these areas, the pumice is also highly lineated and occasionally some primary flow folds can be seen in the tuff. Figures 6 and 7 show some of these features. These structures are thought to be primary in origin; that is, to have formed before the forward motion of the tuff had ceased. Structures of this type in ignimbrites in central Colorado have been described by Chapin and Lowell (in press). They suggest that unusually hot ash flows begin to weld before forward motion ceases and that deposition occurs in a laminar boundary layer. This

Figure 7a. Lineated pumice in the A-L Peak Tuff (SW/4, sec. 10, T. 4 S., R. 3 W., unsurveyed). The lineated pumice is probably a primary structure, that is, it forms in a tuff that begins to weld before the tuff has come to rest. During this stage, the tuff develops a high viscosity and the pumice is stretched in the direction of flow.

Figure 7b. Close-up of lineated pumice in Figure 7a.

Figure 6. Primary flow fold in the A-L Peak Tuff (NW/4, sec. 15, T. 4 S., R. 3 W., unsurveyed). Such folds are occasionally seen in the cauldron-facies A-L Peak Tuff (pinnacles member ?) within the study area (Sixmile Canyon and northern Ryan Hill Canyon); however, they are restricted to the flow-banded member in the outflow facies.



causes the tuff to develop a high viscosity and to behave as a rhyolite lava. During deposition, the pumice is stretched in the direction of movement of the tuff. Continued movement of the tuff may produce shear planes and folds, similar to some structures in rhyolite lavas. The primary folds are aligned with their axes perpendicular to the direction of movement.

Nine measurements on lineated pumice are shown on Plate 1. Most of the symbols on the map represent several measurements taken at the same location. Although there is some variation in the measurements, they average about N 80 E, if one erratic value is omitted. This lineation is almost perpendicular to the other measurements recorded nearby. Bowring (oral communication) reports that in Sawmill Canyon, just west of this study area, the lineations were oriented approximately east-west.

The A-L Peak Tuff has both vertical and lateral variations in the study area. In Sixmile Canyon, it is usually gray, pumice-poor, densely welded, and contains only 1 to 2 percent phenocrysts and 1 to 2 percent lithic fragments. Primary folds are occasionally found in this area, although they are not common.

In Ryan Hill Canyon, The A-L Peak Tuff is less densely welded than in Sixmile Canyon. The Pumice is still lineated, but not as highly as in the Sixmile Canyon area. A few primary folds were seen in the northern part of the canyon, but few, if any, occur in the central to southern part of the canyon. In Ryan Hill Canyon, the A-L Peak matrix is usually gray to reddish brown and the pumice is usually a grayish-red to dark-brown color. The A-L Peak Tuff in Ryan Hill Canyon is slightly more crystal- and lithic-rich than it is in Sixmile Canyon. It usually contains 3 to 8 percent phenocrysts of sanidine and quartz, although it may contain as much as 15 percent phenocrysts in the upper part of the tuff. Two to 15 percent lithic fragments of andesite and rhyolite occur in the A-L Peak Tuff in Ryan Hill Canyon.

On the eastern side of Ryan Hill Canyon, the strata dip to the east, thereby exposing the middle (?) to upper portion of the A-L Peak Tuff and the lower part of the unit of Sixmile Canyon. Unfortunately, much of this, especially in the northern part of the canyon, is largely covered with talus. Although most of this area is unsuitable for taking a measured section, generalizations can be made about the upper A-L Peak based on mapping and the general vertical sequences.

At the top of the section, several thin rhyolite lavas, sandstones and tuffs are interbedded in the A-L Peak Tuff. These rocks are described in the following section (p. 43). Below the lavas, the A-L Peak Tuff contains 4 to 6 percent phenocrysts of sanidine and quartz, and 10 to 15 percent lithic fragments. The percentage of lithic fragments increases gradually from the bottom of the canyon to the base of the rhyolite lava-sandstone interval. Although the tuff is highly welded throughout the section, the degree of welding decreases slightly upwards in the section. The tuff below the rhyolite lava-sandstone interval generally contains three to five times as much sanidine as quartz.

The A-L Peak Tuff above the lava-sandstone interval is similar to the underlying A-L Peak, except that it contains 8 to 10 percent phenocrysts of quartz and sanidine, and the quartz is about as abundant as the sanidine. The tuff in this interval is only moderately to densely welded.

In thin section, the A-L Peak Tuff in Sixmile Canyon is very crystal-poor, containing only about 1 to 2 percent phenocrysts of sanidine and quartz. Sanidine is more abundant than the quartz and usually occurs as subhedral to euhedral grains as much as 1.0 mm in length. The sanidine in this area, as well as all the other areas from which thin sections were made, was partially altered. Some of the sanidines were partially replaced by a low birefringent clay, giving them a cloudy appearance, while others were completely replaced by sericite and other clay minerals. The quartz occurs as small (0.2 mm or less), anhedral grains. Hematite is fairly ubiquitous throughout the thin section, usually occurring as small, bladed or acicular crystals. Pumice occurs in amounts of about 5 percent or less in the most highly welded zones. This pumice has length to thickness ratios greater than 100 to 1; in thin section the pumice rarely exceed 0.3 mm in thickness. Crystals of vapor-phase quartz with a diameter of 0.1 mm, or less, occur in the pumice and along shear planes in the matrix (see Fig. 8).

The A-L Peak Tuff in Ryan Hill Canyon (except that above the rhyolite lava) usually contains 3 to 5 percent phenocrysts of sanidine and quartz. The sanidine has an average length of about 0.75 mm and is euhedral to subhedral. It is between three and five times more abundant than the quartz. The sanidine is always altered to some extent. The quartz has an average diameter of about 0.2 mm and is anhedral. Trace amounts of biotite occur in thin section, and usually a few percent hematite is present as bladed and acicular crystals. This A-L Peak usually contains about 2 to 10 percent lithic fragments, which are probably andesite and rhyolite fragments, and 10 to 15 percent pumice. The amounts of pumice and lithic fragments generally increase upward in the tuff. The pumice and matrix are both devitrified to a fine-grained assemblage of quartz and feldspar; occasional spherulitic and axiolitic structures were seen in the matrix. Outlines of the original glass shards are preserved by hematite dust in the matrix. Most of the thin sections also contain extensive vapor-phase minerals consisting of feldspar and quartz as much as 0.3 mm in diameter. Most of the feldspar has been completely altered to an opaque mixture of clay minerals. Much of the pumice has been replaced by small feldspar crystals which point inward and are surrounded by anhedral quartz.

Figure 8. Photomicrograph of flow-banded A-L Peak Tuff. This sample came from Sixmile Canyon where the tuff is very highly welded and appears flow banded in hand specimen and outcrop. The phenocryst in the photograph is sanidine. The shear planes in the tuff are defined by light-colored vapor-phase minerals. Crossed nichols, 31.25 x.

The uppermost A-L Peak Tuff (that tuff separated from the rest by the rhyolite lava-sandstone interval) contains 8 to 10 percent phenocrysts of quartz and sanidine, and 10 to 15 percent lithic fragments. The main difference between this tuff and the tuff below the rhyolite lavas is that it contains about as much quartz as feldspar. The thin section studied contains about 5 to 6 percent quartz and 3 to 4 percent sanidine. The quartz has an average diameter of about 0.3 mm; the largest quartz phenocryst is 0.7 mm diameter. The sanidine has an average length of about 0.4 mm. The lithic fragments are mostly andesite and rhyolite fragments. Pumice comprises 15 to 20 percent of the rock. The A-L Peak Tuff in this unit is only moderately to densely welded.

<u>Interbedded Rhyolite Lavas, Sandstones, and Tuffs.</u> In the central portion of Ryan Hill Canyon (secs. 22, 23, and 26, T. 4 S., R. 3 W., unsurveyed), a thin sequence of rhyolite lavas (Talr), and sandstones and tuffs (Tals) is interbedded in the upper A-L Peak Tuff. The total thickness of this unit does not exceed 200 to 300 feet; it is probably less than this in most places.

The rocks of this unit are usually very poorly exposed; outcrops are usually small and separated by considerable talus. Because of the poor exposures, it is impossible to trace individual rock units laterally for more than a few tens of feet. However, the general vertical sequence can be established in a few places. As the map shows (Plate 1), the rhyolite lava is underlain and overlain by a sandstone and tuff interval in most places.

The rhyolite lava (Talr) is gray to pink and usually contains 10 to 15 percent phenocrysts. The phenocrysts are mostly quartz and feldspar; in hand specimen, the matrix is aphanitic. One thin section examined contains about 15 percent phenocrysts. About 7 percent of the rock is subhedral, partially corroded quartz with an average diameter of about 0.5 mm; the largest quartz phenocryst is about 1.5 mm in diameter. This rock contains two types of feldspar. About 3 percent of the rock is perthite, with an average diameter of 0.6 to 0.7 mm. Also, about 2 percent of the rock consists of a phenocryst that has been replaced by clay minerals and is too altered to identify. About 2 percent biotite (largely replaced by hematite) is present in the rock. The matrix consists mostly of fine-grained (0.1 mm, or less) cherty and spherulitic quartz, feldspar (sanidine ?), and chalcedony. Also hematite dust is scattered through the matrix.

The sandstone and tuff unit (Tals) consists of a heterogeneous mixture of poorly welded, lithic-rich tuffs, and interbedded sandstones. The sandstones are mostly grayish green, medium grained, lithic rich, feldspar rich and moderately to poorly sorted. The tuffs are generally brown to pink and contain 5 to 10 percent phenocrysts of feldspar and quartz, and 10 to 25 percent lithic fragments (mostly andesite). The tuffs are moderately to poorly welded and frequently pumice rich.

Unit of Sixmile Canyon

The unit of Sixmile Canyon is a thick sequence of andesite and rhyolite lavas, ash-flow tuffs, and volcaniclastic sedimentary rocks. The rocks in this unit undergo rapid lateral facies changes; in some places, thick andesite lavas interfinger with thick rhyolite lavas. Krewedl (1974) named the Sixmile Canyon andesite after some outcrops in the heads of Sixmile and South Canyons. This name was changed to the unit of Sixmile Canyon by Osburn (1978). Krewedl (1974) also mapped a unit in the head of Sixmile Canyon which he called the Sawmill Canyon Formation. Krewedl's Sawmill Canyon Formation consists mostly of A-L Peak Tuff, and to a lesser extent, of the unit of Sixmile Canyon (as mapped for this thesis). Krewedl's South Baldy Peak andesite is also included in the unit of Sixmile Canyon. The unit of Sixmile Canyon has not yet been dated, but the underlying and overlying units have been dated at 31.8 m.y. (A-L Peak Tuff) and 26.3 m.y. (tuff of Lemitar Mountains).

The unit of Sixmile Canyon overlies the A-L Peak Tuff and is part of the cauldron fill of the Sawmill Canyon cauldron. So far, it has not been found outside of the cauldron, but rocks of similar appearance and stratigraphic position are present in the Magdalena cauldron (Chapin, oral communication).

The northern ring fracture of the Sawmill Canyon cauldron transects the northwestern portion of this study area (Plate 2). It is a near-vertical contact between the Hells Mesa Tuff and the unit of Sixmile Canyon. Part of the northern cauldron margin represents a depositional contact along the topographic rim and part of it is the ring fracture (Plate 2). Later faulting has reactivated the cauldron margin in some places; part of the cauldron margin has also been uplifted in a horst block.

The southern ring fracture of the cauldron (Plate 2) apparently was not reactivated by faulting after the deposition of the unit of Sixmile Canyon, since that unit continues unfaulted over the ring fracture. Mapping by Osburn (in progress) indicates that the unit of Sixmile Canyon pinches out against the topographic cauldron margin on the south side of the cauldron. The unit of Sixmile Canyon has a maximum thickness of about 2500 feet.

In some places, the strikes and dips in the A-L Peak Tuff in Ryan Hill Canyon differ from those in the overlying unit of Sixmile Canyon. This could indicate that there is an angular unconformity between the two units; however, faulting is probably responsible for most of the difference in the strikes and dips. The unit of Sixmile Canyon is overlain by the tuff of Lemitar Mountains. There is no apparent angular unconformity between the tuff of Caronita Canyon (upper part of the unit of Sixmile Canyon) and the overlying tuff of Lemitar Mountains, although there is an erosion surface between the two.

Lower Interval of Tuffs, Sandstones and Lavas. A group of tuffs, sandstones and lavas overlies the A-L Peak Tuff in most of the study area. At the head of Sixmile Canyon, this group consists entirely of tuffs and sandstones, and was mapped as Txt. In southern Ryan Hill Canyon, this group consists of rhyolite lavas, tuffs and sandstones. The rhyolite lava (Txr_1) overlies, and is overlain by, a tuff-sandstone sequence (Txt_1 and Txt_2). The tuffs and sandstones in Txt, Txt_1, and Txt_2 typically consist of thin (5- to 20-ft) intervals of interbedded, poorly welded tuffs and sandstones. There are several different tuffs in these units, but most of these are local tuffs that were only seen in a few places. The Txt_2 unit also contains a thin andesite lava.

The complex outcrop patterns in the head of Sixmile Canyon are interpreted to be caused mostly by faulting; however, some of the unit of Sixmile Canyon (Txt) could have been emplaced as slide blocks in the andesite lava (Txa_1). This area is discussed further in the section on structural geology.

The Txt_1, Txr_1, and Txt_2 units all occur in southern Ryan Hill Canyon (secs. 25, 26, and 36, T. 4 S., R. 3 W., unsurveyed). The Txt_1 unit only crops out on the eastern slope of Ryan Hill Canyon. It is a thin unit that is frequently covered with talus. The best exposures occur in ravines where erosion has removed the overlying talus. A rhyolite lava (Txr_1) overlies the tuffs and sandstones.

of the Txt_1 unit. This lava is in turn overlain by another tuff and sandstone unit (Txt_2). The rhyolite lava and Txt_2 units are fairly well exposed on the eastern rim of Ryan Hill Canyon and in the upper reaches of Caronita Canyon. The rhyolite lava occurs as low, blocky to cliffy outcrops, while the Txt_2 unit occurs as low, rounded outcrops.

The tuffs in Txt, Txt_1 and Txt_2 exhibit a wide variety of characteristics in hand specimens. In general, they are lithic-rich, moderately crystal-rich and poorly welded. In thin section, most of these tuffs contain 5 to 15 percent quartz and 5 to 10 percent feldspar (mostly sanidine and some perthite). They also contain 5 to 25 percent lithic fragments, which consist mostly of andesite and lesser amounts of rhyolite. Also, a few lithic fragments are fine-grained silicic fragments which consist mostly of anhedral quartz grains. The tuffs are usually moderately pumice rich; the pumice may comprise 10 to 40 percent of the rock.

The sandstones usually consist of even, parallel beds, although occasionally, cross-bedding was observed. They are mostly medium- to coarse-grained (0.25 mm) sandstones, consisting of angular grains of quartz, feldspar and lithic fragments. The proportion of these grains may vary, but all the sandstones are lithic rich and contain 10 to 50 percent lithic fragments. One thin section of the sandstone contains 40 to 50 percent lithic fragments, 25 to 30 percent quartz, 10 percent sanidine, 5 percent plagioclase and 5 percent opaque minerals (probably magnetite). The sandstone is poorly sorted and the average grain diameter is about 0.9 mm. A number of different types of lithic fragments were observed. The most common types are fine-grained silicic fragments which are probably rhyolites. Lesser amounts of andesite or latite fragments occur in the sandstone.

The rhyolite lava (Txr_1) in southern Ryan Hill Canyon is pink to white and phenocrysts poor. Occasionally, the rhyolite is flow banded or brecciated, but usually it is massive and aphanitic. A few crystals can be seen in hand specimens, but these are probably secondary quartz.

Andesite Lavas (Txa_1). A thick sequence of andesite flows crops out in the upper portions of Sixmile, South and Sawmill Canyons. Krewedl (1974) included the andesites in both his Sixmile Canyon andesite and South Baldy Peak andesite, although there is no difference between the two units. Osburn (1978) included the andesites in the unit of Sixmile Canyon.

These andesite lavas (Txa_1) probably interfinger with the sanidine rhyolite lava (Txr_2) at the head of Ryan Hill Canyon (sec. 15, T. 4 S., R. 3 W., unsurveyed). Most of the unit of Sixmile Canyon has been removed by erosion in this area. However, Osburn (1978) and Bowring (in preparation) report that the andesite lavas probably interfinger with the rhyolite lavas in their study areas. There is a thin layer of andesite lava beneath the sanidine rhyolite lava on the northeastern side of Ryan Hill Canyon; a thin andesite lava flow (Txa_2) overlies the rhyolite lavas in Chavez Canyon.

In a few places, the andesite lavas (Txa_1) may overlie the A-L Peak Tuff; however, in most places the andesite lavas overlie tuffs and sandstones mapped as Txt for this thesis. The andesite lavas are probably about 2000 feet thick in the Timber Peak area; here, they are overlain by tuffs and sandstones which are in the upper part of the unit of Sixmile Canyon.

The best outcrops of the andesite lavas occur on the ridge north of Timber Peak. Here, the andesites usually break along closely spaced joints to form sharp, blocky outcrops. On the sides of this ridge, the andesites are frequently covered with talus. They are usually well exposed on the ridges at the head of Sixmile Canyon (east of Timber Peak).

Osburn (1978) divided the andesite lavas into three types: 1) dense, aphanitic; 2) pyroxene-porphyritic (La Jara Peak-like); and 3) plagioclase-porphyritic. Rock types similar to these were recognized in this study area. The pyroxene-porphyritic lavas were mapped as Txa_3 for this study. The andesites in Txa_1 consist mostly of dense, aphanitic and plagioclase-porphyritic lavas. Also, a few pieces of a very coarse-grained (2 cm or more), porphyritic lava were seen in talus, although no definite outcrops of this unit were observed. Because the andesites in this study area occur on the dip slope of Timber Peak, and because of faulting, it is difficult to determine the vertical distribution of the different andesite types.

The most abundant rock type in the study area is a gray-to-purple, aphanitic andesite. This rock is often dense and massive, but occasionally, it is brecciated or contains moderately abundant to abundant vesicles. The vesicles are frequently filled with calcite, quartz or celadonite. Occasionally, this rock type may contain 1 to 3 percent small (1 to 2 mm) phenocrysts of feldspar, or 1 to 4 percent small (about 1 mm) phenocrysts of magnetite.

In thin section, this rock consists mostly of fine-grained plagioclase with an average length of about 0.1 mm. Three to 4 percent phenocrysts of magnetite were also observed in one thin section. These phenocrysts are euhedral and have an average diameter of 1 mm. Ten to 20 percent of the thin section consists of small opaque minerals (magnetite ?). They have an average length of about 0.02 to 0.03 mm. This rock generally has a trachytic texture.

Second in abundance are the plagioclase-porphyritic andesites. These lavas contain 20 to 50 percent plagioclase. Most of the plagioclase phenocrysts are about 2 to 3 mm in length and are frequently altered to white, chalky clays. Differences in mineralogy indicate that there probably is more than one type of plagioclase-porphyritic andesite. One thin section examined contains about 40 percent phenocrysts of plagioclase with an average length of about 1.9 mm. The matrix consists mostly of plagioclase with an average length of about 0.1 mm. About 30 percent of the matrix consists of opaque minerals. Some of these minerals consist of hematized mafic minerals (probably pyroxene and biotite) and some are probably magnetite. The size of the opaque minerals varies from about 0.01 to 0.25 mm. Another thin section examined contains about 20 percent phenocrysts of plagioclase with an average diameter of about 2.0 mm. It also contains about 15 percent opaque minerals with an average length of about 1.0 mm. These minerals probably consist mostly of pyroxene which has been partially altered to hematite. Some of the opaque minerals may also be magnetite.

The very-coarse-grained, porphyritic lava was found only at one locality (NW/4, SW/4, sec. 4, T. 4 S., R. 3 W., unsurveyed). It consists of about 20 percent plagioclase(?) phenocrysts which range from about 1 to 4 cm in length. The plagioclase phenocrysts are altered to a yellowish-white, chalky clay. The matrix is purple and contains 5 to 10 percent pyroxene (?) which is 2 to 3 mm in length.

In a few places, coarse andesitic breccias crop out. The breccias are comprised of clasts averaging 6 inches to a foot in diameter set in a finer-grained (silt to sand size), purple-to-gray matrix. These rocks are probably laharic breccias deposited along the walls of the Sawmill Canyon cauldron.

Sanidine Rhyolite Lavas (Txr_2). Brown to pinkish-gray, porphyritic, rhyolite lavas with sanidine phenocrysts as large as 1 cm, crop out over a large part of the study area. These lavas were mapped as Txr_2. They were first described by Osburn (1978) who mapped a part of this unit in Sixmile Canyon.

The sanidine rhyolite lavas cover about 3 square miles in the study area and cap the northeastern rim of Ryan Hill Canyon (Fig. 9). The rhyolite lavas are also exposed in the upper portions of Chavez, Caronita, Molino, and Madera Canyons. These rhyolite lavas have been mapped by Bowring (in preparation) and Roth (in progress) in Sawmill Canyon. South of this study area, Osburn (in progress) reports that the rhyolite lavas appear to pinch out against the southern topographic rim of the Sawmill Canyon cauldron.

The rhyolite lavas are probably about 1100 to 1200 feet thick on the eastern rim of Ryan Hill Canyon. Further south, in Caronita Canyon, the rhyolite lavas may exceed 2000 feet in thickness. However, unrecognized faulting may be partially responsible for this apparent thickness.

Where the basal contact is exposed, the sanidine rhyolite lavas overlie the tuffs, sandstones and rhyolite lavas that comprise the units Txt_1, Txt_2, and Txr_1. On the northeastern slope of Ryan Hill Canyon, the sanidine rhyolite may also overlie the A-L Peak Tuff, or andesite lavas from the Txa_1 unit; however, the contact is always covered with talus. The sanidine rhyolite lava is usually overlain by either sedimentary rocks of the Txs_1 unit or andesite lavas of the Txa_2 unit in Chavez and Caronita Canyons. At the head of Molino and Madera Canyons, the sanidine rhyolite may be overlain by either the upper or lower members of the tuff of Caronita Canyon. The sanidine rhyolite lava probably interfingers to the north with andesite lavas of the Txa_1 unit.

The sanidine rhyolite lavas may form bold, prominent ridges, but they are frequently covered with small blocky talus, as on the northeastern rim of Ryan Hill Canyon (Fig. 9). Occasionally, the rhyolite lavas display excellent flow banding (Fig. 10). This flow banding is not displayed everywhere and, in general, becomes more prevalent towards the south. Secondary quartz and chalcedony which formed along shear planes in the rhyolite lava enhance the flow banding.

In hand specimen, the rhyolite usually contains 15 to 40 percent phenocrysts of sanidine, quartz and biotite. About 15 to 30 percent of the rock is sanidine, which is usually about twice as abundant as quartz. Most of the sanidine consists of euhedral to subhedral phenocrysts which have an average length of about 2 to 3 mm, although some of them are as long as 1 cm. The sanidine is usually

Figure 9. View looking northeast at the eastern rim of Ryan Hill Canyon. The rim is capped by a sanidine rhyolite lava (Txr$_2$) that dips to the east and forms a prominent hogback. Talus, derived mostly from the rhyolite lava, covers much of the eastern slope of Ryan Hill Canyon. This talus completely covers the rhyolite and underlying units on the upper slope of the canyon. Figure 19 presents a better view of the large, active talus deposit on this slope. Molino Peak is on the far right side of the photograph.

Figure 10. Example of flow banding in the sanidine rhyolite lava (Txr_2) in Chavez Canyon (NW/4, sec. 25, T. 4 S., R. 3 W., unsurveyed). The area where this photograph was taken contains the most spectacular flow banding in the sanidine rhyolite lava. North of this area, the flow banding is poorly developed or absent. South of this area, the flow banding is only sporadically developed. Flow folds and erratic strikes and dips are common.

altered to a pink or white color, although occasionally, they are clear and display chatoyancy. The quartz usually occurs as small, anhedral phenocrysts with an average diameter of about 0.5 mm. The rhyolite also contains 1 to 3 percent biotite. Two to 3 percent lithic fragments of brown, fine-grained andesite occur in most of the rhyolite lavas. The matrix is usually aphanitic and dense in hand specimen.

There may have been two or more lava flows in this unit. The rocks in the lower part usually contain 15 to 25 percent phenocrysts, while the rocks in the upper part contain 25 to 35 percent phenocrysts. The sanidine/quartz ratio is always about 2 to 1, but the rock contains about 1 percent biotite at the base and 4 percent at the top of the unit.

Thin sections of the sanidine rhyolite lava contain between 20 and 35 percent phenocrysts which consist of sanidine, quartz and biotite. Sanidine, which comprises about 10 to 20 percent of the rock, is usually about twice as abundant as quartz. The sanidine is euhedral and has an average length of about 1.1 mm; the maximum length observed in thin section is about 3.3 mm. The quartz is anhedral to subhedral and has an average diameter of about 0.5 mm; the maximum diameter is about 1.0 mm. Some of the quartz is slightly embayed. Biotite, with an average diameter of 0.3 mm to 0.4 mm, comprises 1 to 4 percent of the rock. Most of the biotite is a deep red color. A trace to 1 percent opaque minerals (probably magnetite) also occurs in the rhyolite.

The matrix consists mostly of chalcedony, and fine-grained quartz and sanidine (?). Some rocks contain spherulitic structures in the matrix. Layers of quartz and chalcedony define the flow banding in these rocks. These minerals probably formed along shear planes in the rhyolite.

Andesite Lavas (Txa$_2$). A thin sequence of andesite lavas overlies the sanidine rhyolite lavas in Chavez and Caronita Canyons. In a few places, these andesite lavas are overlain by sedimentary rocks (Txs$_1$); elsewhere, they are overlain by the tuff of Caronita Canyon. A complete section of these lavas is not exposed; however, the total thickness of the lavas probably does not exceed 30 to 40 feet. The lavas are always partially to completely covered with talus derived from the overlying tuff of Caronita Canyon.

In hand specimen, the andesite lavas are brownish gray, dense to vesicular and fine grained. The vesicles are usually filled with quartz, opal or celadonite. The andesites usually contain 1 to 3 percent small (less than 1 mm) phenocrysts of feldspar (probably plagioclase). The matrix has an aphanitic texture.

Sandstones and Siltstones (Txs$_1$). A thin sequence of sandstones and siltstones crops out in Caronita Canyon (sec. 31, T. 4 S., R. 2 W.) and on Timber Peak. In Caronita Canyon, this unit overlies an andesite lava (Txa_2) and is overlain by the tuff of Caronita Canyon. This unit is 50 feet thick or less in Caronita Canyon and is exposed in only a few elongate outcrops. White to red, very thinly bedded (1 cm or less) siltstones comprise most of the unit in Caronita Canyon. Pieces of red, medium- to coarse-grained sandstone were also observed in talus in areas where this unit was covered.

This unit also occurs in a few outcrops on Timber Peak, where it has a maximum thickness of about 150 feet. The best outcrops are on the north side of Timber Peak. Here, this unit consists mostly of greenish-gray, poorly bedded siltstones and sandstones. A few coarser grained rocks (mostly sedimentary breccias) also occur on Timber Peak. The clasts in this breccia consist mostly of andesite fragments.

Tuff of Caronita Canyon. The tuff of Caronita Canyon is a multiple-flow, simple cooling unit of ash-flow tuff. It consists of a lower member of poorly to densely welded, crystal-poor, moderately lithic-rich, andesitic (in mineralogy) tuff and an upper member of moderately to densely welded, crystal-rich, rhyolite ash-flow tuff. Good exposures of these tuffs can be found in Caronita and Chavez Canyons (sec. 25, T. 4 S., R. 3 W., unsurveyed; and secs. 30 and 31, T. 4 S., R. 2 W.). The tuff of

Caronita Canyon is equivalent to part of the T_6t tuffs mapped by Osburn (1978) in Sixmile and South canyons. Osburn's T_6t tuffs also included some other tuff units. The tuff of Caronita Canyon has also been mapped by Bowring (in preparation) and Roth (in progress) in Sawmill Canyon. Osburn (oral communication) reports that this unit pinches out south of this study area against the southern topographic rim of the Sawmill Canyon cauldron.

The tuff of Caronita Canyon is widely distributed throughout the western half of the study area. A small exposure of this unit occurs on Timber Peak. Further south, larger exposures occur on Italian Peak and on the western side of Ryan Hill Canyon. Most of the eastern slope of Italian Peak consists of the upper member of the tuff of Caronita Canyon. This tuff covers about 1 square mile in Chavez and Caronita Canyons.

The thickness of the tuff of Caronita Canyon is variable throughout the study area. It is about 200 feet thick on Timber Peak, but it may be almost 1000 feet thick on Italian Peak. These differences in thickness are probably due, in part, to differences in elevation of the surface on which the tuff of Caronita Canyon was deposited. There are also differences in the relative thicknesses of the upper and lower members. In parts of the upper reaches of Madera Canyon, the lower member is missing; while in parts of Chavez Canyon, the lower member may be 500 to 600 feet thick.

On Timber Peak, the tuff of Caronita Canyon overlies sedimentary rocks and tuffs in Txs_1. Further south, the tuff of Caronita Canyon may overlie sedimentary rocks in Txs_1, andesites of Txa_2, or the rhyolite lavas of Txr_2. The tuff of Caronita Canyon is overlain by sandstones (Txs_2) in some places; these sandstones consist mostly of material eroded from the upper member. Where the sandstones are absent, the tuff of Caronita Canyon is overlain by either the tuff of Lemitar Mountains or andesite lavas (Txa_3). The andesite lavas occur mostly on Timber Peak and the ridge between Timber Peak and Italian Peak.

Lower Member. The lower member of the tuff of Caronita Canyon is an andesite in mineralogical composition. It contains 3 to 20 percent phenocrysts of plagioclase, biotite and magnetite. The degree of welding increases from a poorly welded base to a densely welded top. The mineral proportions are rather constant throughout the lower member, but the phenocryst content increases upward in the tuff as the degree of welding increases. This member can be divided into three zones based on the degree of welding, phenocryst content and color.

The basal zone of the lower member is brown to pink, poorly welded and usually contains 4 to 5 percent phenocrysts, 5 to 10 percent lithic fragments, and 10 to 20 percent pumice. This basal zone crops out poorly. The best exposures are in stream beds; elsewhere, this zone is usually covered with talus from the overlying, more densely welded zones. This zone is usually about 50 feet thick, or less, although it may be as much as 200 feet thick east of Molino Peak and in parts of Caronita Canyon. The poor exposures of this zone make it difficult to obtain an accurate thickness. This basal zone is frequently missing from the lower member.

The middle zone of the lower member is gray to brown, moderately welded and contains 5 to 10 percent phenocrysts, 5 to 20 percent lithic fragments and 5 to 10 percent pumice. This zone usually crops out moderately well, and forms low, angular outcrops which occasionally form low ledges. It breaks along joints to form angular talus fragments. This zone is usually 50 to 200 feet thick where exposed.

The upper zone is brick-red, densely welded, and contains 10 to 20 percent phenocrysts, about 10 percent lithic fragments, and 15 to 25 percent pumice. The pumice is usually a darker red color than the matrix. The upper zone is usually the best exposed of the three zones and frequently forms ledgy or cliffy outcrops. It breaks along joints to form sharp, angular talus fragments. The upper zone is always present when the lower member is exposed; whereas, the underlying zones are not always present (or not exposed). The upper zone is usually 50 to 100 feet thick, although occasionally, it may be as much as 250 feet thick.

In thin section, the lower member of the tuff of

Caronita Canyon contains 2 to 20 percent phenocrysts of plagioclase, biotite and magnetite. It also contains traces of sanidine, quartz and clinopyroxene. Usually, about 70 percent of the phenocrysts are plagioclase (about An_{48}; Michel-Levy method, 9 grains). The plagioclase is euhedral to subhedral and has an average length of 0.9 mm. Biotite is second in abundance and usually makes up 15 to 25 percent of the phenocrysts. Biotite is usually euhedral and has an average length of 0.75 mm. Magnetite may comprise as much as 10 percent of the phenocrysts (2 percent of the rock). Quartz is present in trace amounts in the lower half of the lower member, but it may comprise 5 to 10 percent of the phenocrysts in the uppermost 10 to 20 feet of the lower member. Trace amounts of sanidine and clinopyroxene also occur in the rock.

The lower member also contains 2 to 20 percent lithic fragments. These consist mostly of andesite fragments and fine-grained silicic rock fragments. In hand specimen, brown, fine-grained lithic fragments with closely spaced (a few mm or less) parallel bands were seen. These may be equivalent to some of the fine-grained silicic fragments observed in thin section.

The pumice has been extensively replaced by cherty quartz and spherulitic chalcedony. In most of the thin sections examined, the matrix is devitrified and occasionally contains spherulites. However, one thin section from a vitrophyre collected by G.R. Osburn at Torreon Springs (section 8, T. 5 S., R. 2 W.) consists mostly of fresh glass.

Upper Member. The upper member of the tuff of Caronita Canyon is a white to gray, densely welded, crystal-rich, rhyolite ash-flow tuff. Where observed, the base of the upper member is welded to the top of the lower member. The contact between the upper and lower members is gradational through a stratigraphic interval of about 10 to 20 feet, in which the tuff gradually becomes more phenocryst rich and the color changes from red in the lower member to gray or white in the upper member. The lower portion of the upper member may be light brown in places, but above the basal portion, the upper member becomes gray to white. At the base of the transition interval, the lower member contains a few percent quartz and sanidine. The quartz in this interval is frequently very large (as much as 4 mm in diameter) and conspicuous, even in hand specimens. Upward in the transition interval, quartz and sanidine becomes more abundant, while the plagioclase content decreases.

The upper member usually crops out very poorly in Ryan Hill Canyon. There, the upper member weathers to large boulders (1 meter or more in diameter) that tend to cover the outcrops. The outcrops that do occur are usually low and somewhat rounded. In Chavez and Caronita Canyons, and around Molino Peak, the upper member usually forms good outcrops along the crests of ridges and on the hilltops. There, the upper member occurs as rounded to blocky outcrops. On the sides of these ridges and hills, the upper member is only partially exposed or is covered with talus.

The upper member of the tuff of Caronita Canyon contains 40 to 55 percent phenocrysts of sanidine, quartz and biotite. The total phenocryst content increases from 35 to 40 percent at the base to about 55 percent at the top of the unit. However, the mineral proportions are fairly constant throughout the upper member. Sanidine is the most abundant phenocryst and quartz is second in abundance. The base of the upper member contains about 20 percent sanidine and 15 percent quartz, while the top contains about 30 percent sanidine and 20 to 25 percent quartz. The sanidine occasionally displays chatoyancy in hand specimens. The quartz is distinctive because of its large size (as much as 6 mm diameter) and because it frequently occurs as euhedral, dipyramidal crystals. The upper member also contains 2 to 4 percent biotite. Most hand specimens also contain 1 to 2 percent small lithic fragments, consisting mostly of red andesitic (?) material. The upper member contains 5 to 10 percent pumice at the base and 10 to 15 percent pumice at the top. This pumice is white to gray and crystal poor.

In thin section, the sanidine is subhedral and ranges from 0.15 to 3.5 mm in length. The quartz is euhedral to subhedral and occasionally embayed. It has an average diameter of 1.6 mm, but the maximum diameter observed in thin section is 4.0 mm. Two to 4 percent biotite and 1 to 2 percent magnetite occur in the rock. The biotite has an average length of about 0.4 mm. The matrix was devitrified in all of the thin sections examined.

Sandstones (Txs_2). Overlying the tuff of Caronita Canyon is a 20- to 80-foot interval of finely laminated to cross-bedded sandstone. This sandstone was mapped by Osburn (1978) in Sixmile Canyon. It also occurs on Timber Peak and was found in talus on the western side of Ryan Hill Canyon, although no outcrops were found. East of Ryan Hill Canyon, it occurs in scattered outcrops in Caronita and Chavez Canyons, and in the upper reaches of Molino and Madera Canyons. The sandstone consists mostly of detritus derived from the underlying upper member of the tuff of Caronita Canyon; in many places, it consists mostly of large, euhedral quartz grains similar to the quartz phenocrysts in the underlying tuff. The sandstone unit is usually 20 to 50 feet thick, but in a few places it may be as much as 80 feet thick.

The sandstone often crops out in ledgy slopes. Usually, the sandstones have even, thick bedding (0.1 to 1.0 m.) and fine to very fine (0.1 to a few mm.), planar, parallel laminations. A few outcrops containing coarse-grained sandstone display planar cross-bedding. In hand specimen, the sandstone is usually brownish gray to gray. It consists mostly of poorly to moderately sorted, fine- to coarse-grained quartz and feldspar in a red to gray matrix. The sandstone usually contains subequal amounts of quartz and feldspar, although quartz usually predominates over feldspar. It usually contains a few percent magnetite (?) grains and rock fragments.

Andesite Lavas (Txa$_3$). A sequence of andesite lavas overlies the tuff of Caronita Canyon on Timber Peak and on the ridge between Timber Peak and Italian Peak. The andesite lavas apparently pinch out to the south; they do not occur east of Italian Peak in secs. 27 and 34, and they were not seen in Caronita and Chavez Canyons. However, a thin sequence of andesite lavas overlies the tuff of Caronita Canyon north of Molino Peak. The lavas are about 150 feet thick on Timber Peak. South and east of Timber Peak, they thin to about 50 feet in thickness. Occasionally, the andesites form ledgy outcrops, but usually they form talus-covered slopes. In many places south of Timber Peak, these andesites are only seen in talus and colluvium. The rocks in this unit consist of greenish-gray to reddish-gray andesites and basaltic andesites. The andesites are dense and fine grained, while the basaltic andesites are dense to vesicular and contain as much as 10 percent hematized pyroxene (?) phenocrysts in an aphanitic matrix.

Tuff of Lemitar Mountains

The tuff of Lemitar Mountains is a multiple-flow, compositionally zoned, simple to compound cooling unit of densely welded rhyolite tuff (Chapin and others, 1978). The outflow sheet can be divided into a crystal-rich upper member and a more crystal-poor lower member. The Socorro cauldron is believed to be the source for the tuff of Lemitar Mountains (Chapin and others, 1978).

Detailed petrographic work on the tuff of Lemitar Mountains has been done by Simon (1973), Osburn (1978) and Chamberlin (in preparation). Simon (1973) studied samples from the Crouch drill hole in the Silver Hill area (he misidentified the unit as tuff of La Jencia Creek due to its presence in a paleovalley). Osburn (1978) described the tuff of Lemitar Mountains in the southeastern Magdalena Mountains, just north of this study area. He measured and described a stratigraphic section of the lower, moderately crystal-poor member in Sixmile Canyon (sec. 7, T. 4 S., R. 2 W.). Chamberlin (in preparation) described a section in the Lemitar Mountains, after which the tuff is named. K-Ar dates of 26.3 ± 1.0 m.y., 27.0 ± 1.1 m.y., and 28.8 ± 0.7 m.y. have been obtained from the tuff of Lemitar Mountains (Chapin, unpub. data). All are biotite dates; the average is 27.4 m.y.

The tuff of Lemitar Mountains is widely distributed throughout the study area. It caps Timber Peak and occurs in scattered outcrops on the ridge trending south from Timber Peak. It also occurs in relatively continuous outcrops throughout the central portion of the study area.

The tuff of Lemitar Mountains is about 500 feet thick on Timber Peak (erosional top); east of Italian Peak (sec. 35, T. 4 S., R. 3 W., unsurveyed), it is about 1400 to 1500 feet thick. Throughout the central part of the study area, the tuff of Lemitar Mountains is about 1500 to 1800 feet thick. Chamberlin (oral communication) reports that it may be as much as 2900 feet thick in the northern Chupadera Mountains. However, Osburn (1978) reports that the tuff is only 650 feet thick at the Tower Mine (NW/4, NW/4, sec. 7, T. 4 S., R. 1 W.).

The relative thicknesses of the upper and lower members is also variable over the study area. East of Italian Peak, the lower member varies from about 200 to 400 feet in thickness, while the upper member is about 1100 to 1200 feet thick. Further east, in Chavez Canyon, the lower member varies from about 300 to 800 feet thick and the upper member is about 1100 to 1200 feet thick.

These thickness variations can be explained in two ways. First, the tuff of Lemitar Mountains could have partially filled an irregular depression remaining after the Sawmill Canyon cauldron formed. The tuff of Lemitar Mountains is usually about 400 feet thick in the outflow facies in the Lemitar Mountains (Chamberlin, 1979, oral communication), compared to an average thickness of about 1500 feet in the study area. Second, the slight increase in thickness from west to east could represent a thickness increase across a hinge zone along the western margin of the Socorro cauldron if it is of the trap-door type (Plate 2).

The tuff of Lemitar Mountains usually overlies the tuff of Caronita Canyon; however, in a few places, it overlies andesite lavas of the Txa_3 unit (on Timber Peak and on the ridge south of Timber Peak) or the sanidine rhyolite lava (north of Molino Peak). In the central part of the study area, the tuff of Lemitar Mountains is overlain by either basaltic andesites (Tba_1) or the tuff of South Canyon. The basaltic andesites apparently pinch out to the south (in sec. 33, T. 4 S., R. 2 W.). Further west, in secs. 35 and 36, T. 4 S., R. 3 W., it is overlain at different locations by one of the following: tuffs and sandstones (Tt_1), rhyolite lavas (Tr_1), the tuff of South Canyon, or mudflow deposits of the Popotosa Formation (Tpl). This variation in overlying units was probably caused by topographic depressions on top of the tuff of Lemitar Mountains. The Popotosa Formation also overlies a regional unconformity formed on the older Oligocene rocks.

Lower Member. Osburn (1978) divided the lower member of the tuff of Lemitar Mountains into three zones on the basis of outcrop pattern, degree of welding, total phenocryst content, pumice and lithic content, and color. In general, the lower member avarages 13 percent phenocrysts of sanidine, quartz and biotite. The phenocryst morphologies and sizes are fairly constant throughout the lower member (Osburn 1978, Fig. 9).

The basal zone of the lower member is light gray to brown in color, poorly to moderately welded, moderately lithic rich, and pumiceous. East of Italian Peak (secs. 27 and 34, T. 4 S., R. 3 W., unsurveyed), the basal zone is very poorly welded and thus forms rounded to very irregularly shaped outcrops. On Timber and Molino Peaks, the poorly welded tuff is absent or scarce, and the basal zone is usually gray to white and moderately welded. There, it forms moderately steep slopes and weathers to angular talus fragments. The basal zone usually contains 10 to 15 percent phenocrysts of sanidine and quartz, and 5 to 10 percent lithic fragments. However, one thin section of the very poorly welded tuff only contains 5 to 8 percent phenocrysts. Osburn reported trace amounts of plagioclase in the lower zone; however, none was observed in thin sections from the lower zone in this study area. This basal zone is usually 50 to 100 feet thick, although it may be absent or very thin in Chavez Canyon. It may be as much as 100 to 150 feet thick on Molino Peak.

Above this basal zone, the lower member is grayish red to reddish brown. Outcrops are often steep and cliffy and they may appear brecciated; the tuff breaks to form sharp, angular fragments. This second zone has a gradational contact with the basal zone. It usually contains 8 to 12 percent phenocrysts of quartz and sanidine, and minor biotite. This zone usually contains a few lithic fragments, and pumice is not prominent.

The third and upper zone of the lower member often has a streaked appearance produced by an increase in the size and abundance of light-gray, highly compressed pumice and by darkening of the matrix. See Osburn (1978, p. 38-41) for photographs and a description of the mineralogy of this zone. The phenocryst content of this zone increases from 8 to 15 percent upward in the section. The rock has an average quartz content of 2.5 percent.

In thin section, sanidine is the most abundant phenocryst (8 to 10 percent), has an average length of about 0.9 mm, and may show a perthitic texture (Osburn, 1978, p. 35). Quartz occurs in amounts between 1 and 6 percent and has an average diameter of 0.7 mm. Trace amounts of biotite and magnetite also occur in the lower member. Osburn reported a trace amount of plagioclase; but it was largely altered to clay minerals.

Upper Member. The upper member of the tuff of Lemitar Mountains is usually red to grayish red; it is crystal rich and usually contains 30 to 35 percent phenocrysts of sanidine, plagioclase, quartz, and biotite. It usually weathers to form rounded outcrops which may form rounded, talus covered slopes, with occasional cliffs and ledges. In the south-central portion of the study area, the upper member occasionally weathers to form "slabby" outcrops. These "slabs" are usually a few inches thick and one foot to several feet in width and length.

The contact with the underlying lower member is gradational over an interval of 5 to 50 feet. This contact is marked by a gradual increase in the total phenocryst content to about 35 percent, and a parallel increase in plagioclase content. Osburn (1978) referred to this zone as the "transition zone." The base of the upper member was mapped at the increase in phenocryst content, or where the prominent pumice streaking in the lower member ends.

The upper few tens of feet of the tuff of Lemitar Mountains may be gray or pinkish gray. Osburn believed this to be a zonation in the tuff rather than alteration, since most of the phenocrysts were fresh. The total phenocrysts content ranges up to almost 50 percent, but the plagioclase content is only about 2 percent in this part of the tuff.

The upper member contains both gray and red pumice. Osburn reports that the red pumice is scarce in the northern part of his area, but becomes more abundant to the south. Both the gray and red pumice occur in this study area, but the red pumice predominates. The red pumice is quartz- and sanidine-poor, but plagioclase- and biotite-rich; it may occur as large streaks several feet in length (see Fig. 11).

In thin section, sanidine is the most abundant phenocryst in the upper member and may comprise as much as 25 percent of the lower portion of the upper member. Osburn (1978) reports that plagioclase comprises about 7 percent

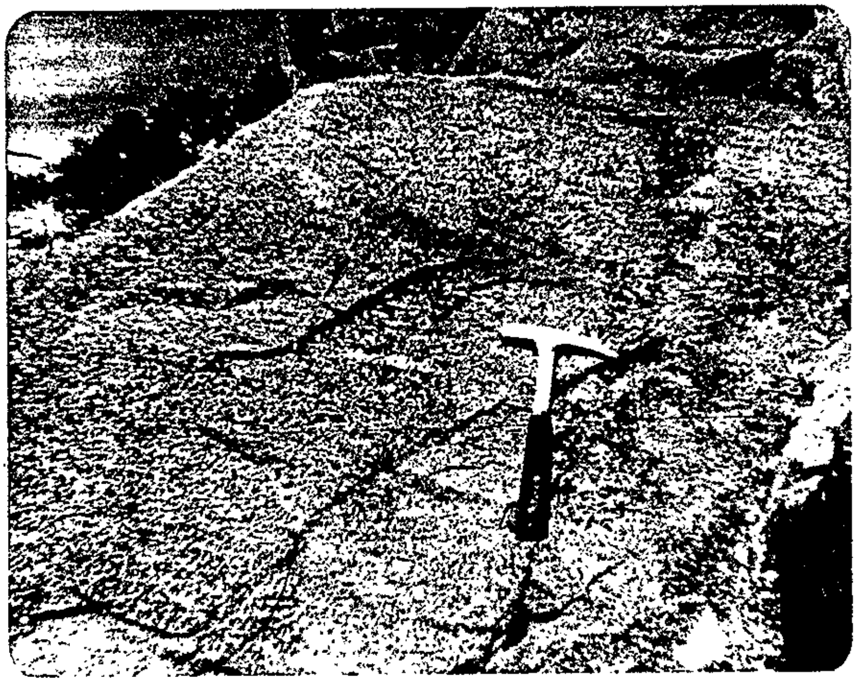


Figure 11. Red pumice in the upper member of the tuff of Lemitar Mountains (SW/4, sec. 19, T. 4 S., R. 2 W.). The tuff also contains gray pumice, but it is less abundant than the red pumice in the area where this photograph was taken. The red pumice contains abundant plagioclase and biotite, but little quartz and sanidine. Some of this pumice may be several feet in length.

and quartz about 1 percent of the rock in this lower portion. Thin sections from the upper portion of the upper member contain as much as 50 percent total phenocrysts: sanidine (average length, 1.4 mm) comprises about 25 percent of the rock, quartz (average length, 1.6 mm) comprises about 15 percent of the rock and biotite comprises 3 to 5 percent of the rock. Another phenocryst, which is too altered to identify, comprises about 2 percent of the rock. This mineral may be plagioclase.

Tuffs and Sandstones (Tt_1)

A sequence of thin, welded tuffs and sandstones overlies the tuff of Lemitar Mountains in sec. 35, T. 4 S., R. 3 W., unsurveyed. This unit probably occurs in a paleovalley which formed on an erosion surface on top of the tuff of Lemitar Mountains.

These tuffs and sandstones occur at the same stratigraphic interval as the unit of Luis Lopez, mapped by Chamberlin (in preparation) in the northern Chupadera Mountains. The unit of Luis Lopez is the moat fill of the Socorro cauldron and is widely exposed in the northern Chupadera Mountains. However, because of the limited exposures, it is not possible to determine if the tuffs and sandstones in the study area correlate with the unit of Luis Lopez.

The thickness of this sequence of tuffs and sandstones varies from 0 to 350 feet. The sequence is composed of at least three tuff units and one sandstone unit. Each of these units is 100 feet, or less, in thickness.

The tuffs consist mostly of pink-to-brown, crystal-poor (1 to 5 percent phenocrysts), moderately lithic-rich (10 to 20 percent), poorly to moderately welded, rhyolitic (?) ash-flow tuffs. They weather readily and form very poor outcrops. The sandstone occurs towards the top of the sequence. This sandstone consists of very coarse, angular grains of quartz, feldspar and lithic fragments. In a few places, it may consist of angular breccia clasts.

Rhyolite Lava (Tr_1)

A gray, crystal-poor, spherulitic, rhyolite lava overlies the tuffs and sandstones of the Tt_1 unit in NW/4 sec. 35, T. 4 S., R. 3 W., unsurveyed. It also unconformably overlies the tuff of Lemitar Mountains. This rhyolite lava, like the underlying tuffs and sandstones, probably occurs in a paleovalley cut in the underlying tuff of Lemitar Mountains. The rhyolite lava is overlain by the tuff of South Canyon. Like the underlying tuffs and sandstones, the rhyolite lava could be correlative with the unit of Luis Lopez, but there are insufficient exposures to determine this.

The rhyolite lava is probably about 200 to 250 feet thick. It crops out in a few blocky outcrops; elsewhere, it is largely covered with colluvium. This rhyolite is very crystal poor; few phenocrysts of any kind can be seen in hand specimen. The most characteristic feature of this rhyolite is the abundant spherulites it contains. These spherulites are usually 1 to 2 cm in diameter and tend to occur in clusters of 10 to 20 or more. These clusters are bound together by flow-banded rhyolite. Individual spherulites may be egg shaped to football shaped, and have a length of 5 to 15 cm.

Basalt and Basaltic Andesite Lavas (Tba_1)

A sequence of porphyritic, pyroxene-bearing, basalt and basaltic andesite lava flows overlies the tuff of Lemitar Mountains throughout most of the central part of the study area. These lavas pinch out to the south and are not present in the south-central portion of the study area (sec. 33, T. 4 S., R. 2 W.). Osburn (1978) mapped these basaltic andesites north of this study area. Chamberlin (oral communication) reports that basaltic andesite lavas are present at this stratigraphic level in the Lemitar Mountains. Basaltic andesite lavas are also present between the tuff of Lemitar Mountains and the tuff of South Canyon in the Joyita Hills (Spradlin, 1976) and elsewhere in the Magdalena area.

The lavas are usually about 50 feet thick, or less. However, in W/2, sec. 21, T. 4 S., R. 2 W., they may be as much as 350 feet thick. Osburn (1978) reports that these lavas may be as much as 600 feet thick along South and Sixmile Canyons. He also states that some faults appear to cut the tuff of Lemitar Mountains, but not the tuff of South Canyon; these faults may control the thickness of the basaltic andesites. Faults do not appear to control their thickness in most places in this study area. However, a few places do contain somewhat thicker than normal accumulations of the lavas and these could have accumulated next to faults. The lavas usually occur as low, rounded hills covered with colluvium of small, angular fragments; occasionally, they crop out along the sides of stream beds.

In hand specimen, the basalt and basaltic andesite lavas are usually gray to black and occasionally grayish brown. They are porphyritic and may contain a few percent phenocrysts of pyroxene, plagioclase and olivine set in an aphanitic matrix. Small olivine and pyroxene phenocrysts about 1.0 mm in diameter are common; the olivines are frequently altered to iddingsite and/or hematite.

One thin section of the basaltic andesites contains 40 to 45 percent phenocrysts of plagioclase (An_{60}; Michel-Levy method, 10 grains). This plagioclase has a seriate texture with sizes ranging from about 0.5 mm to 1.3 mm. The plagioclase is mostly euhedral. The smaller phenocrysts of plagioclase are arranged in a very crude parallel alignment. Clinopyroxene (probably augite) comprises 4 to 5 percent of the rock and occurs as subhedral to euhedral phenocrysts with an average diameter of about 0.35 mm. Some of the pyroxene occurs in glomeroporphyritic clumps which may be as much as 1.8 mm in diameter. Two to 3 percent phenocrysts of euhedral to subhedral olivine, with an average diameter of 0.5 mm. occur scattered throughout the rock. The olivine has been partially resorbed. The outer rims of most of the olivine are altered to iddingsite (?) or hematite; some olivine crystals are almost completely replaced by these minerals. The matrix of the rock consists mostly of glass and microlites of plagioclase. It also contains a few percent pyroxene and olivine. The thin section contains about 10 percent vesicles, a few of which are filled with calcite.

Rhyolite Dome (Tr_2)

A pink-to-gray, phenocryst-poor, spherulitic, rhyolite dome crops out in sec. 19, T. 4 S., R. 2 W. This rhyolite overlies the basaltic andesites (Tba_1) and is overlain by the tuff of South Canyon. The rhyolite is described as a dome because of its restricted lateral extent. However, it could also be a rhyolite lava with a very restricted distribution. The rhyolite occurs at the same stratigraphic interval as the unit of Luis Lopez (in the northern Chupadera Mountains). It has a maximum thickness of about 600 feet. The rhyolite occurs in relatively continuous, blocky outcrops along the crest of a hill; along the sides of this hill, the rhyolite crops out in more ledgy exposures surrounded by colluvium.

In hand specimen, the rhyolite usually has a pink matrix, which is filled with gray to white spherulites and masses of secondary quartz and chalcedony. These spherulites are usually about 1 to 2 cm in diameter and they vary from 0 to about 20 percent in abundance. Usually, the secondary quartz and chalcedony forms 10 to 50 percent of the rock. It occurs mostly as small, rounded to irregular masses, a few mm to 2 cm, or more, in diameter, and scattered throughout the rock. In thin section, the rhyolite consists mostly of spherulitic aggregates of alkali feldspar and silica minerals, and cherty quartz. The thin section also contains a few crystals of secondary quartz as large as 0.3 mm in diameter.

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). Osburn (1978) named this tuff after a measured stratigraphic section at the mouth of South Canyon (SW/4, sec. 30, T. 3 S., R. 3 W.). All of the tuff units above tuff of Lemitar Mountains have been called the upper tuffs by some recent workers. Simon (1973) mapped upper tuffs in the Silver Hill area, but the relationship between his upper tuffs and the tuff of South Canyon is unknown. The tuff of South Canyon is equivalent to the upper "Potato Canyon Tuff" of Spradlin (1976) in the Joyita Hills. The tuff of South Canyon has recently been described by Allen (in preparation) and Bowring (in preparation) in the

Magdalena Mountains, and Chamberlin (in preparation) in the Lemitar and Chupadera Mountains. Chapin and others (1978) have correlated the eruption of the tuff of South Canyon with the collapse of the Hop Canyon cauldron. 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.

The tuff of South Canyon occurs in outcrops which trend north-northwest in the central portion of the study area. There, it overlies the tuff of Lemitar Mountains, the basaltic andesite lavas (Tba_1) or a rhyolite dome (Tr_2). It is overlain in most of this area by basalt and basaltic andesite lavas (Tba_2), although in secs. 17 and 18, T. 4 S., R. 2 W., it is overlain by tuffs of the Twt unit. The tuff of South Canyon is usually between 250 and 750 feet thick. Most of the variation in thickness is due to erosion on top of the tuff of Lemitar Mountains. The tuff of South Canyon also crops out in sec. 36, T. 4 S., R. 3 W., on the western side of Ryan Hill Canyon. There, it overlies either the tuff of Lemitar Mountains or rhyolite lavas of the Tr_1 unit and is overlain by the lower Popotosa Formation. A small outcrop of the tuff of South Canyon also occurs on the western side of Ryan Hill Canyon in sec. 21, T. 4 S., R. 3 W., unsurveyed.

See Osburn (1978) for a detailed description of the mineralogy and zonation of the tuff of South Canyon. In general, the tuff of South Canyon contains subequal amounts of quartz and sanidine except near the top of the unit, where sanidine may be nearly twice as abundant as quartz. The sanidine often displays chatoyancy. The total phenocryst content increases from about 3 percent at the base of the tuff to a maximum of about 21 percent above the middle of the tuff and then decreases to about 12 percent at the top of the tuff (see Osburn, 1978, Fig. 14). Most of the tuff contains a trace of several percent lithic fragments; the basal portion of the tuff may contain as much as 8 percent lithic fragments. The tuff contains 10 to 35 percent pumice.

The tuff of South Canyon can be divided into three zones based on degree of welding, character of the pumice, and presence of lithophysal cavities. The basal zone is poorly welded, crystal poor (3 to 9 percent phenocrysts), and may contain 3 to 8 percent lithic fragments. This basal interval is best exposed in sec. 18, T. 4 S., R. 2 W., where it is about 50 to 100 feet thick. South of this area, the basal zone is usually 10 to 50 feet thick. This zone usually weathers very easily and may form saddles between topographic highs of the overlying material (see Fig. 12). In sec. 33, T. 4 S., R. 2 W., a portion of this zone was unwelded.

Above the basal zone is a lithophysal zone which is highly welded and may contain lithophysal cavities as much as 6 inches in length. This zone occurs sporadically in sec. 18, T. 4 S., R. 2 W.; elsewhere, it is usually not exposed.

Figure 12. Basal, poorly welded, moderately lithic-rich zone of the tuff of South Canyon (SE/4, sec. 18, T. 4 S., R. 2 W.). This could be an air-fall tuff or a series of thin, ash-flow tuffs at the base of the unit. Osburn (oral communication) reports that the basal portion of the tuff of South Canyon occasionally contains bedded tuffs in Sixmile and South Canyons.

The upper zone has a streaked appearance imparted by abundant light-gray pumice in a darker, pale-red or grayish-red matrix. The upper zone is the most common of the three zones; most of the tuff of South Canyon in this study area belongs to this zone. The upper zone is moderately to densely welded and weathers to angular, blocky talus which covers most of the exposures.

In thin section, the tuff of South Canyon consists mostly of sanidine and quartz, which are usually present in subequal amounts. Osburn (1978) reported traces of badly altered plagioclase, but no plagioclase was observed in thin sections from this study area. Trace amounts of magnetite (?) and small, euhedral biotite phenocrysts occur in the tuff of South Canyon. As much as 8 percent lithic fragments occur in the lower, crystal-poor part of the tuff, but they decrease in abundance upward in the tuff. The lithic fragments consist of gray-to-red, aphanitic, silicic rock fragments (some are flow-banded), andesite, and crystal-poor to crystal-rich tuff (?) fragments. Fragments from both the lower and upper tuff of Lemitar Mountains also occur in the tuff of South Canyon.

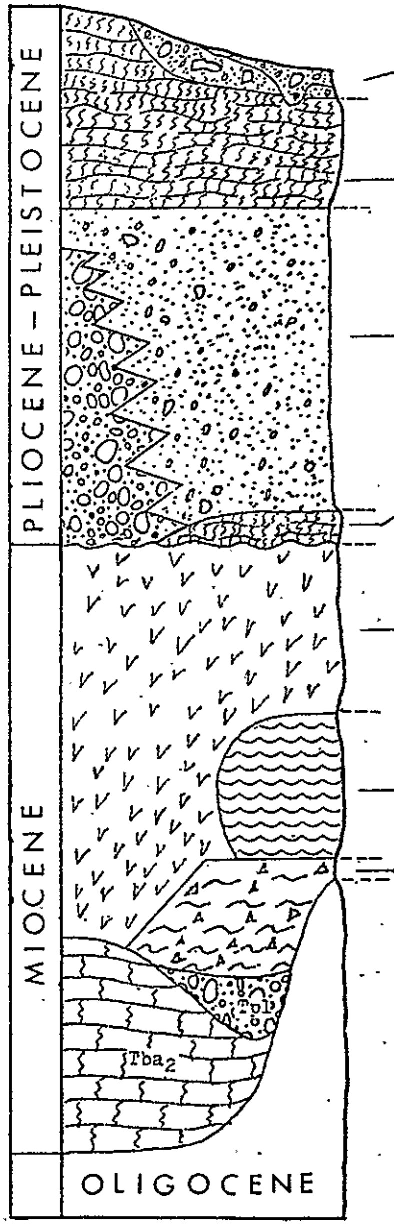
The sanidine is subhedral to euhedral and has an average length of 1.0 mm. The largest phenocryst in the section has a length of 3.0 mm. Carlsbad twinning is common in sanidine, and much of the sanidine shows exsolution of albite in thin section (see Osburn, 1978, Fig. 16). Quartz occurs as subhedral to euhedral crystals, which are occasionally embayed and have an average diameter of 1.0 mm. They often show internal conchoidal fracturing.

Basalt and Basaltic Andesite Lavas (Tba$_2$)

A sequence of basalt and basaltic andesite lavas overlies the tuff of South Canyon in the central portion of the study area. These rocks are similar to the basalt and basaltic andesite lavas (Tba$_1$) that underlie the tuff of South Canyon. They usually contain 10 to 25 percent phenocrysts of pyroxene, olivine and plagioclase. These lavas have not been dated, so they could be anywhere from 12 m.y. old (age of overlying Pound Ranch lavas) to 26.2 m.y. old (age of the underlying tuff of South Canyon).

The thickness of these lavas varies from 0 to 600 (?) feet in this study area. Osburn (1978) reports that they post-date erosion of the tuff of South Canyon and are cut by a later period of erosion in the area he mapped. This appears to be the case in this study area as well, and it probably explains much of the thickness variation throughout the area. The lavas pinch out to the north of this study area in secs. 17 and 18, T. 4 S., R. 2 W., but they are exposed again further north in the area mapped by Osburn (1978).

In secs. 16, 17 and 21, T. 4 S., R. 2 W., the basaltic andesite lavas are overlain by either tuffs of the Twt unit or the Pound Ranch lavas. Elsewhere in the study area, the upper contact of these lavas is not exposed.



Qa	Post Santa Fe Alluvium: (0-100 ft.) ALLUVIAL FAN, PIEDMONT SLOPE and AXIAL STREAM DEPOSITS: mostly poorly sorted, pebble- to boulder-size sediments; lesser amounts of sand and silt.
Tsb_2	Sierra Ladrones Formation - lava flows: (0-250 ft.) BASALTS: gry. to blk., aphanitic to slightly porphyritic basalts with phen. of plag., pyroxene, and olivine. Basalts cap mesa in eastern portion of study area.
Ts	Sierra Ladrones Formation - sedimentary unit: (300-500+ ft.) PIEDMONT-SLOPE and AXIAL STREAM DEPOSITS: Outcrops predominately poorly indur., pbly. ss.; minor boulder cgl.
Tsb_1	Sierra Ladrones Formation - lava flows: (0-30 ft.) BASALTS: gry. to blk., aphanitic to slightly porphyritic basalts with phen. of plag., pyroxene, and olivine. Outcrops poor; probably interbedded in sed. rocks of Sierra Ladrones Formation.
Tpr_2	Upper Pound Ranch Lavas: 10.5 ± 0.4 m.y. (0-600 ft.) QUARTZ LATITE LAVA FLOWS: dense. porphyritic, qtz. latite (chem. 70.3% SiO_2) lava flows. Zoned blk. basal vitrophyre, middle mod.-rd. to gry.-rd., finely flow-foliated interval, and upper, pale-rd., crudely flow-foliated interval. Phen of plag., biotite and hornblende.
Tpr_1	Lower Pound Ranch Lavas: 11.8 ± 0.5 m.y. (0-400 ft.) RHYOLITE LAVAS: dense, porphyritic, pale-rd.-brn., rhyolitic lavas. Phen. of plag., qtz., potash feld., biotite and hornblende; crudely flow-foliated.
Twt	Tuff Interval: (0-300 ft.) ASH-FLOW and BEDDED TUFFS: poorly welded, pumiceous, lithic-rich, rhyolitic ash-flow tuffs; minor interbedded air-fall beds with similiar characteristics.
Tpl	Lower Popotosa Formation: (0-150 ft.) MUD-FLOW DEPOSITS: dense rd., well-indurated breccias and cgl. Some deposits are in paleovalleys.
Tba_2	Lava Flows: (0-350 ft.) BASALTIC ANDESITE to BASALTIC LAVAS: La Jara Peak like, gry., dense basaltic andesites with abun., small, rd., hematized ferromag. phen. Also, minor, rd.-blk, olivine-rich, plag.-porphyritic basalts with olivine clots to 2 cm.

Figure 13: Miocene to Holocene stratigraphic section for rocks in the eastern Magdalena Mountains and west-central Chupadera Mountains. Descriptions modified after Osburn, 1978.

These lavas usually form gentle, rounded slopes covered with colluvium. In hand specimen, the lavas are usually gray to black when fresh, and brownish gray when altered. They contain 10 to 25 percent phenocrysts of pyroxene, olivine and plagioclase. Frequently, both the pyroxene and olivine are replaced by hematite, so it is difficult to estimate the relative abundance of these minerals in hand specimen.

Osburn (1978) reported that some of these rocks in his study area contain olivine clots as much as 2.0 cm in diameter. These rocks are coarsely porphyritic and contain as much as 25 percent phenocrysts of plagioclase, olivine and pyroxene. The SiO_2 content of these rocks is 49.5 percent (Osburn, 1978, appendix B).

A thin section of a sample from SW/4, section 21, T. 4 S., R. 2 W., contains about 15 percent phenocrysts of olivine, pyroxene and plagioclase in a matrix that consists mostly of plagioclase. Olivine phenocrysts with an average diameter of 0.4 mm comprise about 5 percent of the rock. Most of them are subhedral and have been partially resorbed. They are usually partially altered to iddingsite (?) and hematite. Subhedral to anhedral pyroxene phenocrysts (probably augite) with an average diameter of 0.75 mm comprise about 5 percent of the rock.

Plagioclase comprises most of the matrix and a few percent of the phenocrysts. It has an average diameter of 0.2 mm but has a seriate texture. Osburn (1978) reported that the plagioclase compositions in the rocks he studied vary between An_{49} and An_{70} (Rittmann zone method, 6 grains). The plagioclase in the thin section studied for this thesis has a composition of An_{68} (Michel-Levy method, 8 grains).

The matrix is composed mostly of plagioclase with a pilotaxitic texture. Thirty to 40 percent of the matrix also consists of small pyroxene, olivine and magnetite grains.

Lower Popotosa Formation

The Popotosa Formation was named by Denny (1940) for exposures of fanglomerates and playa deposits of the lower Santa Fe Group along Arroyo Popotosa southeast of the Ladron Mountains. The Popotosa consists of a variety of rock types, including mudstones, siltstones, sandstones, conglomerates and mudflow deposits. Only the mudflow deposits of the lower Popotosa Formation are exposed in this study area. Most of these belong to the "fanglomerate facies" described by Bruning (1973).

The lower Popotosa Formation crops out in three locations. One outcrop occurs in sec. 13, T. 4 S., R. 2 W. The base of this outcrop is not exposed and the top is eroded; north of this study area, in the areas mapped by Osburn (1978) and Chamberlin (in preparation), the lower Popotosa is overlain by playa mudstones that probably belong to the upper Popotosa. Several smaller outcrops of the lower Popotosa occur in sec. 18, T. 4 S., R. 2 W.

Osburn (1978) called these pre-Pound Ranch lava sediments (Ts), but their age and lithologic characteristics correlate with those of the lower Popotosa. These sedimentary rocks overlie the upper member of the tuff of Lemitar Mountains and the tuff of South Canyon. They are overlain by the upper Pound Ranch lavas. They consist mostly of reddish-brown, well-cemented mudflow breccias and conglomerates. In sec. 36, T. 4 S., R. 3 W., the Popotosa overlies both the tuff of South Canyon and the upper member of the tuff of Lemitar Mountains. There, the Popotosa is overlain by a poorly welded tuff (Tt_2) of uncertain age. This tuff may be equivalent to the Twt tuffs that underlie the upper Pound Ranch lavas further north.

The age of these sedimentary rocks must be between that of the underlying tuff of South Canyon (26.2 m.y.) and the overlying Pound Ranch lavas (10.4 m.y.). They overlie the tuff of South Canyon with angular unconformity in sec. 18, so they are probably a few million years younger than that unit. In sec. 36, the Popotosa dips steeply (35 degrees), but not as steeply as the underlying units. The Popotosa appears to be cut by an erosion surface in sec. 18; Osburn (1978) reported that the lower Popotosa appears to be cut by an erosional unconformity of considerable relief southeast of the Pound Ranch.

The Magdalena Mountains were probably uplifted and eroded during Miocene time, thus acting as a source for the Popotosa Formation (Bruning, 1973). The Popotosa

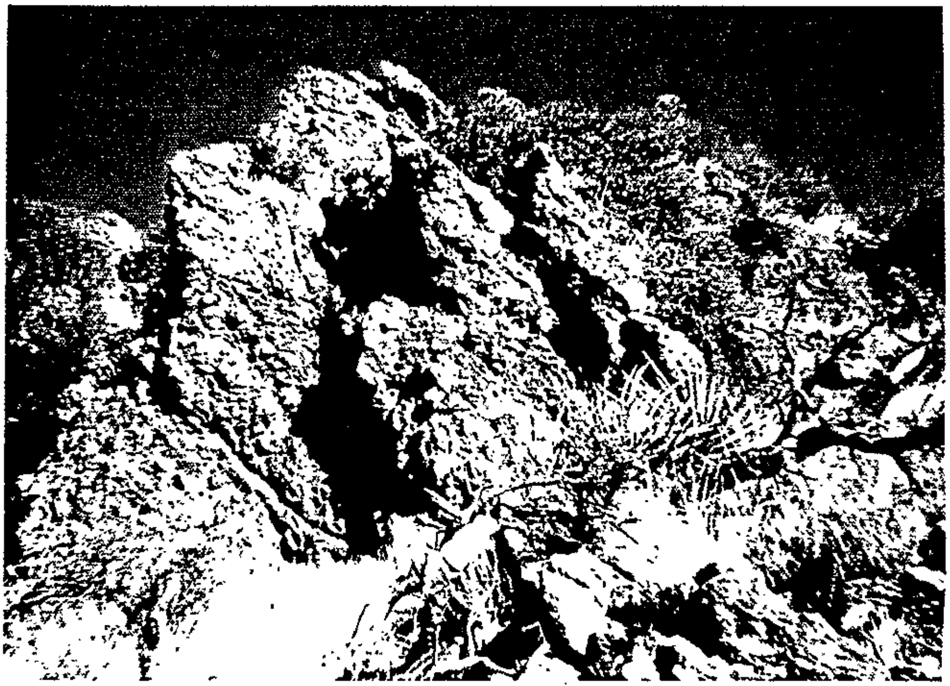
Formation probably accumulated in topographic depressions, producing thickness variations at the time of deposition. Subsequent erosion may have produced even greater variations in thickness. In sec. 18, The Popotosa is about 200 feet thick and in sec. 36, it may be as thick as 500 feet. Elsewhere, an accurate thickness cannot be determined.

The lower Popotosa mudflow deposits usually form well-exposed outcrops. They frequently crop out as cliffs and ledges. Usually, the outcrops are fairly massive and display few sedimentary structures; however, in a few places, the mudflow deposits are crudely bedded (see Fig. 14). The Popotosa mudflow deposits are well indurated, but they frequently weather to individual boulders (Fig. 15).

The rocks are usually reddish brown in color and consist of angular to rounded, boulder and cobble clasts in a sandy to silty matrix. The clasts are very poorly sorted and the larger clasts are often supported by the finer-grained matrix. This is characteristic of clasts transported by mudflows. Fragments of the upper member of the tuff of Lemitar Mountains are the most abundant type of clast; they usually comprise 50 to 75 percent of the cobble and boulder clasts. The other clasts consist of fragments of the tuff of South Canyon, andesite or basaltic andesite, the lower member of the tuff of Lemitar Mountains and the tuff of Caronita Canyon.

Figure 14. Outcrop of lower Popotosa mudflow deposits (SW/4, sec. 36, T. 4 S., R. 3 W., unsurveyed). These rocks dip 35 to 40 degrees to the east.

Figure 15. Outcrop of lower Popotosa mudflow deposits from same location as in Figure 14. These deposits consist of angular to rounded, cobble to boulder clasts. Fragments of the upper member of the tuff of Lemitar Mountains (L) comprise about 75 percent of the clasts in this area. The other clasts consist mostly of andesite (A); the lower member of the tuff of Lemitar Mountains, and the tuff of Caronita Canyon (lower member, C_l; upper member, C_u).




L
L
L
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Pre-Lava Ash-Flow Tuffs (Twt and Tt_2(?))

A thin sequence of poorly welded, lithic- and pumice-rich, light-colored ash-flow tuffs (Twt) underlies the Pound Ranch lavas in the Pound Ranch area (Osburn, 1978). Only a few small exposures of this unit occur in the north-central portion of this study area (secs. 17 and 18, T. 4 S., R. 2 W.). A small outcrop of tuffs of similar appearance (Tt_2) occurs in SE/4, SW/4, sec. 36, T. 4 S., R. 3 W. in Ryan Hill Canyon. These tuffs are poorly welded, lithic and pumice rich and light brown; they may be equivalent to the Twt tuffs, but limited exposures make it impossible to demonstrate this.

The tuffs in both Ryan Hill Canyon and secs. 17 and 18 overlie an erosional unconformity. The Twt tuffs are overlain by the upper Pound Ranch lavas, while the Tt_2 tuffs have an erosional top. The Twt tuffs are 0 to 200 feet thick in secs. 17 and 18, and the Tt_2 tuffs are 0 to about 60 feet thick.

Osburn (1978) reported that the Twt tuffs contain as much as 20 percent phenocrysts of plagioclase, sanidine, quartz, biotite and hornblende. This mineralogy is similar to that of the lower Pound Ranch lavas and the two units may be related.

Lower Pound Ranch Lavas

Crystal-rich, quartz-rich lavas crop out in sec. 15, T. 4 S., R. 2 W., along the northern border of the study area. Osburn (1978) named these the lower Pound Ranch lavas. These lavas have been dated at 11.8 ± 0.5 m.y. using the K/Ar method on biotite (Osburn, 1978). In mineralogy, the lavas are latites or quartz latites; but chemically, they are rhyolites (73.0 percent SiO_2; Osburn, 1978; appendix C). Chamberlin (in preparation) has mapped lavas interbedded in the Popotosa Formation in the Socorro Peak area that are similar in lithology and age to the Pound Ranch lavas.

The lower Pound Ranch lavas crop out in a much smaller area than the upper Pound Ranch lavas. The lower Pound Ranch lavas cover about one quarter of a square mile in this study area. These lavas are not exposed more than about a mile south of the northern border of this thesis area. It is possible that the lavas never flowed much further south than their present exposures.

Osburn (1978) reported a minimum thickness of 400 feet for the lower Pound Ranch lavas. The lavas are probably this thick in sec. 15, but the top of these lavas is eroded. These lavas usually weather to form rounded boulders that cover much of the outcrop, although occasional cliffs and ledges do occur.

In hand specimen, the lower Pound Ranch lavas are usually light brown or pink and contain abundant, coarse phenocrysts of plagioclase, sanidine, quartz and biotite. Crude flow banding can occasionally be seen in the lavas; the flow banding is defined by gray streaks in the brown matrix.

In thin section, the rock contains 25 to 30 percent phenocrysts of quartz, plagioclase, sanidine and biotite. About 10 to 12 percent quartz occurs as anhedral to subhedral, frequently embayed grains as much as 4.0 mm in diameter, but averaging about 1.0 mm. Zoned plagioclase, which varies in length from 0.5 to 4.0 mm and has an average length of 1.5 mm, comprises 9 to 10 percent of the rock. Osburn (1978) reported compositions from An_{24} to An_{43} (Rittmann zone method, 10 grains).

Some of the plagioclase occurs in glomeroporphyritic aggregates, which may poikiliticly enclose crystals of biotite. Three to 5 percent subhedral sanidine occurs in the rock. It has an average length of about 1.6 mm, but one phenocryst observed in thin section measures 1.0 cm in length. Some euhedral sanidine phenocrysts as long as 2.0 cm occur in hand specimens. The sanidine in thin section often poikiliticly encloses crystals of biotite and plagioclase. Two to 3 percent biotite, 1 percent magnetite and a trace amount of hornblende also occur in the rock. The groundmass consists of spherulites (probably intergrowths of alkali feldspars and silica minerals), and fine-grained quartz and potassium feldspar (?).

Upper Pound Ranch Lavas

The upper Pound Ranch lavas are porphyritic lavas containing 10 to 25 percent phenocrysts of plagioclase, biotite and hornblende. They occur in extensive outcrops in the area south of the Pound Ranch. Osburn (1978) mapped most of these outcrops and located a probable vent about one mile southwest of Pound Ranch (about one mile north of this study area). These lavas crop out in secs. 15, 16, 17, 18, 21 and 22, T. 4 S., R. 2 W. It is likely that they never flowed much farther south than their present exposures. These lavas have been dated at 10.5 ± 0.4 m.y. using the K/Ar method on biotite (Osburn, 1978). In mineralogy, these lavas are andesites, but chemically, they are rhyolites or quartz latites (72.3 percent SiO_2; Osburn, 1978; Appendix C).

The upper Pound Ranch lavas are probably 600 feet thick, or more, in sec. 16; they apparently pinch out to the south. These lavas were deposited on an erosion surface and they may unconformably overlie all units above the tuff of Lemitar Mountains. In this study area, the lavas are not overlain by any units except Quaternary alluvium. The upper Pound Ranch lavas usually weather to rounded boulders that cover the more gentle slopes; however, they also crop out as cliffs and ledges on the steeper slopes.

The upper Pound Ranch lavas are zoned texturally, but not mineralogically (Osburn, 1978). Close to the vent, this unit consists of a basal vitrophyre, overlain by a finely flow-foliated zone which gradually becomes more massive upward. The finely flow-foliated zone is not present in this study area; Osburn reports that it is restricted to within about a mile of the vent. The basal vitrophyre is a few feet to 100 feet thick. It crops out fairly regularly in sec. 22; elsewhere, the outcrops are more sporadic. Above the vitrophyre, the lavas are usually grayish red to light red. They frequently are brown to brownish red on the weathered surfaces. A crudely defined flow banding is usually present, although some outcrops appear almost massive.

Osburn (1978) reported an upward increase in the phenocryst content from 10 to 25 percent. Thin sections examined for this thesis contain 15 to 20 percent phenocrysts of plagioclase, biotite, and hornblende. Plagioclase comprises 70 to 80 percent of the phenocrysts and has an average length of 1.5 mm, and a maximum length of 3.3 mm. It occurs as euhedral to subhedral phenocrysts, and occasionally in glomeroporphyritic aggregates. Much of the plagioclase is strongly zoned; Osburn (1978) reported that the composition may vary from An_{32} to An_{55} (Rittmann zone method, 20 grains). Some of this plagioclase poikiliticly encloses crystals of biotite and possibly hornblende.

Biotite and hornblende each comprise 2 to 3 percent of the rock. They are both pleochroic and display greenish-brown to red colors. The euhedral to subhedral biotite phenocrysts have an average length of about 0.7 mm. The hornblende is also euhderal to subhedral and has an average cross-sectional diameter of 1.0 mm. The matrix of the vitrophyre consists mostly of glass, some of which has undergone partial spherulitic devitrification.

Tertiary Intrusive Rocks

White Rhyolite Dikes

The white rhyolite dikes are light in color, massive to flow banded, and contain 0 to 30 percent phenocrysts of quartz, sanidine and biotite. A few of the more crystal-rich dikes also contain plagioclase; dikes that have been mineralized may contain sulfides. Most of the dikes occur in the northwestern portion of the study area (secs. 3, 4, 5 and 10, T. 4 S., R. 3 W., unsurveyed), although one also occurs in Ryan Hill Canyon (sec. 26, T. 4 S., R. 3 W., unsurveyed). Most of the dikes were emplaced along north or north-northwest trending faults; some dikes also trend east-west, parallel with the northern Sawmill Canyon ring fracture. Most of the dikes are near vertical, although locally the dip may vary. The dikes usually range from a few inches to about 150 feet in thickness. Some of the more resistant dikes stand up as "walls" above the surrounding surface (Fig. 16).

In hand specimen, the white rhyolite dikes are usually white or gray and may contain as much as 30 percent phenocrysts. Quartz is usually the dominant phenocryst and may comprise as much as 20 percent of the rock. Sanidine is second in abundance but is usually not easily recognized in hand specimens. Traces to a few percent

Figure 16. White rhyolite dike in NE/4, sec. 4, T. 4 S., R. 3 W., unsurveyed. These dikes are a few inches to about 150 feet in width. Some of the largest dikes form prominent outcrops, as shown here, but most outcrops are much more subdued.

biotite may also be present. Many of the white rhyolite dikes have been silicified and mineralized. Pyrite (frequently altered to limonite) and minor chalcopyrite occur in a few dikes. The gold mine in SW/4, sec. 3, T. 4 S., R. 3 W., unsurveyed, is located along a white rhyolite dike (see section on economic geology).

In thin section, the quartz is usually euhedral to subhedral and has an average diameter of 0.4 mm. Sanidine is subhedral and has an average length of 0.9 mm; it has usually been partially replaced by clay minerals. Biotite usually has an average length of 1.0 mm. Some biotite(?) phenocrysts are bleached and colorless. Traces of badly altered plagioclase occur in a few rocks.

Rhyolite Intrusions

Two types of rhyolite intrusions occur in the study area: one contains sanidine and minor quartz and the other is very crystal poor. The sanidine rhyolite intrusions occur in the upper reaches of Rincon-Madera Canyon (sec. 13, T. 4 S., R. 3 W., and sec. 18, T. 4 S., R. 2 W.). This rock type occurs in two intrusions in the study area; Osburn (1978) also mapped one of these intrusions and reported that at least two others occur in the area he studied. These intrusions may have been emplaced along fault zones (see Plates 1 and 2); alternatively, they may have been faulted since their emplacement.

The crystal-poor rhyolite intrusions occur in Italian Canyon (secs. 21, 27 and 28, T. 4 S., R. 3 W., unsurveyed) and Ryan Hill Canyon (sec. 36, T. 4 S., R. 3 W.). The intrusion in Italian Canyon appears to have partially domed the overlying strata; some of the units west of the intrusion dip to the west but the regional dip is to the east.

In outcrop, the crystal-poor rhyolite frequently stands out as blocky cliffs partially covered with talus. These rhyolites are flow banded to massive and are usually pink to gray in color. Occasionally, they contain abundant spherulites. Breccia occurs along the margin of the intrusion in Italian Canyon.

The sanidine rhyolite intrusions usually weather to low, subdued outcrops, except where the rocks are silicified. These rocks closely resemble the Txr_2 rhyolite lavas. They are pale red to pinkish gray and contain 10 to 20 percent phenocrysts. Sanidine, the predominent phenocryst, frequently occurs as large, tabular crystals, which may be almost 1.0 cm in length. The quartz is small and not conspicuous in hand specimen. A few andesite lithic fragments occur in some areas.

One thin section of the sanidine rhyolite contains about 6 to 8 percent sanidine and 2 to 4 percent quartz phenocrysts. The sanidine has a maximum length of 4.5 mm, but averages about 2.0 mm. The quartz is subhedral and has an average diameter of 0.4 mm. About 1 percent biotite and a trace of magnetite occurs in the rock.

In thin section, the crystal-poor rhyolites contain few, if any, phenocrysts. A few small crystals of quartz (about 0.1 mm diameter) occur in the thin section, but most of these are probably secondary quartz. The matrix consists of fine-grained (0.01 mm or less diameter) quartz and potassium feldspar (?).

Monzonite Dikes

Two monzonite dikes occur in the northwestern portion of the study area (NW/4, sec. 3 and SE/4, sec. 4, T. 4 S., R. 3 W., unsurveyed). These rocks are usually a mottled green color and contain very coarse (5 cm or more in length) feldspar phenocrysts. The dikes in this study area are 30 to 50 feet thick and can be followed for only a short distance on the surface. Some of these dikes in the Magdalena Mountains stand up as walls; however, in this study area, the dikes usually form low, rounded outcrops.

Hand specimens of the monzonite dikes are grayish green and coarsely porphyritic. Phenocrysts of feldspar, quartz and mafic minerals may comprise 25 to 30 percent of the rock. The feldspars probably consist of both sanidine and plagioclase, but they are altered to a white, clayey material. Many of the feldspar phenocrysts are 1 cm or more in length, and a few are as much as 5 cm long. The quartz usually occurs as small grains, 1 to 2 mm in diameter, and may comprise as much as 5 percent of the rock. Most of the mafic minerals are probably biotite, although some pyroxene and magnetite may also be present.

Both of the monzonite dikes in this study area have been intensely altered. The surrounding country rock has occasionally been altered and the intrusive contacts may be bleached. Krewedl (1974) reported that many of the mafic minerals had been replaced by chlorite; this probably produced the green color common in the rocks. Silicification of the dike and country rocks are also common.

Mafic Dikes

Small, fine-grained mafic dikes are common in secs. 3 and 4, T. 4 S., R. 3 W., unsurveyed, in the northwestern portion of the study area. A few dikes also occur in secs. 9 and 10, T. 4 S., R. 3 W., unsurveyed. Most of the dikes probably intruded along faults, although displacement along these faults may be difficult to prove. In many cases, the mafic dikes intrude the same faults as the white rhyolite dikes. Usually, the mafic dikes appear to be younger than the white rhyolite dikes. The mafic dikes are a few inches to a few feet in width and usually cannot be followed for more than a few tens of feet along strike.

The mafic dike rocks are generally green in color and fine grained. Occasionally, a few small phenocrysts of plagioclase (?) can be seen in hand specimen. Alteration tends to obscure the textures. Thin sections examined for this study consist mostly of a fine-grained assemblage of calcite, quartz and clay minerals. Relics of plagioclase (?) and pyroxene (?) phenocrysts can be seen. Traces of hematite are present as replacement products of other minerals.

Tertiary-Quarternary Rocks

Sierra Ladrones Formation

Sediments. The Sierra Ladrones Formation consists of gently dipping, poorly consolidated sands and gravels, boulder alluvium and interbedded basalts, which comprise the upper part of the Santa Fe Group. The Sierra Ladrones Formation was named by Machette (1978) for the Sierra Ladrones, which are low foothills of the Ladron Mountains. In the type area, the Sierra Ladrones Formation is early Pliocene to middle Pleistocene in age and the sediments consist of alluvial-fan, piedmont-slope, alluvial-flat, flood-plain and axial-stream deposits (Machette, 1978).

In this study area, the Sierra Ladrones Formation crops out mainly in a group of low, rounded hills in secs. 13, 14 and 24, T. 4 S., R. 2 W., and on a basalt-capped mesa in secs. 25, 26, 35 and 36, T. 4 S., R. 2 W. A few small outcrops also occur in stream beds in secs. 14, 15, 23, and 24; Figure 17 shows a typical outcrop in a stream bed.

In the rounded hills (secs. 13, 14, and 24), the outcrops are almost always mantled by a lag gravel of rounded cobbles and boulders. Outcrops can only be seen in a few places in sec. 13, where stream erosion has removed the lag gravel. These outcrops consist mostly of sandy gravels, although occasionally, outcrops of

Figure 17. Outcrop of Sierra Ladrones Formation in a stream bed (SW/4, sec. 14, T. 4 S., R. 2 W.). The sands and gravels of this unit are usually partly consolidated, but they crop out poorly. The sediments in the outcrop shown here dip about 10 degrees to the east; quaternary alluvium overlies the Sierra Ladrones Formation.

boulder alluvium occur. The boulders and cobbles in the coarser-grained deposits probably remain behind after the outcrops are eroded and the finer-grained sediments removed. This eventually results in a layer of boulders and cobbles which cover the older deposits. These boulders and cobbles are mostly rounded and consist of fragments of tuff of Lemitar Mountains, tuff of South Canyon, basaltic andesites and Pound Ranch lavas. A few scattered outcrops of basaltic lavas (Tsb_1) crop out at the base of the low hills in secs. 13 and 14. These basalts are probably interbedded in the sediments. A minimum thickness for the sediments of about 350 feet is indicated by the topographic relief.

Outcrops of the sediments in the Sierra Ladrones Formation on the basalt-capped mesa (secs. 25, 26, 35, and 36) consist mostly of sandy gravels. The sediments and overlying basalt flows are nearly flat lying although, locally, the dips may be 3 to 5 degrees. The topographic relief indicates that the sedimentary unit is at least 300 feet thick on the basalt-capped mesa. This unit erodes easily and is therefore poorly exposed in most places; the best outcrops are in NW/4, sec. 25. Pebble imbrications at this location indicate transport directions from the southeast to the northwest (see Plate 1). Transport directions from outcrops in sec. 14 also indicate transport from the southeast to the northwest.

Basaltic Lavas. A series of basaltic lava flows are interbedded in the Sierra Ladrones Formation in the eastern portion of the study area. These lavas all have similar petrographic characteristics; they consist of a fine-grained mosaic of plagioclase, pyroxene and olivine. These rocks were mapped as two lava flows (Tsb_1 and Tsb_2), based on their general stratigraphic and field relationships.

The Tsb_1 lavas in secs. 13, 14 and NW/4, sec. 24, T. 4 S., R. 2 W. are probably interbedded in sands and gravels of the Sierra Ladrones Formation. These lavas may dip 5 degrees or more to the northeast. The Tsb_2 lavas overlie the sands and gravels, and are not overlain by younger units. They are essentially flat lying, although they may dip as much as 3 degrees to the northeast. Figure 18 shows the outcrop expression of some of these basalts in the western Chupadera Mountains. Orientations can occasionally be obtained on vesicles in the lavas, but in most places, it is difficult to obtain strike-dip data.

The basalt flows have not yet been dated, but they are interbedded in the Sierra Ladrones Formation, which is probably of Pliocene to middle Pleistocene age (Machette, 1978). The Tsb_2 lavas probably have a maximum thickness of about 200 feet; however, the top of these lavas is eroded. The Tsb_1 lavas are not well enough exposed to obtain an accurate thickness estimate but they are probably less than 100 feet thick.

These rocks usually weather to gentle slopes covered with blocky colluvium. Many of these blocks are several

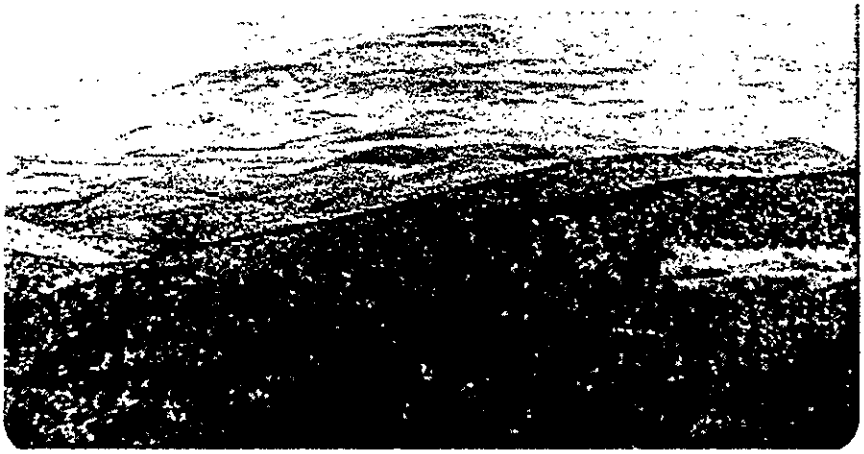

Figure 18. View looking east from Molino Peak. The Chupadera Mountains are in the center of the photograph. The Rio Grande can be seen just above the top of the Chupadera Mountains. The dark outcrops in the center of the photograph are basalts capping a low mesa; the western portion of this mesa is in the thesis area. The basalts overlie sands and gravels of the Sierra Ladrones Formation. A portion of a manganese mine in NW/4, sec. 30, T. 4 S., R. 2 W. can be seen in the lower right corner of the photograph.

feet in diameter and it is frequently difficult to determine whether they are true outcrops or loose blocks.

In hand specimen, the basaltic lavas are usually dense, gray to black, and fine grained. They consist mostly of plagioclase, pyroxene and olivine phenocrysts with a diameter of about 1 mm. Occasionally, a few larger phenocrysts (2 to 4 mm diameter) can be seen. Some of the basalts contain as much as 15 percent vesicles, which are occasionally filled with calcite.

In thin section, the basalts consist of 5 to 10 percent corroded olivine grains surrounded by an intergranular mixture of euhedral to subhedral labradorite and interstitial grains of augite. The two lava flows (Tsb_1 and Tsb_2) both contain similar percentages of constituents, although the amounts of individual minerals may vary by a few percent between flows.

Plagioclase (An_{54}; Michel-Levy method, 10 grains) comprises about 60 to 70 percent of the rock. It has a maximum length of 1.9 mm and averages 0.7 mm in length. Anhedral pyroxene (probably augite) comprises 10 to 25 percent of the rock and is intergrown with the plagioclase. The pyroxene has an average length of 1.0 mm, but some phenocrysts are as long as 4.0 mm. The olivine has an average length of about 0.75 mm; the largest phenocryst is 1.85 mm in length. Some of the olivine has been partially altered to iddingsite. One to 3 percent magnetite and ilmenite (?) also occur in the basalts.

Quaternary Units

Alluvial Fan Deposits

Poorly consolidated gravels and sands that accumulated as alluvial-fan deposits in the eastern portion of the study area were mapped as Quaternary gravels (Qg). Two alluvial fan deposits occur in this area. Both of these fans are currently being dissected by active streams, but the northern fan (secs. 21, 26, and 27, T. 4 S., R. 2 W.) is more dissected than the southern fan. These fans were apparently deposited on an erosion surface that had been formed after the deposition of the Santa Fe Group.

Outcrops of the Quaternary gravels are usually poorly exposed. Where they do occur, they consist of poorly sorted deposits which contain sand to boulder size clasts. Some of the boulders are 1 foot or more in diameter. Most of the clasts are subrounded to well rounded; the coarser clasts (boulders and cobbles) are better rounded than the finer clasts. They consist mostly of tuff of Lemitar Mountains, with lesser amounts of tuff of Caronita Canyon, rhyolite lava and andesite.

Alluvium

Quaternary alluvium includes mostly Holocene deposits of poorly sorted sand and gravel. In most places, these sediments were deposited in active stream channels. However, in the eastern portion of the study area, some of these sediments may have been deposited on relatively undissected alluvial fans.

Talus

Material mapped as talus includes mostly clasts of cobble to boulder size. Some house-size blocks may have slid down the steeper slopes, especially in Sixmile and Ryan Hill Canyons. This unit includes both active and stabilized talus deposits. Some rock glaciers, as much as a mile in length, occur in Ryan Hill Canyon (see Fig. 19). They frequently exhibit wave-like ridges that were probably formed during movement of the talus pile.

Figure 19. Active talus deposit in Ryan Hill Canyon (NE/4, sec. 22, and SE/4, sec. 15, T. 4 S., R. 3 W., unsurveyed). This deposit is about 0.5 miles long and 750 feet wide. Some of the largest talus deposits display wavelike ridges on their surfaces.

STRUCTURE

Regional Structure

The Socorro-Magdalena area is located at the junction of several important regional structures. In this area, the Rio Grande rift transects the northeastern portion of the Datil-Mogollon volcanic field. North of Socorro, the rift is confined mostly to a series of large, single basins. In the Socorro-Magdalena area, the rift widens to include several north-trending parallel basins separated by intrarift horsts (Chapin, 1971, 1978). Northwest of Socorro, the Colorado Plateau forms a high, rigid block that has resisted much of the Tertiary structural deformation. The northeast-trending Morenci lineament and the west-northwest-trending Capitan lineament intersect in the Socorro area (see Chapin and others, 1978, Fig. 1). These regional structural elements combine to produce a complex setting for the local geology.

Pre-existing structures have undoubtedly influenced later structural deformation. Central New Mexico was deformed in late Mississippian to Permian time (ancestral Rocky Mountains) and again during the Late Cretaceous to middle Eocene Laramide orogeny. The Rio Grande rift apparently broke along crustal weaknesses formed during these two structural events (Chapin and Seager, 1975). In west-central New Mexico, the Paleozoic and Mesozoic rocks were folded and thrust faulted during the Laramide orogeny (Kelly and Wood, 1946; Tonking, 1957; and Kelly and Clinton, 1960). These structures are still poorly understood, but they probably influenced the geometry of the later Tertiary structures. Since no pre-Oligocene rocks are exposed in this study area, it is not possible at the present time to evaluate the effects of Laramide structures on subsequent structures.

After cessation of the Laramide orogeny (middle Eocene), the existing uplifts were worn down to produce an erosion surface of low relief (Epis and Chapin, 1975). Detritus eroded from some of the Laramide uplifts was shed into the Baca basin to produce the Eocene (?) Baca Formation (Snyder, 1971). The subsequent mid-Oligocene volcanic and volcaniclastic sedimentary rocks were deposited on a relatively flat surface and were able to spread over wide areas. Between about 32 and 26 m.y. ago, several overlapping cauldrons formed in the Socorro-Magdalena area (Fig. 20). Portions of the North Baldy, Sawmill Canyon and Socorro cauldrons are located within this study area.

The Morenci and Capitan lineaments intersect the Rio Grande rift in the Socorro-Magdalena area (Chapin and others, 1978). These lineaments are major crustal weaknesses and therefore may have had a major influence on the development of subsequent structures. The geometry of the Sawmill Canyon cauldron may have been influenced by the pre-existing Morenci lineament (p. 120). The Rio Grande rift began to form between 32 and 27 m.y. ago (Chapin, 1978), concurrent

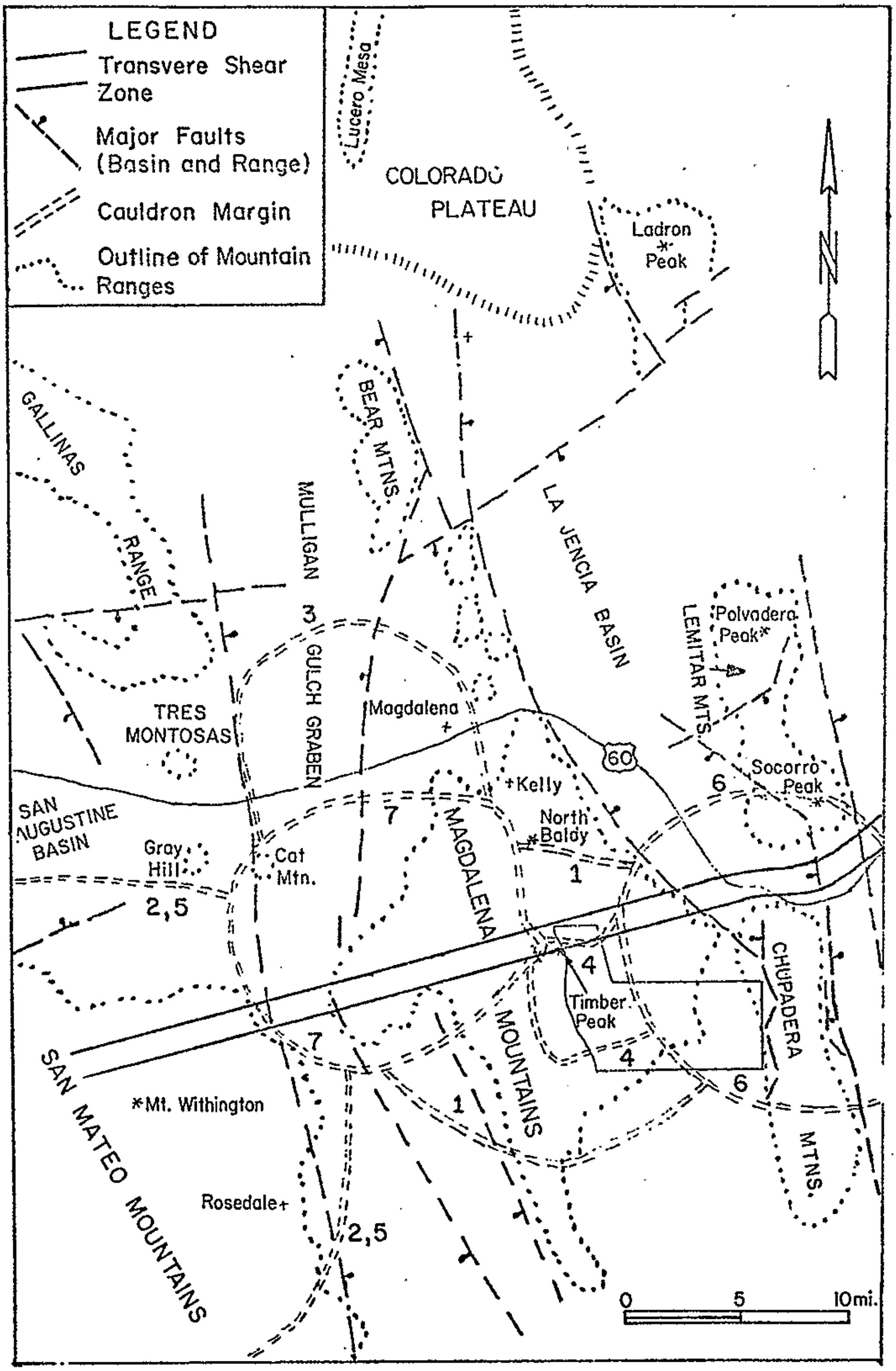

Figure 20. Regional structure map of the Socorro-Magdalena area. From oldest to youngest, the cauldrons and their ash-flow tuff sheets are: 1) North Baldy--Hells Mesa Tuff, 2) Mt. Withington--A-L Peak Tuff, gray-massive member (?), 3) Magdalena--A-L Peak Tuff, flow-banded member, 4) Sawmill Canyon--A-L Peak Tuff, pinnacles member, 5) Mt. Withington--Potato Canyon Tuff, 6) Socorro--tuff of Lemitar Mountains, 7) Hop Canyon--tuff of South Canyon. Figure modified after Blakestad (1978), Chapin and others (1978), and Osburn (1978).

with cauldron development in the Socorro-Magdalena area. The structural geology of the Socorro cauldron may be complicated by contemporaneous rift faulting. It has recently been recognized that the Morenci lineament separates fields of oppositely tilted fault blocks (Chapin and others, 1978). North of this "transverse shear zone," the strata dip to the west; while south of it, the strata dip to the east. Chapin and others (1978, p. 115) state that this shear zone "is acting as an incipient transform fault connecting en echelon segments of the Rio Grande rift." This "transform fault" apparently connects the Albuquerque graben to the northeast, and the Mulligan Gulch and Winston grabens to the southwest. Since this transverse shear zone penetrates deeply into the crust, magmas have tended to rise along this zone more readily than in other areas. Modern magma bodies also appear to accumulate along this zone (Chapin and others, 1978). The transverse shear zone is about 1.5 km or more in width. Within this zone, the structures may be quite complex and produce blocks with erratic orientations.

During the early stages of rifting (32 to 26 m.y. ago), basaltic andesite lavas were interbedded with high-silica ash-flow sheets. Although the silicic volcanism died out, abundant basaltic andesite volcanism continued until about 20 m.y. ago. Chamberlin (1978) correlated this period (32 to 20 m.y. ago) with high heat flow, rapid spreading, and "domino-style" structural deformation

(p. 133) in the Lemitar Mountains. This same structural style occurred in the Magdalena Mountains, probably during the same time interval. In the early Miocene (about 24 (?) m.y. ago), a broad basin (the Popotosa basin) began to develop in the Socorro-Magdalena area. The ancestral Magdalena Mountains were uplifted to provide detritus for this basin in the early to middle Miocene (23 (?) to 15 m.y. ago). By the middle Miocene (15 to 11 m.y. ago), this uplift was largely worn down and covered by Popotosa sediments (Bruning, 1974).

Silicic lavas, domes and intrusions were emplaced along the transverse shear zone in the Socorro and eastern Magdalena Mountains. After this period (during the interval 12 to 7 m.y. ago) large intrarift horsts formed, creating the modern topography (Chapin, 1978) and disrupting the Popotosa basin. Upper Santa Fe sediments (early Pliocene to middle Pleistocene) were deposited with angular unconformity on moderately to steeply tilted strata of the Popotosa Formation. These upper Santa Fe sediments are cut by some high-angle faults, but the sediments usually have gentle dips.

Local Structure

The transverse shear zone divides the Magdalena Mountains into two structural provinces. North of the transverse shear zone, the Magdalena Mountains consist of west-tilted fault blocks that expose Precambrian, Paleozoic and Tertiary rocks. South of the transverse shear zone, east-tilted fault blocks expose mostly Tertiary volcanic rocks. The transverse shear zone transects the northwestern corner of this study area (see Plate 2). Most of this study area is south of the shear zone and the strata dip to the east. However, in secs. 3 and 4, T. 4 S., R. 3 W., unsurveyed (on the transverse shear zone) some of the dips are to the west. North of this study area, the western dips become more consistent.

The study area includes parts of three overlapping cauldrons: the North Baldy, Sawmill Canyon and Socorro cauldrons. The margins of the Sawmill Canyon and Socorro cauldrons pass through this study area. Plate 2 shows these structures.

North Baldy Cauldron

The North Baldy cauldron (Fig. 20) is the oldest cauldron that has been identified in the Magdalena Mountains. Little is known about the shape of this cauldron since it is largely buried beneath younger volcanic rocks. The northern cauldron margin passes just south of North Baldy Peak and trends east-west. This part of the cauldron margin was described by Blakestad (1978). The southern cauldron margin traverses the Devils Backbone (the southern tip of the Magdalena Mountains) with an east-west (?) trend. This part of the cauldron has not yet been mapped, so the details remain to be worked out. The eastern and western parts of the North Baldy cauldron have been buried beneath younger rocks.

The Hells Mesa Tuff erupted from the North Baldy cauldron and caused its collapse (Chapin and others, 1978). Outside the cauldron, this tuff is usually about 600 feet, or less, in thickness; inside the cauldron, it may be as much as 3850 feet thick (Krewedl, 1974). After the Hells Mesa Tuff erupted, a sequence of rhyolite lavas, domes (?) and volcaniclastic sediments filled the cauldron. Bowring (in preparation) informally named these rocks the unit of Hardy Ridge. This unit has so far been mapped in Sawmill and Ryan Hill canyons, and on Hardy Ridge. The details of the cauldron fill of the North Baldy cauldron are poorly understood due to limited exposures.

In this study area, the fill of the North Baldy cauldron has been mapped in two areas: the northwestern corner of the thesis area (secs. 3, 4, and 5, T. 4 S., R. 3 W., unsurveyed) and sec. 36, T. 4 S., R. 3 W. The outcrops in the northwestern corner of the study area consist entirely of a thick sequence of Hells Mesa Tuff. In Ryan Hill Canyon, one outcrop of Hells Mesa Tuff occurs in sec. 36. This tuff is more lithic-rich than the Hells Mesa to the north, but it is very similar in mineralogy. The Hells Mesa in this area is overlain by rhyolite lavas and volcaniclastic sedimentary rocks of the unit of Hardy Ridge.

Sawmill Canyon Cauldron

The Sawmill Canyon cauldron encompasses part of the southeastern Magdalena Mountains (Fig. 20). Portions of the northern and southern cauldron margins are shown on Plate 2. The approximate position of the western cauldron margin is shown in Figure 20; however, since the exact location of this margin is not yet known, it is not shown on Plate 2. S. Roth is currently mapping in southern Sawmill Canyon and a more precise location of the western margin may be known shortly. The eastern limit of the cauldron is not known at the present time since that area is covered with younger rocks.

The Sawmill Canyon cauldron does not have the circular shape attributed to most cauldrons of this type. There are several possible explanations for this. The Sawmill Canyon cauldron is located on the Morenci lineament (Chapin and others, 1978). This lineament is a deep structure that probably controlled the ascent of the magma body that produced the Sawmill Canyon cauldron. The cauldron is roughly elongate parallel with this lineament (Plate 2). The magma body that produced the cauldron may have been elongate parallel to the lineament, and the geometry of the cauldron may reflect this elongation.

Another possible explanation is that the portion of the cauldron shown on Plate 2 is only a small part of a larger cauldron. The Sawmill Canyon cauldron may widen east of the area shown on Plate 2. Since this part of the cauldron is buried beneath younger rocks, it is difficult at the present time to determine the overall shape of the cauldron.

The eruption of the pinnacles member of the A-L Peak Tuff has been correlated with the collapse of the Sawmill Canyon cauldron (Chapin and others, 1978; also see p. 31, this thesis). This tuff may be as much as 3000 feet thick inside the cauldron. If the pinnacles member did erupt from this cauldron, then it was hot enough to develop flow banding and lineated pumice inside the cauldron, but not outside of it.

Inside the cauldron, the A-L Peak Tuff is overlain by andesite and rhyolite lavas, tuffs and sandstones in the unit of Sixmile Canyon. This unit may be as much as 2500 feet thick inside the cauldron, but it is not present outside the cauldron, except possibly in the older Magdalena cauldron.

The northern cauldron margin (Fig. 21) trends approximately east-west from South Baldy to about 0.5 miles northwest of Buck Peak; then it trends northeast until it intersects the younger Socorro cauldron (see Osburn, 1978; Fig. 20, this thesis; and Bowring, in preparation). This cauldron margin is a steeply dipping to vertical contact between the Hells Mesa Tuff on the north and the unit of Sixmile Canyon on the south. Plate 2 shows that part of this margin is interpreted to be the ring fracture and part of it to be the topographic rim of the cauldron. Apparently, little or no slumping occurred along the northern cauldron margin, and the topographic rim of the cauldron is located close to the ring fracture. The northern cauldron margin is exposed to

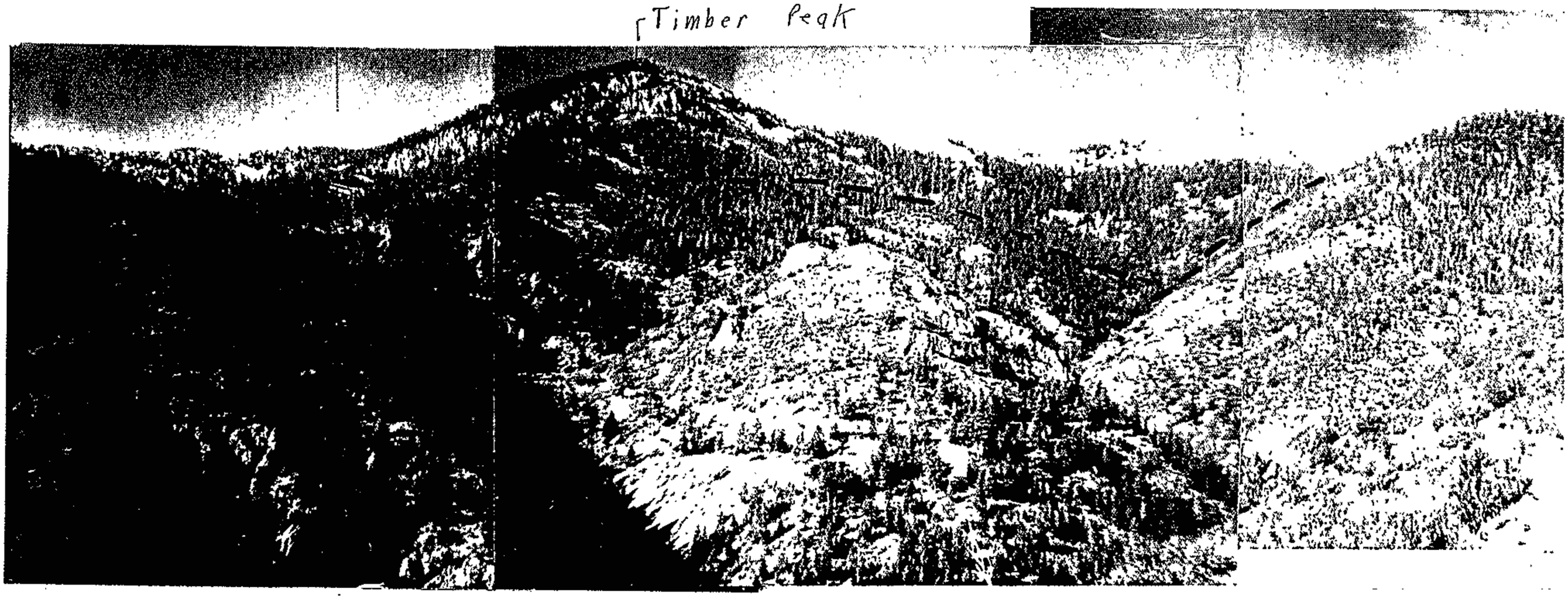

Figure 21. View from the gold mine road showing the northern Sawmill Canyon cauldron margin (shown by dashed lines on photograph). The gold mine (crossed pattern) is located on this cauldron margin. Timber Peak is capped by the lower member of the tuff of Lemitar Mountains. The treeless ridge north of Timber Peak (right skyline) consists of andesite (Txa_1) that filled the northern margin of the Sawmill Canyon cauldron. The area shown here is also on the transverse shear zone.

considerable depth because of topographic relief in excess of 1000 feet and a north-trending horst block that has uplifted a mile-long segment of the cauldron margin in excess of 1000 feet. The level of exposure of the cauldron margin in the gold mine area is more than 2000 feet deeper than at the north end of Timber ridge, about 1.5 miles to the west. Therefore, the northern cauldron margin is mapped as the ring fracture in the horst block (gold mine area), but as the topographic rim outside the horst block (Plate 2).

Osburn (1979, oral communication) has recently identified a remnant of the topographic rim of the southern cauldron margin south of this study area (Plate 2). His mapping has shown that the margin has an east-northeast trend. This margin probably intersects this study area along the southern edge of secs. 33 or 34; unfortunately, this location is entirely covered with younger rocks. This topographic margin is expressed as an unconformity between the unit of Sixmile Canyon and either the underlying Hells Mesa Tuff or unit of Hardy Ridge. The southern topographic rim has also been identified in Sawmill Canyon by S. Roth.

The southern ring fracture of the Sawmill Canyon cauldron has been identified in Ryan Hill and Sawmill canyons (see Plate 2). This ring fracture is placed where the A-L Peak Tuff suddenly becomes thicker and outcrops of the unit of Hardy Ridge end (sec. 26, T. 4 S., R. 3 W., unsurveyed in Ryan Hill Canyon). The outcrops of the unit of Hardy Ridge in this study area are between the main ring fracture and the topographic rim of the Sawmill Canyon cauldron. The A-L Peak Tuff that overlies the unit of Hardy Ridge appears to thin to the southeast against the topographic rim of the cauldron. The wide zone between the southern ring fracture and southern topographic rim of the cauldron indicates that considerable slumping and caving of this cauldron wall occurred during cauldron collapse (Plate 2).

A few small outcrops of tuffs and rhyolites in Ryan Hill Canyon (S/2, sec. 26) may be megabreccia deposited just inside the ring fracture. Lipman (1976) discussed the origin and occurrence of breccias intermixed in intracaldera ash-flow tuffs. He described "megabreccia" as deposits "in which many clasts are so large that the fragmental nature of the deposit is obscure in many individual outcrops" (Lipman, 1976, p. 1397). Figure 22 is a model that Lipman used to illustrate the way in which most megabreccia forms. Most megabreccia accumulates in the deeper portions of the cauldron. Lipman described the deep portions of some cauldron fill deposits that consist mostly of megabreccia with only minor amounts of interbedded tuff. The upper portions of most cauldrons contain only a small amount of megabreccia (Lipman, 1976, p. 1408).

Bowring (in preparation) has mapped what he interprets

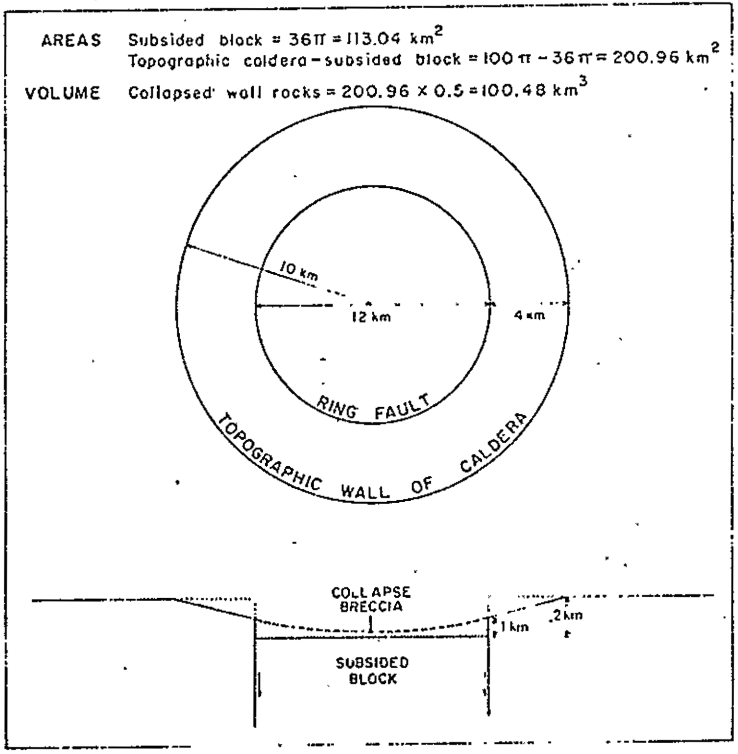

Figure 22. Geometric model presented by Lipman (1976) to illustrate the formation of cauldron collapse breccias. According to Lipman, major slumping and caving of the caldera walls will take place during the early stages of cauldron collapse. Most of this breccia will be interbedded with the intracaldera ash-flow tuff in the deeper portions of the cauldron. Reproduced from Lipman, 1976, Figure 12.

to be megabreccia in Sawmill Canyon. However, megabreccia is generally uncommon in exposures of the fill of the Sawmill Canyon cauldron. This may indicate that only the upper portions of the cauldron are exposed.

Resurgent doming of the Sawmill Canyon cauldron cannot be demonstrated in this study area. Block faulting has obscured many of the relationships that would be needed to prove resurgence if it has occurred.

Socorro Cauldron

The Socorro cauldron is one of the youngest cauldrons in the Magdalena Mountains and is believed to have collapsed during eruption of the tuff of Lemitar Mountains (Chapin and others, 1978). Figure 20 shows the inferred geometry of the Socorro cauldron. Much of the cauldron has been down-faulted and buried beneath younger rocks, so the exact boundaries are not known in most places.

Chamberlin (in preparation) has delineated the northern cauldron margin on Socorro Peak. The tuff of Lemitar Mountains is as much as 3000 feet thick in the northern Chupadera Mountains but only about 400 feet thick in the Lemitar Mountains (Chapin and others, 1978). Chamberlin has also mapped cauldron collapse breccia (mesobreccia in the terminology of Lipman, 1976) and moat deposits (unit of Luis Lopez) in the Chupadera Mountains. The central and southern Chupadera Mountains have not yet been mapped, but reconnaissance indicates that the southern cauldron margin probably transects this mountain range.

The western margin of the Socorro cauldron is not as well defined as the northern margin. If the location of the cauldron margin shown on Plate 2 and Figure 20 is correct, then this margin is probably the hinge zone of a trap-door cauldron. This conclusion was reached because the tuff of Lemitar Mountains does not exhibit a marked thickness increase across the cauldron margin. In sec. 33, T. 4 S., R. 2 W. (inside the cauldron), the tuff of Lemitar Mountains is about 1800 feet thick; while about 3.5 miles west, in sec. 35, T. 4 S., R. 3 W., unsurveyed (outside the cauldron), the tuff of Lemitar Mountains is still about 1400 to 1500 feet thick.

Part of the cause for this thick section, both inside and outside the cauldron, may be that the tuff of Lemitar Mountains filled a depression remaining after the Sawmill Canyon cauldron had collapsed. The slight increase in thickness across the hinge zone would then represent thickening across the cauldron margin.

About 650 feet of the tuff of Lemitar Mountains was measured at the Tower Mine in the western Chupadera Mountains (Osburn, 1978). About 1 km to the southeast, the tuff of Lemitar Mountains is as much as 2800 feet thick. Chapin and others (1978, p. 120) presented several possible explanations for these thickness changes. One possibility is that the buried Sawmill Canyon cauldron acted as a rigid block which did not subside as much as the eastern half of the Socorro cauldron. Another possible explanation is that a major, north-trending, down-to-the-east rift fault located just east of the Tower mine was active during the collapse of the Socorro cauldron. This could have caused the eastern half of the Socorro cauldron to subside more than the western half. The eastern half of the Socorro cauldron also contains as much as 2000 feet of moat deposits (unit of Luis Lopez) between the resurgent dome in the northern Chupadera Mountains and the northern cauldron margin.

Although the Socorro cauldron is believed to be roughly circular (Chapin and others, 1978, Fig. 2), it is possible that the major fault separating the eastern and western portions is actually part of the ring fracture zone of the cauldron. This would imply that the Socorro cauldron is elongate in a north-south direction. The Socorro cauldron erupted during the early stages of rifting along the Rio Grande rift, so the cauldron may be elongate parallel with the rift.

Osburn (1978) delineated a zone that may represent the cauldron margin in his study area (north of this study area). He cited a change in structural style, the presence of intrusions and more intense alteration as evidence for the cauldron margin. The inferred location of the cauldron margin in this study area (Plate 2) is continuous with the margin delineated by Osburn. Two rhyolite intrusions and a rhyolite dome occur along this cauldron margin. Extensive manganese mineralization also occurs along this margin in Chavez Canyon. The zone of intersection between the Sawmill Canyon and Socorro cauldrons contains the most intense mineralization. The Socorro cauldron margin shown on Plate 2 delineates a boundary between continuous outcrops of the tuff of Lemitar Mountains inside the cauldron, and more scattered outcrops outside the cauldron (see Plate 1).

The general regional structural trends in the eastern Magdalena Mountains seem to parallel the curvature of the Socorro cauldron. However, these trends seem to continue outside the cauldron and they may be unrelated to the cauldron development. The evidence presented above does not conclusively delineate the western margin of the Socorro cauldron; however, if the cauldron margin is a hinge zone, then it would not display all the features normally attributed to cauldron margins.

Block Faulting

Middle to late Cenozoic block faulting has extensively deformed the strata in the southeastern Magdalena Mountains. The transverse shear zone (Plate 2 and Fig. 20), which transects the northwestern corner of this study area, separates fields of oppositely tilted blocks. Most of this study area lies to the south of the transverse shear zone, where the strata dip to the east and the faults dip to the west. The structural style frequently produces hogbacks such as those shown in Figure 23.

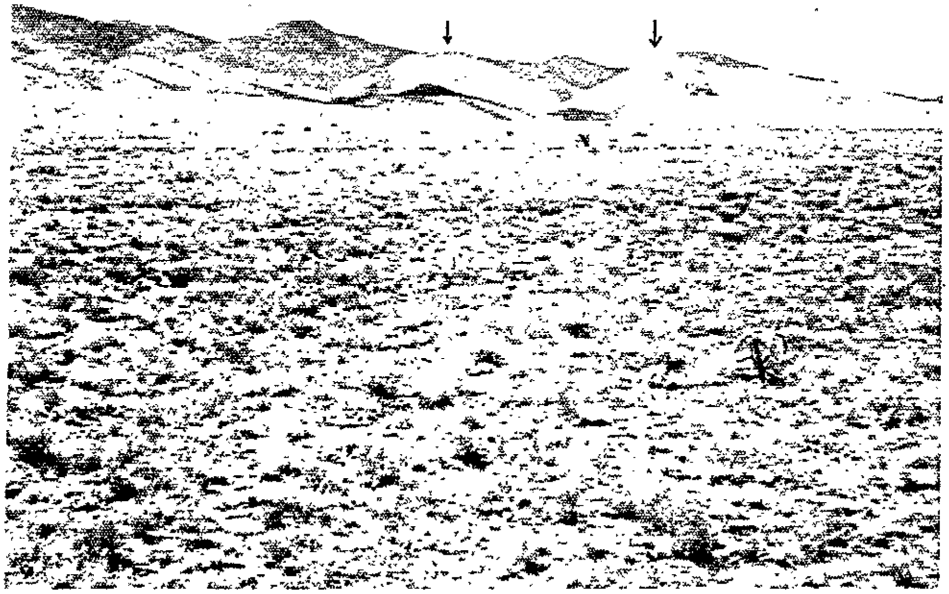

Figure 23. View looking northwest at hogbacks formed by faulted, east-dipping strata. This area is about 4 miles south of the transverse shear zone, so the strata dip uniformly to the east. The left arrow on the photograph points to a hogback formed by the tuff of Lemitar Mountains (27 m.y. old), which dips about 30 to 35 degrees to the east. The right arrow points to a hogback formed by the upper Pound Ranch lavas (10.5 m.y. old). Dips in the Pound Ranch lavas are very erratic, but the lavas probably dip 10 to 20 degrees to the east. These lavas unconformably overlie older Oligocene rocks that were faulted, tilted and eroded before the lavas were deposited. Later, both the Pound Ranch lavas and the older Oligocene rocks were cut by younger faults.

The dip of fault planes varies within the study area. In some places (for example, on Molino Peak), faults with dips as steep as 70 degrees intersect faults with dips as shallow as 30 degrees. Chamberlin (1978) has mapped normal faults in the Lemitar Mountains which dip as shallow as 10 degrees. The Lemitar Mountains are north of the transverse shear zone, so the strata there dip to the west and the faults dip to the east; otherwise, the structural style is the same as that south of the transverse shear zone.

Morton and Black (1975) presented a model for the origin of tilted fault blocks in the Afar region of Africa. This area has undergone rifting and extension along a spreading center. Their model involves progressive tilting of both the strata and the fault planes. Early faults form with a dip of 60 to 70 degrees; but as extension proceeded, these fault planes are tilted so that the dips become more shallow. When the strata are tilted 20 to 30 degrees, the fault planes dip about 40 degrees in the opposite direction. Morton and Black felt that once this point was reached, continued extension would produce new faults with dips of 60 to 70 degrees. Continued crustal extension and tilting of the blocks may eventually produce a third set of faults. Figure 24 illustrates the concept of progressive block tilting. The second and third generations of faults are more closely spaced according to this model.

Regional mapping in the Socorro-Magdalena area has

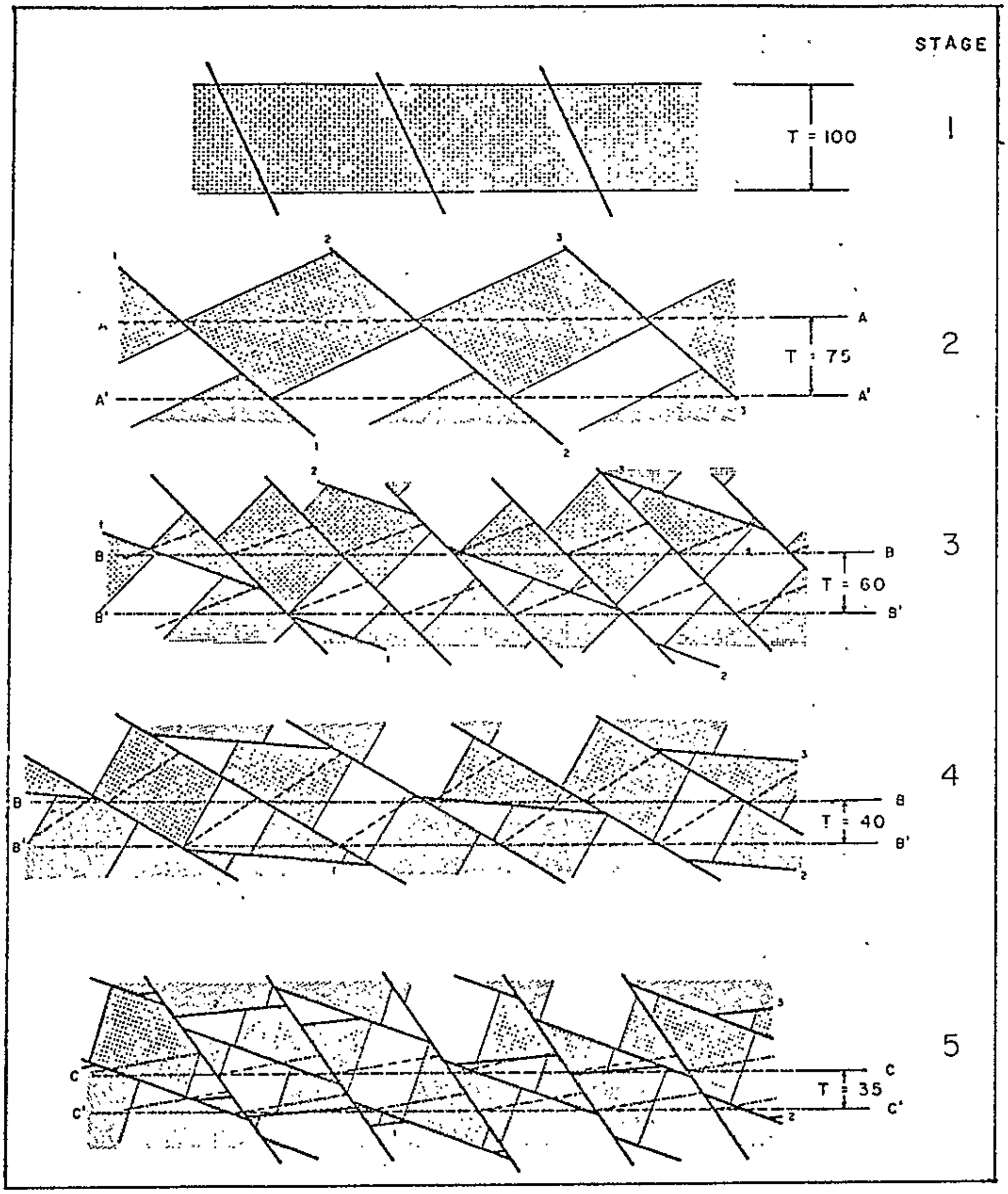

Figure 24. Model developed by Morton and Black to show progressive block tilting. Reproduced from Morton and Black, 1975, Figure 6. T is the mean thickness of any unit.

defined a structural style that appears to be very similar to that described by Morton and Black. Chamberlin (1978) referred to this as "domino-style" faulting. In areas with this structural style, the oldest rocks (Oligocene and early Miocene rocks) are tilted the steepest, are cut by low-angle normal faults, and are the most structurally complex. Most Pliocene and Quaternary strata have dips of 20 degrees or less and are only cut by high angle faults.

Morton and Black envisioned the upper crust undergoing progressive block tilting over lower crust that behaved in a ductile manner. They estimated that faulting would extend about 10 to 30 km into the crust. Although precise depths cannot be given, Chamberlin (1978) considers progressive block tilting to have occurred in the Lemitar Mountains when the rigid crust was thinner than when horst-and-graben-style structures formed.

"Domino-style" structural deformation apparently occurred in the southeastern Magdalena Mountains as well. Although no horizontal normal faults were mapped, some normal faults have dips as shallow as 30 degrees. These faults occur only in Oligocene rocks. Chamberlin (1978) defined two periods of "domino-style" normal faulting in the Lemitar Mountains: 29 to 20 m.y. ago, and 12 to 7 m.y. ago. Since most of the rocks in this study area are Oligocene in age, it is not possible to date all of the faulting. However, based on the timing of the faulting that can be dated, the "domino-style" faulting probably occurred during the two time intervals outlined by Chamberlin. Osburn (1978) reported that some faults in Sixmile Canyon (about 1 mile north of this study area) appear to cut the tuff of Lemitar Mountains, but not the tuff of South Canyon. If this is correct, then regional extension started at least 26 m.y. ago in this area.

The A-L Peak Tuff contains come of the steepest dips of the rocks in the southeastern Magdalena Mountains; it is also among the oldest rocks in this area (32 m.y.). However, this A-L Peak contains laminar flow structures and some of these steep dips could be primary dips. The remaining Oligocene rocks have moderate to steep dips (about 30 to 65 degrees) and are occasionally unconformably overlain by younger rocks. In southern Ryan Hill Canyon (sec. 36), Popotosa mud-flow breccias (early to middle Miocene age) with dips of about 35 degrees unconformably overlie Oligocene rocks with dips between 42 and 65 degrees. The Popotosa Formation is, in turn, unconformably overlain by younger tuffs of uncertain age (possibly associated with the Twt tuffs and therefore about 10 to 12 m.y. old) which have a dip of 10 degrees or less. The Popotosa Formation in sec. 36 overlies a low angle fault (35 degrees) with more than 2000 feet of displacement but it is not cut by this fault. Apparently, the fault was inactive by the time the Popotosa sediments were deposited.

The Pound Ranch lavas and associated tuffs (10 to 12 m.y. old) in the north-central part of the study area unconformably overlie older Oligocene rocks (Fig. 23). Osburn was able to demonstrate several hundred feet of displacement on faults which cut the Oligocene rocks but not the Pound Ranch lavas (see Osburn, 1978, Fig. 27 and Plate 1, section A-A'). Although faults such as those Osburn described could not be mapped in this study area, they undoubtedly exist beneath the Pound Ranch lavas. The youngest documented faults in the study area cut Pliocene (?) basalts in the eastern portion of the study area.

In well-exposed outcrops, the faults in this study area are expressed as breccia zones or as slickensided surfaces, or a combination of the two. Outcrops that display these characteristics are the most abundant where the relief is moderately low (about 500 feet or less). In places with higher relief (for example, Timber Peak, Italian Peak and Ryan Hill Canyon), the faults are rarely exposed and mapping of faults must be based on stratigraphic displacement. As Plates 1 and 2 show, the faults sometimes bifurcate and rejoin again. Also, high-angle faults may intersect low-angle faults, or east-dipping faults intersect west-dipping faults. When this happens, the older fault is displaced by the younger fault.

There are several places in the study area where thick, massive units conceal faulting. For example, south of Molino Peak in SE/4, sec. 23 and SW 4, sec. 24, T. 4 S., R. 3 W., unsurveyed, several faults can be mapped which cut the tuff of Lemitar Mountains and the tuff of Caronita Canyon. However, after these faults enter the sanidine rhyolite lava (Txr_2), they can no longer be followed since they do not displace any mappable units. Primary structures within the rhyolite lava (erratic foliation, shear planes and breccia) make it difficult to follow the faults. In this case, the faults probably turn to the southwest and follow the trend of the rhyolite lava. Several other thick units occasionally conceal faulting. These include the Hells Mesa Tuff, A-L Peak Tuff and the tuff of Lemitar Mountains.

Morton and Black (1975) hypothesized that the faults in the Afar region originally formed with a dip of 60 to 70 degrees. However, in the southeastern Magdalena Mountains, the faults are thought to have formed with a steeper dip (75 to 90 degrees) because where the faults are well exposed, they intersect the bedding with an angle of almost 90 degrees. In Rincon-Madera Canyon (sec. 20, T. 4 S., R. 2 W.), a major fault (about 1500 feet displacement) that dips about 57 degrees to the west intersects bedding that dips about 30 degrees to the east. Osburn (1978) observed the same relationships in the area he studied.

The fault surfaces appear to be essentially planar over the distance through which they can be mapped. The faults on the cross section (Plate 1) were drawn as straight lines, although it is uncertain whether there is any curvature at depth. The model developed by Morton and

Black (1975) could employ either straight or curved fault surfaces. Anderson (1971) developed a model for extensional structures that requires curved fault planes to converge at a few kilometers depth into a subhorizontal zone of décollement. Morton and Black (1975) felt that movement along such a subhorizontal fault in an area undergoing extensional tectonics would be unlikely. In either case, over the depth through which the faults are shown in the cross sections, the faults are thought to be nearly straight.

Gold Mine Area. Although the general structural geology of this study area has been described, there are two smaller areas that need further discussion. The northwestern corner of this study area is a complex region where the transverse shear zone intersects the margin of the Sawmill Canyon cauldron. Two major north-trending faults in this area have produced a horst block. The westernmost fault is downthrown to the west and displaces the tuff of Lemitar Mountains against the Txt unit (in the unit of Sixmile Canyon). The easternmost fault is downthrown to the east and is located about 0.5 miles east of the gold mine. This horst block apparently exposes rocks from deeper in the crust than those rocks on either side of the horst. It contains a high concentration of white rhyolite dikes and a complex series of outcrops.

South of the gold mine (in sec. 10, T. 4 S., R. 2 W., unsurveyed), the A-L Peak Tuff and unit of Sixmile Canyon crop out in confusing outcrops. There are several possible explanations for these outcrop patterns. Some of the strata in this area dip as steeply as 80 degrees to the east. However, all of the mappable faults in that area are near-vertical. The most likely interpretation for this is that the area has undergone two or more periods of faulting. The early faults were tilted along with the strata. These early faults were then cut by younger, high-angle faults. The result is a complex juxtaposition of blocks such as that shown in Figure 24, stages 3, 4 or 5. After an area such as this is eroded, the resulting outcrops may appear confusing.

Some of the tuff units (Twt) could have been emplaced as slide blocks in the andesite lava while the Sawmill Canyon cauldron was being filled. A combination of slide block emplacement and subsequent faulting could also have occurred, but most of the complexities are probably due to faulting.

Southern Margin of the Sawmill Canyon Cauldron. Plate 2 shows a wide zone between the southern ring fracture and southern topographic rim of the Sawmill Canyon cauldron. This area apparently contains some anomalous structural features. Much of the manganese mineralization in Chavez Canyon occurs in brecciated rock, but no faults could be mapped. Also, some major faults appear to die out or bifurcate as they approach the ring fracture. For example, several major faults north of the manganese mines in NW/4, sec. 30, T. 4 S., R. 2 W. appear to die out as they approach the cauldron margin.

G. R. Osburn is currently mapping south of this study area. He reports (1979, oral communication) that many of the faults turn sharply inside this zone. This appears to be the case in this study area as well. A major fault on the western side of Ryan Hill Canyon with more than 2000 feet displacement turns sharply as it crosses the cauldron margin (see Plates 1 and 2). Also, some of the faults in Rincon-Madera Canyon (sec. 28, T. 4 S., R. 2 W.) apparently bifurcate as they approach the ring fracture zone.

ECONOMIC GEOLOGY

Two types of mineralization occur in this study area: gold and silver in the northwestern corner of the study area, and manganese in the south-central portion of the study area. Although the mineralogy of these two types of deposits is different, all of the ore deposits in this study area are localized along the cauldron margins of the Sawmill Canyon cauldron (see Plate 2). Local geologic features (see following sections) also influenced the distribution of the mineralization.

Some of the best documented cauldron structures in the world are located in the San Juan volcanic field. Lipman and others (1976) reported that much of the mineralization in that area was localized by the cauldron structures but that mineralization occurred 2 to 15 m.y. after cauldron collapse. The mineralization is, therefore, genetically unrelated to the magmas that produced the calderas. Lipman and others (1976) state that this situation is typical of many cauldrons in the San Juan Mountains.

Apparently, cauldrons serve primarily as a structural control for the emplacement of later mineralization. The cauldron margins are deep-seated structures that are especially susceptible to later intrusion, alteration and mineralization. This appears to be the case in the Sawmill Canyon cauldron. The gold-silver mineralization on the northern margin is concentrated in a narrow zone along the ring fracture. However, the manganese mineralization on the southern margin occurs in a wide zone between the ring fracture and the topographic rim (Plate 2). The central portion of the cauldron, as it has been defined so far, contains no significant mineralization.

Although the regions described above contain several types of local alteration, there also appears to be a regional potassium alteration that was associated with an ancient geothermal system. This alteration has been previously discussed by Chapin and others (1978), and Osburn (1978), so it will only be mentioned briefly here. Julie D'Andrea (Florida State University) is currently conducting a more detailed geochemical study of this potassium metasomatism. In general, it is characterized by an addition of potassium into the rocks and a depletion of sodium in the same rocks. In the more K_2O-rich rocks, the plagioclase feldspars have been completely replaced by a "clay-like" aggregate.

The exact limits of this alteration zone are not yet known. Chapin and others (1978) reported that the alteration extends from near south Baldy in the Magdalena Range northward to the Ladron Mountains. Some of the rocks in this study area have also been affected. It is apparently most intensive in certain stratigraphic units, such as the tuff of Lemitar Mountains and the tuff of South Canyon. Other units, such as the Hells Mesa Tuff and the A-L Peak Tuff, have undergone sericitic alteration (in the feldspars), but not potassium metasomatism.

Gold Mine Area

A gold-silver mine (Timber Peak mine) and several precious metal prospects occur in the northwestern corner of the study area (secs. 3 and 10, T. 4 S., R. 3 W., unsurveyed). This area is located at the southern end of the Water Canyon district (Jones, 1904; Lasky, 1932). Jones (1904) reported that gold, silver and copper ores had been found in the southern part of the Water Canyon district, but gold and silver are likely to be the only major ores. Although little is known about the history of the Timber Peak mine, Jones (1904) presented the most detailed account of the mining operation.

> The Timber Peak Mining Company in the early season of 1900 completed a 150 ton roll-crushing concentrating plant enclosed in a steel building. The plant was operated only a short time and then closed down indefinitely.
>
> The plant was dismantled the following season and a greater portion of the machinery was shipped to Mexico; the building was removed across the range to Cat Mountain.
>
> Several causes are assigned to this failure; but it seems certain that the blame should not be laid to the mine. The Timber Peak ore bodies are the largest in the district, but must be classed as low grade; beneath the superficial oxidized zone heavy sulfides are encountered.
>
> The ore is about equally divided between gold and silver. (Jones, 1904, p. 127)

The lower workings of this mine are now inaccessible; one short adit remains open, but only minor mineralization was seen in that tunnel. Apparently, the "heavy sulfides" that Jones referred to are no longer accessible in the mine.

The gold-silver mineralization is located in a structurally complex area. The transverse shear zone traverses this area and is probably responsible for most of the complex faulting. The mineralization is also located on the northern ring fracture of the Sawmill Canyon cauldron (Plate 2). Also, a north-trending horst block, transverse to the cauldron margin, has uplifted the mineralized area by 1000 to 2000 feet (p. 137).

The mineralization in this area is also associated with white rhyolite dikes. These dikes intruded several north-trending faults and the east-trending ring fracture of the Sawmill Canyon cauldron. The gold mine occurs at a place where several thick north-trending white rhyolite dikes curve to intersect the ring fracture.

Although there are several varieties of white rhyolite dikes, the most common varieties are a fine-grained, phenocryst-poor rhyolite and a porphyritic rhyolite that contains 10 to 20 percent quartz phenocrysts. The mineralization occurs mostly along the margins of the dikes, although some dikes contain disseminated mineralization in places.

The topographic expression of the dikes indicates that they intruded near-vertical faults (Plate 1 and Fig. 16). Some of the strata in this area dip as steeply as 80 degrees. If the model presented in the structural geology section is correct, then the early faults would have been tilted along with the strata. Therefore, any near-vertical, north-trending faults are probably young. It would be risky to date these faults (and the dikes that intruded them) based on their dip, but it is likely that they are much younger (at least several m.y.) than the Sawmill Canyon cauldron.

The relationships described above are similar to those described by Lipman and others (1976) in the San Juan volcanic field. He reported that the major post-caldera mineralization is closely associated with distinctive, quartz-bearing igneous rocks that were emplaced several m.y. after the calderas had formed. These quartz-bearing igneous rocks were apparently not associated with the igneous activity that produced the calderas. Instead, the calderas act as a major structural control for later igneous activity.

Krewedl (1974, Fig. 4, Section F-F') speculated that the gold mine area was located over a large intrusion that produced the white rhyolite dikes. The main evidence for this is the existence of the dikes themselves. There also appears to be a higher concentration of dikes in the horst block previously discussed.

The gold mine area contains several types of alteration. The andesites in the Spears Formation and some of the andesites in the unit of Sixmile Canyon have been propylitically altered. The most intense propylitic alteration occurs in andesites (from the unit of Sixmile Canyon) found in small dumps around the gold mine. The Hells Mesa Tuff is intensely bleached and propylitically altered throughout the northwestern portion of the study area. The feldspars in the Hells Mesa have been partially replaced by calcite, sericite, and clay minerals (?). All of the dikes in the area have been intensely altered (see sections on white rhyolite, mafic and latite dikes). Silicification commonly occurs along faults and in association with the white rhyolite dikes. The intrusive contacts of some of the white rhyolite dikes are bleached. This is especially true near the gold mine.

Most of the mineralization is confined to the area immediately around the gold mine. As mentioned previously, the lower workings of the mine are not exposed; the part of the mine that is exposed contains only minor mineralization. The most intensively mineralized rocks were found scattered around the entrance to the adits.

The host rocks for this mineralization consist of andesites in the unit of Sixmile Canyon, white rhyolite dikes and Hells Mesa Tuff. No mineralization was seen in the andesites that crop out at the surface; however, the most intense mineralization occurs in andesite fragments found near the mine entrance. These andesites are part of the unit of Sixmile Canyon; they probably occurred near the ring fracture and adjacent to the white rhyolite dikes before they were mined. The white rhyolite dikes also contain mineralization, but is is difficult to determine whether the rhyolites or the andesites contain the most mineralization since most of the mine is now inaccessible. Only minor mineralization was seen in the Hells Mesa Tuff.

Away from the gold mine, only traces of mineralization were seen. This mineralization was always confined to the white rhyolite dikes or to the adjacent intruded rocks. Krewedl (1974) believed that the mineralization (he described only silica veinlets and goethite) is confined to the Hells Mesa Tuff. However, it appears that the mineralization is associated mostly with the white rhyolite dikes, so trace amounts of mineralization could be found in whatever rocks the dikes have intruded.

A detailed mineralogical and chemical study of the ore deposits was not conducted for this study. Samples were examined with a hand lense and a binocular microscope. Based on this study, the mineralization consists of barite, pyrite, chalcopyrite, galena and sphalerite. The sulfide minerals are usually disseminated throughout the host rock. However, the barite usually occurs as veins along joints and white rhyolite dikes; it probably filled open spaces.

The only samples that contain significant sulfide mineralization are those collected at the gold mine. Elsewhere, only trace amounts of pyrite and chalcopyrite (?) were seen. The gold mine samples always contain less than 20 percent disseminated sulfide minerals. At least 90 percent of this mineralization consists of pyrite. Only a few percent of the other sulfide minerals were seen and these occur in only a few samples. These minerals (chalcopyrite, galena and sphalerite) usually occur as small (less than 1 mm diameter) crystals disseminated in the host rock and in small quartz veinlets. Limonite pseudomorphs (after pyrite) are common in the rocks and limonite stain frequently coats the joint surfaces.

The gold and silver reported by Jones (1904) probably occurs as impurities or inclusions in other minerals or in microscopic crystals. No gold or silver minerals could be identified in hand specimens or under the binocular microscope.

Manganese Mineralization

Most of the manganese mineralization in this study area is concentrated in a wide zone between the southern ring fracture and the southern topographic rim of the Sawmill Canyon cauldron. Minor manganese mineralization also occurs north of this zone; it consists mostly of manganese minerals coating joint surfaces, but no mines or prospects were found. A small manganese prospect occurs in the Pliocene (?) basalts near the eastern margin of the study area.

Numerous prospects and mines occur within the mineralized zone (Plate 2). The most intense manganese mineralization is in NW/4, sec. 30, T. 4 S., R. 2 W.; and NE/4, sec. 25, T. 4 S., R. 3 W., unsurveyed. This area is located at the intersection of the southern ring fracture of the Sawmill Canyon cauldron with the hinge zone of the Socorro cauldron. The boulder shown in Figure 25 came from a large calcite vein in this area. Most of the ore in the mineralized zone was probably low grade. All the ore mined occurred

Figure 25. Boulder of banded black and white calcite and minor manganese minerals from a manganese mine in NE/4, sec. 25, T. 4 S., R. 3 W., unsurveyed. This boulder came from a 15- to 20-foot-wide vein which had been strip mined.

within about 50 feet of the surface; it was apparently stripped from shallow pits, since no adits were seen.

Although the cauldron margin is the major regional control for the mineralization, local structures control the precise location of the ore. The rocks in the zone between the ring fracture and the topographic rim have been brecciated in many places where faults could not be mapped. The exact cause of this brecciation is not clear, but it could be related to the existence of the cauldron margin. Usually the brecciation produced large spaces between the breccia fragments. These fragments were usually not rotated extensively or sheared. Much of the breccia has been cemented with manganese minerals and calcite. Most of the north-northwest-trending faults shown on Plates 1 and 2 are also mineralized. This mineralization occurs as a coating on joint surfaces and as an open-space filling where larger voids were formed.

The mineralization occurs in rocks as old as the unit of Sixmile Canyon and as young as the Pliocene (?) basalts (Tsb_2). However, only one prospect was found in the young basalts and the Oligocene rocks appear to be more highly mineralized than the basalts. It appears that the main control for mineralization in the Oligocene rocks was structural. Therefore, much of the mineralization probably occurred after all of the Oligocene rocks were deposited but before the Pliocene (?) basalts erupted.

The host rock in the immediate vicinity of the ore deposits is frequently bleached and the feldspars may be altered to clays. However, this alteration appears to be very irregularly distributed around the ore deposits. Occasionally, fault zones are bleached in places where there is little or no mineralization. Silicification occasionally occurs around faults and adjacent to mineralization, but it is much less abundant than in the gold mine area. Calcite is commonly found along faults and in association with the mineralization.

Several large calcite veins occur in the study area. The largest vein occurs in NE/4, sec. 25, T. 4 S., R. 3 W., unsurveyed, and is at least 10 feet wide. The boulder shown in Figure 25 is from this vein. Osburn (1978) reported that one calcite vein in his study area is at least 100 feet wide. The large veins in this study area consist mostly of banded, coarsely crystalline, white calcite, which is interlayered with lesser amounts of black calcite and manganese oxides.

A detailed mineralogical and geochemical study of the manganese minerals in this study area has not yet been conducted. The major minerals reported in other parts of Socorro County are psilomelane, hollandite, cryptomelane and coronadite (Hewett, 1964; Willard, unpublished report). Miesch (1956, p. 25) concluded that psilomelane was the most prominent ore mineral in the Luis Lopez district. The Luis Lopez district is a major manganese district located about 5 to 10 miles east of the manganese mineralization in this study area.

All of the manganese oxides occur as open-space filling. Most of the minerals occur in massive, botryoidal and banded aggregates. Accessory minerals include calcite, quartz, barite and fluorite (only found in one area).

CONCLUSIONS

This study has made several contributions to the geology of the southeastern Magdalena Mountains. These contributions are divided into three sections: stratigraphy, structural geology and economic geology.

Stratigraphy

All of the rocks exposed in this study area are of Tertiary age; volcanic units comprise the majority of the stratigraphic units. A smaller number of sedimentary units are interbedded in the Tertiary volcanic rocks. In general, these volcanic and sedimentary units fit well with the regional stratigraphy defined by Chapin and others (1978). However, there are several features of these units in this study area that are unique to the southeastern Magdalena Mountains, or that are important in understanding the regional geology of the Socorro-Magdalena area. These features are listed below from oldest to youngest.

1) A thick accumulation (at least 2000 feet) of Hells Mesa Tuff exists in the southeastern Magdalena Mountains. The Hells Mesa Tuff is unusually thick in this study area because the area is located entirely within the North Baldy cauldron, which was the source for the Hells Mesa Tuff (Chapin and others, 1978). A heterogeneous assemblage of rhyolite lavas and domes (?), tuffs, and volcaniclastic sediments (the unit of Hardy Ridge) filled the cauldron after the Hells Mesa Tuff was erupted.

2) A thick accumulation (at least 3000 feet) of A-L Peak Tuff crops out in Ryan Hill and Sixmile canyons. This unusual thickness occurs within the Sawmill Canyon cauldron (Plates 1 and 2, and Fig. 20), which is thought to have collapsed during eruption of the pinnacles member of the A-L Peak Tuff. Inside the cauldron, the A-L Peak Tuff is very densely welded; it is flow banded and contains lineated pumice in many places. The A-L Peak Tuff thickens dramatically inside the ring fracture of the cauldron; it appears to thin as it approaches the southern topographic rim of the cauldron.

3) The unit of Sixmile Canyon is a thick (at least 2500 feet), heterogeneous assemblage of rhyolite and andesite lavas, tuffs, and volcaniclastic sedimentary rocks that filled the Sawmill Canyon cauldron after the A-L Peak Tuff was erupted. This unit is confined to the Sawmill Canyon cauldron.

4) The tuff of Lemitar Mountains is unusually thick in the southeastern Magdalena Mountains. This tuff probably erupted from the Socorro cauldron (Chapin and others, 1978); a slight increase in thickness occurs in the tuff across the "hinge zone" of the Socorro cauldron. The tuff of Lemitar Mountains may have partially filled a depression remaining in the Sawmill Canyon cauldron; this could account for the unusual thickness of the tuff outside the Socorro cauldron.

5) Deposits similar in appearance and stratigraphic

position to the unit of Luis Lopez (moat deposits of the Socorro cauldron) are present in the southeastern Magdalena Mountains (western part of the Socorro cauldron), but are usually less than 50 feet thick. This probably indicates that the eastern part of the Socorro cauldron subsided further than the western part. These rocks include basaltic andesite lavas (Tba_1), tuffs and sandstones, rhyolite lavas and a rhyolite dome (?). Some of these rocks were deposited in a large paleovalley in southern Ryan Hill Canyon. The basaltic andesite lavas (Tba_1) pinch out from north to south.

6) The lower Popotosa Formation (mostly mudflow deposits) was deposited on an extensive erosion surface in the southeastern Magdalena Mountains. In this study area, the lower Popotosa was probably confined mostly to paleovalleys and depressions.

7) A thick sequence of 11.8 to 10.5 m.y. old, rhyolite lavas (Pound Ranch lavas) erupted from a vent located about 1 mile north of this study area (Osburn, 1978). These lavas are confined to the north-central portion of the study area. They unconformably overlie several units, including basaltic andesite lavas (Tba_2), the tuff of South Canyon and the lower Popotosa Formation. Lavas of equivalent age and similar composition overlie the Popotosa Formation in the Socorro Peak area.

8) The Sierra Ladrones Formation, probably of early Pliocene to middle Pleistocene age, crops out in the

eastern portion of the study area. This formation consists of poorly consolidated sands and gravels with interbedded basaltic lavas. Paleocurrent directions, taken from pebble imbrications in the sedimentary units, are from the southeast to the northwest (Plate 1).

Structure

Parts of several overlapping cauldron structures occur in the southeastern Magdalena Mountains. These cauldrons have had a major influence on the geologic evolution of this area. Based on this study, several conclusions can be made about these cauldron structures:

1) This study area occurs entirely inside the North Baldy cauldron. A thick sequence of Hells Mesa Tuff, which erupted from the cauldron and partially filled it, crops out in the northwestern corner of the study area. The unit of Hardy Ridge, also part of the cauldron fill, occurs in the southern part of Ryan Hill Canyon.

2) Parts of the northern and southern cauldron margins of the Sawmill Canyon cauldron traverse this study area (Plate 2). A segment of the ring fracture and part of the topographic rim of the cauldron have been delineated along the northern cauldron margin. Apparently, little or no slumping occurred along this part of the northern cauldron margin and the ring fracture and topographic margin nearly coincide. Considerable slumping, however, occurred along the southern margin and produced a wide zone between the

ring fracture and the southern topographic rim of the cauldron.

3) The part of the Sawmill Canyon cauldron that has been defined so far appears to be elongate in an east-northeast direction (Plate 2). The Morenci lineament, of similar trend, transects the northwestern portion of this study area and may have influenced the shape of the Sawmill Canyon cauldron.

4) The western margin of the Socorro cauldron does not display all of the features usually attributed to cauldron margins. However, the tuff of Lemitar Mountains does appear to thicken from west to east across this margin, which appears to be a hinge zone on a trap-door cauldron. Two intrusions and a rhyolite dome (?) occur near the cauldron margin.

This study area is located within the Rio Grande rift. Extensive block faulting, caused by extension in the rift, has broken the study area. Several conclusions can be reached about the structures related to extension in the rift:

1) The transverse shear zone (Chapin and others, 1978) transects the northwestern portion of this study area. This structure separates fields of oppositely tilted fault blocks. Most of this study area is located south of the transverse shear zone, where the strata dip to the east and most of the faults dip to the west. However, a small part of the study area (the northwestern portion) contains strata that dip to the west.

2) The fault-block tilting probably occurred in a manner similar to that envisioned by Morton and Black (1975) for the Afar rift in Africa. Chamberlin (1978) described a similar structural style in the Lemitar Mountains which he called "domino-style" faulting. This structural style involves the progressive tilting of fault blocks and the formation of new generations of faults when the old faults become too shallow for movement to occur along them (Fig. 24).

3) The southern cauldron margin of the Sawmill Canyon cauldron has probably influenced the later faulting. Some of the extensional faults appear to die out or bifurcate as they approach the cauldron margin. Also, some of the faults bend as they cross the cauldron margin.

Economic Geology

Several conclusions can be reached about the mineralization in this study area:

1) All of the significant mineralization is localized along the cauldron margin of the Sawmill Canyon cauldron. The main importance of this cauldron is that it is a deep structure which may act as a control for subsequent mineralization.

2) Gold-silver mineralization is concentrated in a narrow zone along the northern margin of the Sawmill Canyon cauldron. The mineralization is also closely associated with the white rhyolite dikes that intruded many of the north-trending faults and the east-trending

ring fracture of the Sawmill Canyon cauldron.

3) The manganese mineralization is concentrated in a wide zone between the ring fracture and the southern topographic rim of the Sawmill Canyon cauldron. This mineralization occurs as an open-space filling in breccia and along faults. The mineralization occurs in rocks as old as the unit of Sixmile Canyon and as young as the Pliocene (?) basalts (Tsb_2). However, the Oligocene rocks contain most of the mineralization.

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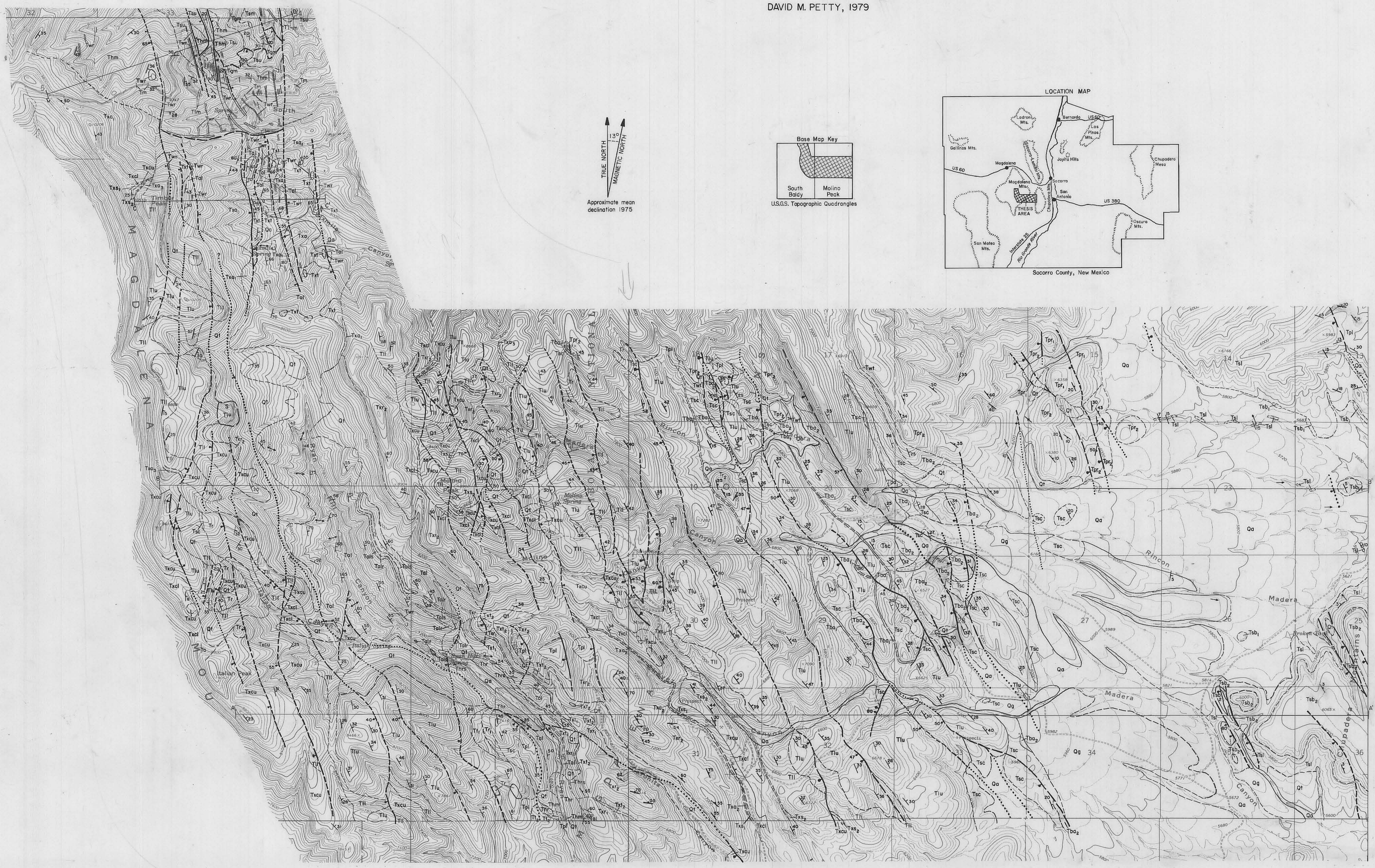
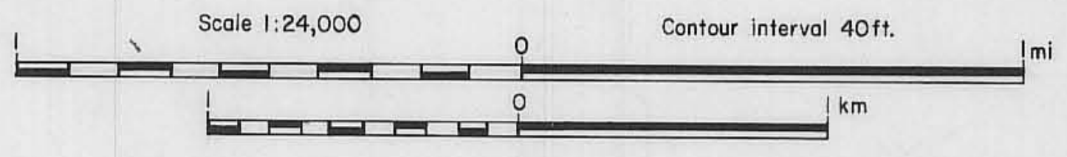
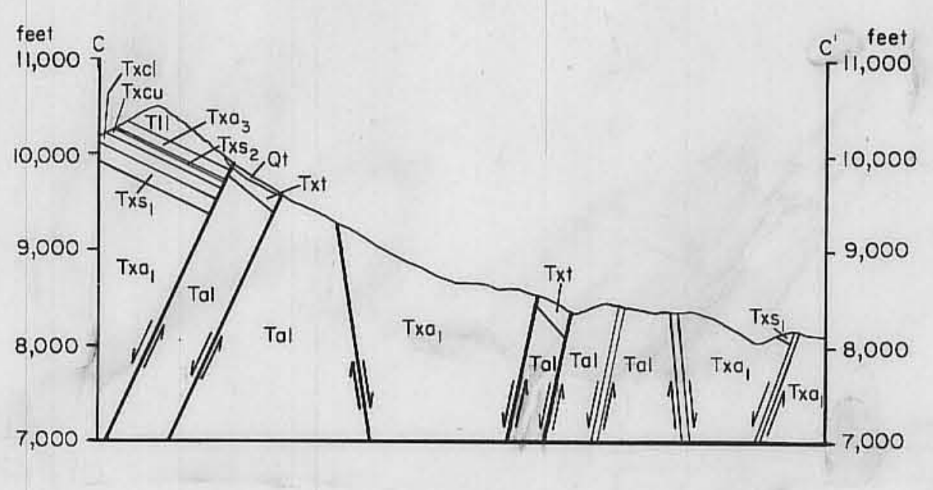
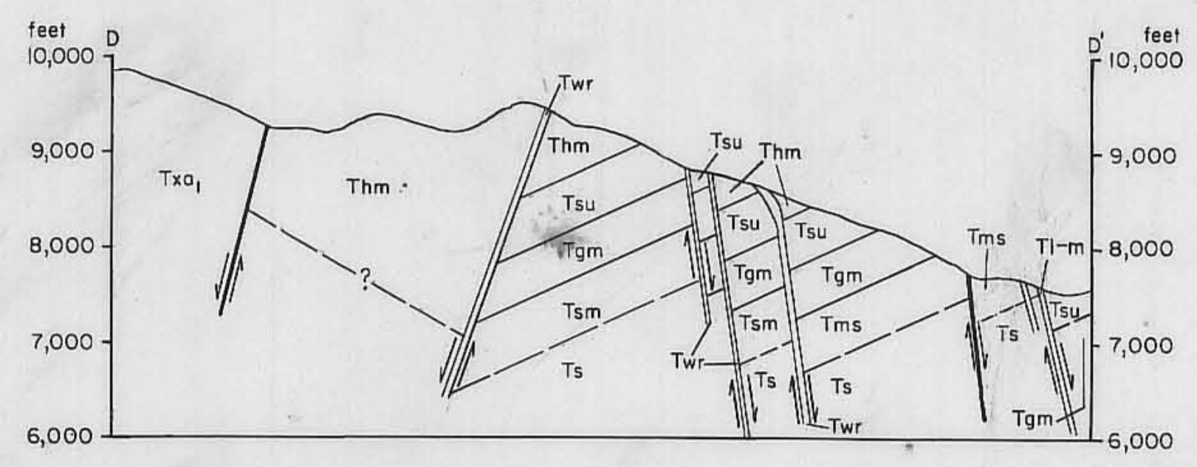
GEOLOGIC MAP AND SECTIONS OF THE SOUTHEASTERN MAGDALENA MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

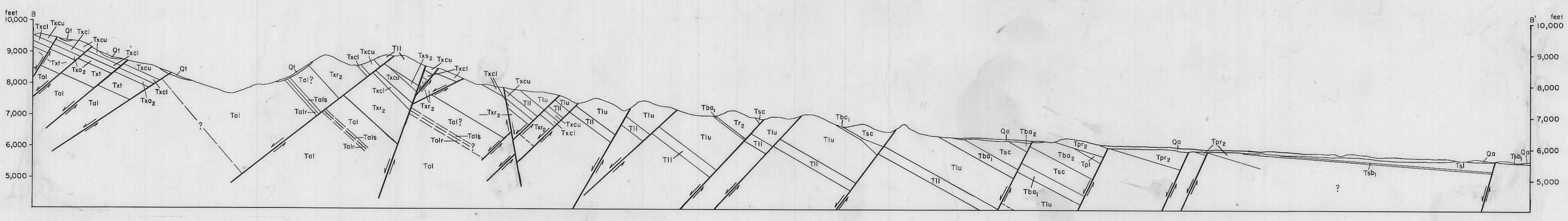
DAVID M. PETTY, 1979

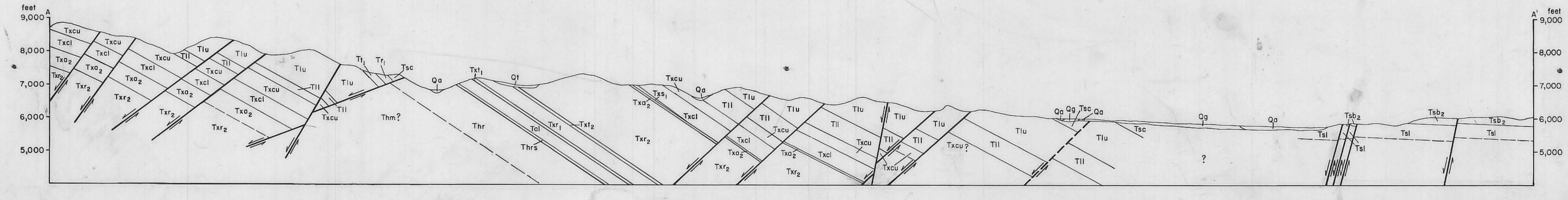












EXPLANATION

Unit	Description	
Qt	talus and colluviun	Quaternary
Qa	alluvium	
Qg	alluvial fan deposits: gravels and sands	Santa Fe Group
Tsb2	basaltic lavas	Sierra Ladrones Formation — Pliocene
Tsl	conglomerates, sandstones and mudstones	
Tsb1	basaltic lavas	
Tpr2	upper Pound Ranch lavas: quartz latite	Miocene
Tpr1 Twt	lower Pound Ranch rhyolite lavas (Tpr1) and associated tuffs (Twt)	
Tpl	lower Popotosa Formation: mudflow deposits, fanglomerates	
Tba2	basaltic—andesite lavas	Oligocene
Tsc	tuff of South Canyon: rhyolite ash—flow tuff	
Tr2	rhyolite dome	
Tba1	basaltic andesite lavas	
Tlu	upper crystal—rich member	tuff of Lemitar Mountains
Tll	lower crystal—poor member	
Txa3, Txs2	Txa3 — andesite lavas Txs2 — sandstone	unit of Sixmile Canyon
Txcu	Txcu — upper crystal—rich member	tuff of Caronita Canyon
Txcl	Txcl — lower crystal—poor member	
Txs1	Txs1 — sandstones and siltstones	
Txa2	Txa2 — andesite lavas	
Txr2	Txr2 — sanidine rhyolite lava	
Txa1	Txa1 — andesite lavas and laharic breccias	
Txt2	Txt2 — tuffs, sandstones and andesite lavas	
Txr1	Txr1 — rhyolite lavas	
Txt1	Txt1 — tuffs and sandstones	
Txt	Txt — tuffs and sandstones	
Tal, Tals, Talr	A-L Peak Tuff: crystal—poor, rhyolite ash—flow tuff; interbeded rhyolite lavas (Talr); and sandstones and tuffs (Tals)	
Thrs Thr	unit of Hardy Ridge: crystal—poor, rhyolite lavas (Thr); and sandstones and tuffs (Thrs)	
Thm	Hells Mesa Tuff: crystal—rich, quartz—rich, rhyolite ash—flow tuff	
Tsu	latite to andesite lavas and laharic breccias	Spears Formation
Tgm	tuff of Granite Mountain: latite ash—flow tuff	
Tsm	"turkey track" andesite lava flows	
Ts	latitic and andesitic conglomerates and sandstones (section D-D' only)	

Unit	Description
Tt2	crystal—poor, slightly welded tuff
Tr1	rhyolite lavas—in southern Ryan Hill Canyon
Tt1	tuffs and sandstones in southern Ryan Hill Canyon
Tr	rhyolite intrusions
Twr	white rhyolite dikes
Tm	mafic dikes
Tl—m	latite to monzonite dikes

SYMBOLS

Contact: dashes where approximately located, dotted where concealed

50

Faults: long dashes where approximately located, short dashes where inferred, and dotted where concealed; arrow and number indicate dip direction and inclination of fault plane, ball and bar on downthrown block

S

Slide block

35 inclined — vertical

Strike and dip of bedding

45

Strike and dip of foliation in lavas

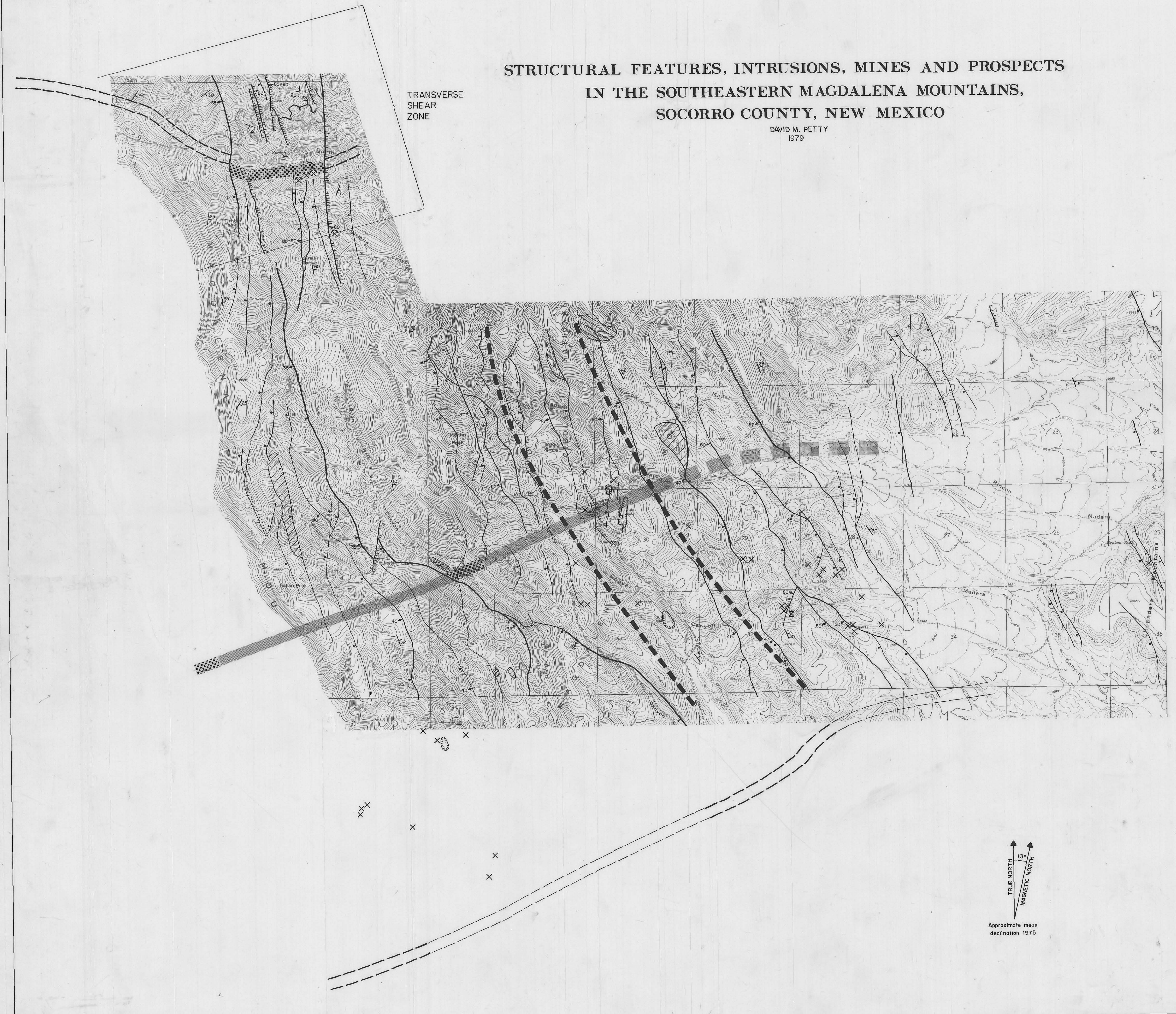
Trend of lineation

Transport direction in sediments, from pebble imbrication

PLATE I

STRUCTURAL FEATURES, INTRUSIONS, MINES AND PROSPECTS IN THE SOUTHEASTERN MAGDALENA MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

DAVID M. PETTY
1979



EXPLANATION

The transverse shear zone separates fields of oppositly tilted fault blocks (Chapin and others, 1978). To the south, the strata dip to the east and most faults are downthrown to the west. To the north, the strata dip to the west and most faults are downthrown to the east.

Normal Fault: long dashes where approximately located; short dashes where inferred; dotted where concealed. Arrow and number indicate dip direction and inclination of fault plane. Ball on faults downthrown to the west; hatchures on faults downthrown to the east.

40 65

Fault displacement:
> 1000 feet
300–1000 feet
< 300 feet

35 Strike and dip of bedding.

▩ Mapped ring fracture of Sawmill Canyon cauldron.

▒ Projected ring fracture of Sawmill Canyon cauldron.

Remnant of topographic wall of Sawmill Canyon cauldron. Heavy lines where mapped and light lines where inferred.

Inferred hinge zone of the Socorro trap-door cauldron.

△△△△ Megabreccia: consists mostly of blocks derived from the unit of Hardy Ridge.

Phenocryst-poor rhyolite dome and intrusions (excluding white rhyolite dikes).
Rhyolite intrusions with abundant, large sanidine phenocrysts.
} ages overlap and range from post-tuff of Lemitar Mountains to post tuff of South Canyon

Gold-silver mine

⚒ Gold-silver prospect

Large manganese strip mine

⧖ Small manganese strip mine

× Manganese prospect

Structure based on Plate I (this study) and geologic mapping by S.A. Bowring (in preparation), G.R. Osburn (in progress), and S.J. Roth (in progress).

Approximate mean declination 1975

Scale 1:24,000 Contour interval 40 ft.
1 0 1 mi
1 0 1 km

PLATE 2

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