GEOLOGY OF THE TRES MONTOSAS-CAT MOUNTAIN AREA, SOCORRO COUNTY, NEW MEXICO

A Thesis

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Master of Science

by

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ABSTRACT

The Tres Montosas-Cat Mountain area is situated on a relatively deeply eroded horst between the Gallinas and San Mateo Mountains. This horst is called the Gallinas uplift. Paleozoic sedimentary rocks are represented by small exposures of the Abo Formation and by rocks in the Banner drill hole which may be part of the Sandia Formation. Bedrock consists dominantly of volcaniclastic sedimentary rocks, welded ash-flow tuffs, and minor interbedded lava flows of the Spears Formation (early to middle Oligocene). Remnants of ash-flow tuffs of the Hells Mesa and A-L Peak Formations overlie the Spears Formation, especially in the southern portion of the district. A new stratigraphic unit, the tuff of Gray Hill, is described. It overlies the A-L Peak Tuff and consists of a crystal-poor, moderately to densely welded, multiple-flow compound cooling unit of ash-flow tuffs. Northeast-trending paleovalleys were important in controlling the distribution of many of the ash-flow tuffs. Mafic lava flows, of probable late Pliocene age, cap piedmont gravels in grabens formed during basin and range faulting. Chemical analyses of these flows (basalt of Council Rock) indicate that they are high in silica and alkalies and are alkali-trachytes to trachyandesites.

Major structural features of the map area are: 1.) the Mt. Withington cauldron margin; 2.) high-angle faults with a dominant north-northwest trend; 3.) a north-trending monoclinal fold forming the eastern flank of the Gallinas uplift; and 4.) northeast-trending faults related to the Morenci-Magdalena lineament and the San Augustin arm of the Rio Grande rift. A subsidary graben extends northward from the edge of the Mt. Withington cauldron as do dikes and gold-bearing veins of the Cat Mountain district. The monoclinal flexure and some of the north-trending, high-angle faults are the result of the intrusion of an elongate Oligocene batholith approximately twenty miles long. Intrusives from this batholith rose to within 2000 feet of the surface. Two intrusives are exposed in the map area and a third is inferred from felsic dike swarms, epithermal quartz veins, hydrothermal alteration, and a weak aeromagnetic low. Late Cenozoic block faulting uplifted the San Mateo and Gallinas horsts; the Tres Montosas-Cat Mountain area occupies a subdued area where the San Augustin arm of the Rio Grande rift cuts the San Mateo-Gallinas axis.

Hydrothermal alteration, related to the movement of fluids along faults, is widespread in the map area. Analyses of fluid inclusions from vein fluorite indicate that the ore-forming fluids were saline solutions at temperatures near 180°C. The solutions contained lead, copper, and zinc. A small oxide copper deposit, the Sixty prospect, of probable supergene origin is exposed south of Highway 60. Core from a deep drill hole at the Sixty prospect shows altered rocks to a depth of 1622 feet with chalcopyrite, sphalerite, and galena present in veinlets near the bottom. The alteration and mineralization in the drill hole suggest that the hole is near a buried intrusive. The Tres Montosas-Cat Mountain area is one of the most favorable parts of the Magdalena area for base metal exploration.

INTRODUCTION

Purpose of the Investigation

The objectives of this investigation are to determine the stratigraphic relationships, structural trends, distribution of intrusive rocks, and the distribution of mineralization and hydrothermal alteration in the Tres Montosas—Cat Mountain area, Socorro County, New Mexico. This thesis was undertaken as part of the extensive mapping project of the Magdalena area conducted by the New Mexico Bureau of Mines and Mineral Resources.

The objectives listed above are important for the following reasons:

1. The stratigraphic relationships provide further data for correlating rock types between the Bear, Magdalena, Gallinas, and San Mateo Mountains and allow the extension of geologic work westward into the heart of the Datil-Mogollon volcanic province.

2. An understanding of the structural trends may be used to locate additional intrusive bodies with the possibility of associated porphyry- or replacement-type deposits.

3. The overall relationships between stratigraphy, structure, mineralization and the distribution of intrusive rocks are important in evaluating the economic potential of the map area.

Location and Accessibility

The Tres Montosas-Cat Mountain area is located approximately ten miles west of Magdalena, New Mexico, in the northeast corner of the Datil-Mogollon volcanic province (see Fig. 1). The area mapped covers a nearly rectangular area of about forty square miles. The northern part is in the Cibola National Forest. The area is approximately bounded by 37° 7' N latitude on the north, 34° 00' N latitude on the south, 107° 23' 07" W longitude on the east, and 107° 28' 30" W longitude on the west.

Easy access to the area is provided by several routes. U. S. Highway 60 crosses the north-central part and New Mexico Highway 52 provides access to the southwestern part. The eastern and southeastern parts can be reached by the Cat Mountain Ranch road and Tres Montosas can be reached by the North Lake road. Numerous unimproved ranch roads and woodcutters trails provide easy access to the remainder of the area. Only in sandy areas along the northern boundary is a four-wheel drive vehicle required.

Previous Investigations

The earliest recorded geologic investigation in the Tres Montosas area was conducted by Herrick (1900) as part of a reconnaissance survey of western Socorro and Valencia Counties. He observed that the Datil, Gallinas, and Bear Mountains were composed of trachyte and rhyolite intrusives. Lindgren, Graton, and Gordon (1910) presented a general discussion of

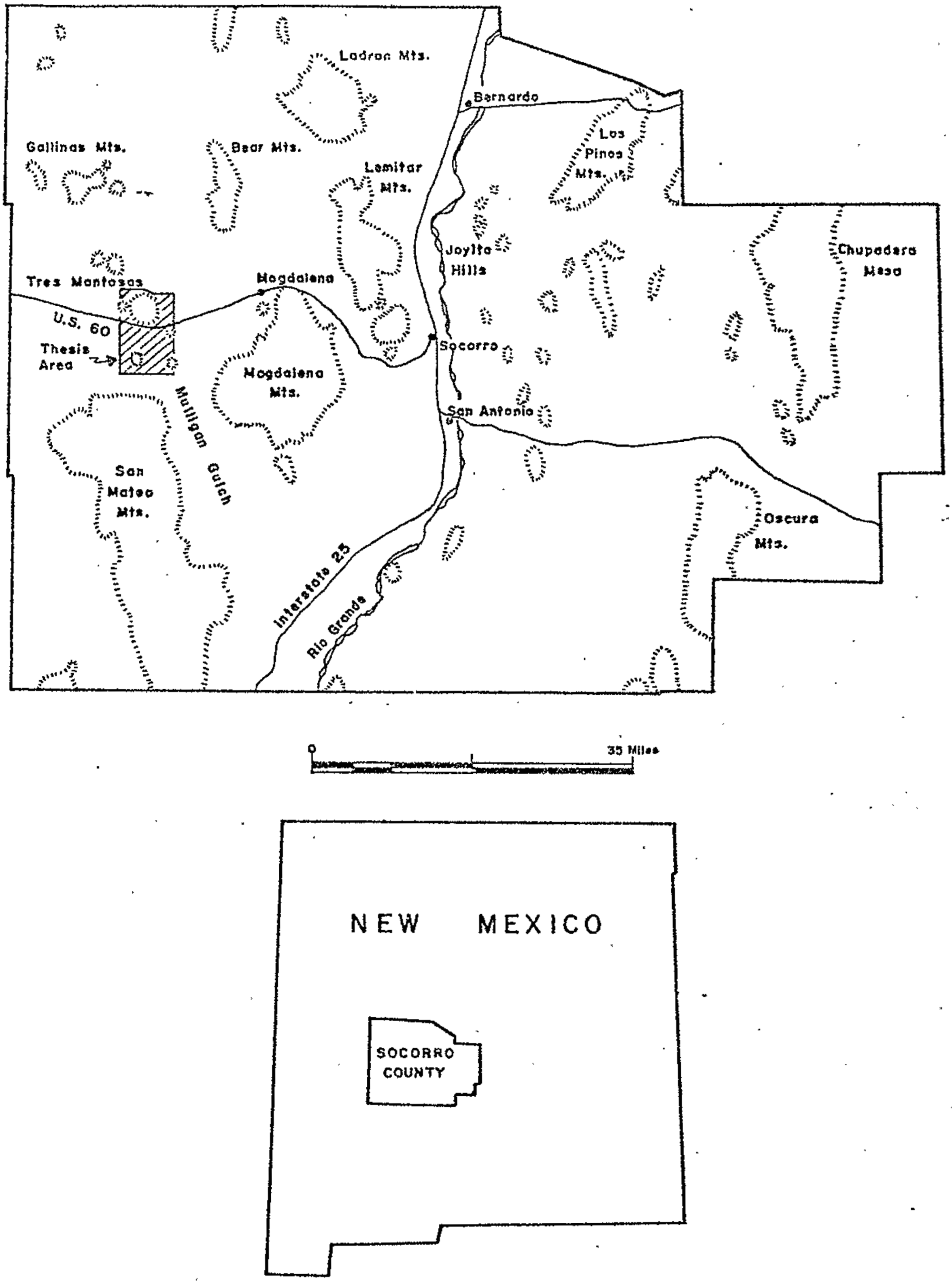

Figure 1. Location map of the Tres Montosas-Cat Mountain area.

geology and ore deposits of the Magdalena mining district and the Rosedale mining district in the San Mateo Mountains. Winchester (1920) observed volcanic rocks overlying sedimentary rocks of Cretaceous age along Alamosa Creek (now the Rio Salado) and named these the Datil Formation. He described a type section consisting of tuffs, rhyolites, conglomerates, and sandstones in the northern Bear Mountains.

Lasky (1932) catalogued and described the base metal deposits of Socorro County which included brief descriptions of the gold mines near Cat Mountain and the mines of the Council Rock district just north of the map area. Laughlin and Koschman (1942) published a detailed investigation of the geology and ore deposits of the Magdalena mining district. They reported that several of the Tertiary volcanic units observed there extended to the north and northwest outside the district. Thurmond (1951) prepared a private report at the Sixty propsect in Sec. 6, T. 3 S., R. 5 W. Slawson and Austin (1962) investigated lead isotopes from mines in the Council Rock district.

Detailed stratigraphic work on the Datil Formation was done by Tonking (1957) and Givens (1957) in the Puerticito and Dog Springs Quadrangles, respectively. Tonking divided the Datil Formation into three members: Spears, Hells Mesa, and La Jara Peak; Givens further subdivided the Hells Mesa Member into seven informal units. Equivalents of the La Jara Peak Member have not been recognized on the

Gallinas uplift. Willard (1959) tentatively correlated the La Jara Peak Member with the Mangas basalt, a post-Datil sequence. Weber (1963) formally excluded the La Jara Peak Member from the Datil Formation and in 1971 he elevated the Datil Formation to group status. Chapin (1971-a) elevated the Spears, Hells Mesa, and La Jara Peak Members to formational status. Brown (1972) subdivided the Hells Mesa Formation into two informal units: the tuff of Goat Springs and the tuff of Bear Springs. Deal and Rhodes (in press) subsequently renamed the tuff of Bear Springs the A-L Peak Tuff for a type section on A-L Peak in the northern San Mateo Mountains. Chapin (1974-b) restricted the Hells Mesa Formation to the quartz-rich, crystal-rich ash-flow tuffs formerly called the tuff of Goat Springs.

Recent work by Elston and others (1968, 1970, 1973) has attempted to fit the Datil-Mogollon Volcanic Province into an overall volcano-tectonic framework. Chapin (1971-b) discussed modifications of the Rio Grande rift and its effects upon the structural trends of the Magdalena area and Chapin and others (1974) proposed an exploration framework for the Magdalena-Tres Montosas area. Deal (1974) and Deal and Rhodes (in press) investigated the formation and development of the Mt. Withington cauldron in the northern end of the San Mateo Mountains which they proposed as the source of the A-L Peak Tuff and the Potato Canyon Tuff.

Most recently, several theses and dissertations have studied the volcanic stratigraphy, structure, and mineralization in the Magdalena area. Brown (1972) completed an investigation of the Bear Mountains and contributed greatly to the understanding of the stratigraphy of the Datil Group. Simon (1973) recently finished an investigation of the stratigraphy, structure, and mineralization of the Silver Hill area. Siemers (1973) completed a study of the Paleozoic stratigraphy of the Magdalena Mountains and the origin of the Popotosa Formation was the subject of a dissertation by Bruning (1973). Woodward (1973) mapped the Lemitar Mountains and discussed their stratigraphic and structural relationship to the Rio Grande rift. Chamberlin (1974) conducted a detailed investigation of the Council Rock area immediately north of the Tres Montosas area and Krewedl (1974) completed a dissertation in the central Magdalena Mountains. Blakestad (1976) is remapping the Kelly mining district.

Numerous radiometric dates have been published on the rocks of the Datil-Mogollon province. Weber and Bassett (1963) reported K-Ar age dates for the Nitt and Anchor Canyon stocks in the Kelly mining district and for the base of the Hells Mesa Member at Tonking's type section. Burke and others (1963) dated a latite boulder from the base of the Spears Member and two unwelded tuffs of the Hells Mesa

Member. Kottlowski, Weber and Willard (1969) published 49 radiometric dates of Cretaceous and Tertiary igneous rocks in the New Mexico region and Weber (1971) reported five previously unpublished dates for Tertiary igneous rocks in central New Mexico. Chapin (1971-a) reported a K-Ar age date for the La Jara Peak Formation and discussed its possible significance to mineral exploration. Recently, Simon (1973) presented a new date on the unit of Arroyo Montosa, which consists of interbedded fanglomerates and dacite lava flows. Smith and others (in press) dated the A-L Peak Tuff and the Potato Canyon Tuff in the San Mateo Mountains using the fission track method.

Methods of Investigation

Detailed geologic mapping was conducted at a scale of 1:24000 using the Tres Montosas 7.5-minute quadrangle published by the U. S. Geological Survey as a base map. The detailed mapping of the Sixty copper prospect was don: on a base prepared by S. S. Thurmond in 1951 (Brunton compass and chain) at a scale of 1" = 200'. Aerial photographs of the GS-VARJ series, 3-20-63, at a scale of 1:31680 and of the GS-VMA series, 1956, at a scale of 1:23480 were used to aid in the location of outcrops and in structural interpretations. Mapping was done during the summer and fall of 1971 and the summer of 1975. A topographic base map on mylar was used for the preparation of the final geologic map.

Two hundred thirty-five thin sections were made and examined from samples collected over the area. These were used to correlate rock units, to study hydrothermal alteration, and to interpret the paragenesis of vein minerals. A diamond-drill hole located in Sec. 6, T. 3 S., R. 5 W. was logged by C. E. Chapin and forty-eight thin sections were made from the core. Modal analyses of ten thin sections from the Tres Montosas stock were prepared by J. E. Bruning using a Zeiss microscope equipped with a Swift automatic point counter. Five of these samples were collected by R. M. Chamberlin from the north border of the stock. Several samples of fluorite were collected for fluid inclusion analyses. Four basalt samples were also prepared for X-ray fluorescence and AA analyses.

Geography

Physiographically the Tres Montosas-Cat Mountain area comprises the southern end of a north-trending topographic high which connects the San Mateo Mountains with the Gallinas Mountains. The present topography is strongly controlled by block faulting with the San Augustin graben to the west and the Mulligan Gulch graben to the east. Relief over most of the area is relatively low, not exceeding 700 feet; however, Tres Montosas in the northwest corner is a prominent landmark with relief of 1300 feet above the surrounding area. The southern boundary approximately coincides with the northern margin of the Mt. Withington cauldron as defined by Deal (1973). The map area is near the boundary between the Datil-Mogollon volcanic province and the Colorado Plateau province (Fig. 1).

Acknowledgements

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Appreciation is extended to Pete Evans of the Pete Evans Ranch and to Bob Dunlap of the Cat Mountain Ranch for their hospitality in allowing access to their lands. S. Thurmond and W. Brunson provided information concerning the Sixty copper prospect and the Banner Mining Company allowed access to core from a hole they drilled at this prospect.

Dr. C.T. Smith and Dr. K.C. Condie served on the thesis committee and provided the author with helpful ideas and discussions both in the field and in the office. Richard Chamberlin also provided ideas and helped in the field.

The author would like to extend thanks to Dr. Charles E. Chapin. As thesis advisor it was he who first suggested the problem and then aided greatly in the field and in office discussions. Special thanks also go to my wife, Linda, for typing the manuscript.

STRATIGRAPHY AND PETROLOGY

Prevolcanic Rocks

Prevolcanic rocks (Abo Formation) crop out in only one small area. To the north, Givens (1957) mapped the base of the Spears Formation which rests comformably on the Baca Formation but, to the south, the base of the Spears Formation rests unconformably on the Abo Formation and south of Highway 60 it rests uncomformably on carbonaceous siltstones of unknown age. A similar relationship is present in the Bear Mountains where the base of the volcanic pile rests on progressively older rocks southward into the Kelly mining district.

The Tres Montosas and Bear Mountain areas are situated on the flanks of a Laramide uplift which was truncated by the late Eocene erosion surface (Epis and Chapin, 1975). The resultant detritus formed the Baca Formation in a basin to the north. The transition from conformable to unconformable contact relationships at the base of the volcanic pile is not exposed at the surface.

Sandia Formation

A single exposure of quartzite, interpreted to be part of the Sandia Formation of Pennsylvanian age occurs over an area about the size of a football field in the south-central part of the Tres Montosas stock. This block is believed to be a xenolith caught up as the stock rose through the Paleozoic sedimentary section.

Chapin (oral commun., 1975) has found similar quartzite blocks in the upper portions of the Magdalena composite pluton. In the deeper portions of this pluton (the Nitt and Anchor Canyon stocks) xenoliths of limestone and Pre-cambrian rocks are exposed. He has interpreted these to be the result of selective flotation of stoped blocks: quartzites have lower densities than limestones, thus they would be selectively floated while limestones would sink. The elevation of the quartzite xenolith in the Tres Montosas stock above its parent strata is at least 2000 feet, the same figure Chapin (op. cit.) has calculated for the quartzite xenoliths in the Magdalena composite pluton.

The quartzite is a medium grained, moderately sorted, pure quartz sandstone. The Sandia Formation in the Magdalena Mountains consists of gray to black, sandy carbonaceous shales and siltstones with thin beds of gray, medium-grained, crinoidal limestones and greenish-gray to brown, medium to coarse-grained quartzites (Siemers, 1973).

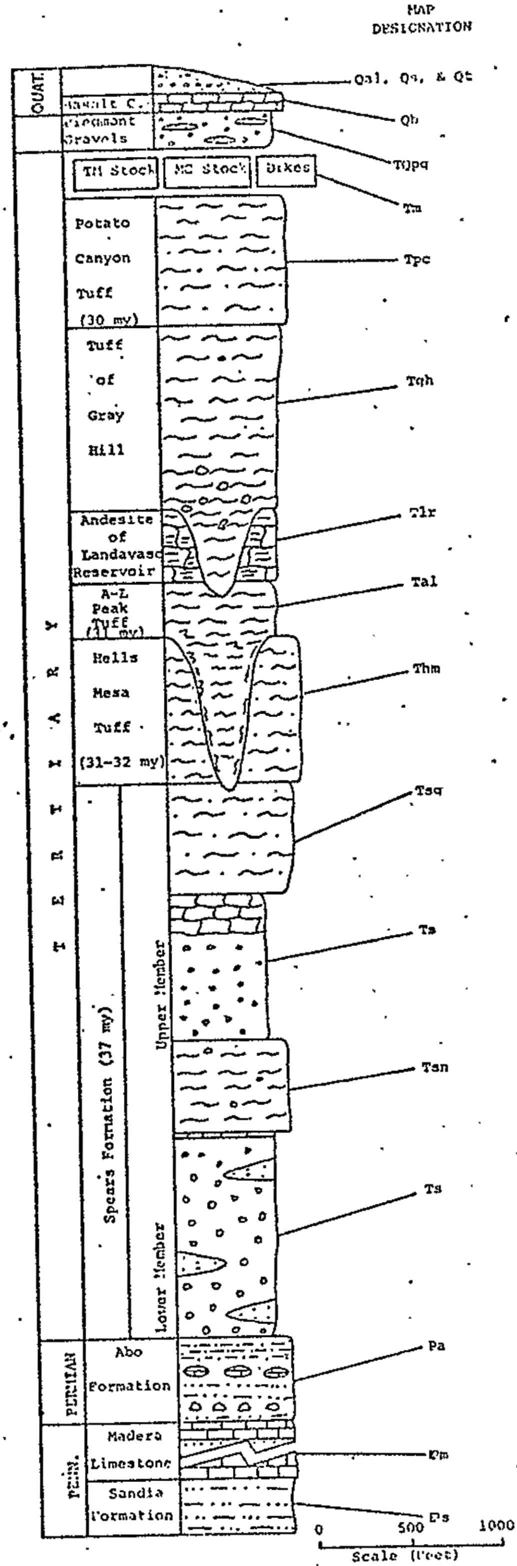
Abo Formation

The only other pre-Tertiary rocks exposed cover an area of about three-quarters of a square mile on hill "7484" in the northeast corner of the map area. These rocks are a series of interbedded quartzites, quartzite breccias, limestone pebble to boulder conglomerates, and siltstones. They form a high, rounded hill with exposures only where streams cut through the cover. Siemers (1973) measured a partial section and obtained a thickness of as much as 150 feet, but cross sections suggest a minimum thickness of 450 feet.

The section examined in this report (see Fig. 2) is consistent with that measured by Siemers with the exception of the presence of more limestone conglomerates and thin silty beds near the top of the section that were observed during subsequent mapping. Siemers' petrographic descriptions have been used to supplement samples taken by the author.

The lower contact of the Abo Formation is obscured by faulting; the upper contact is a depositional contact with the Spears Formation. The lower Spears through the tuff of Nipple Mountain is in fault contact with the Abo but the upper part of the Spears clastic and andesitic rocks are in depositional contact with the Abo. Figure 3 is a photograph at the Abo-Spears contact showing clasts of Abo in the overlying Spears Formation.

The Abo is thinly bedded with shaly beds two to six inches thick and conglomerate and breccia beds as much as eight feet thick. Quartzite and quartzite breccias with thin interbedded silty layers predominate at the base of the exposed section. Limestone conglomerates become abundant upward, grading back into quartzites and shales. Above this interval, limestone conglomerates, quartzite breccias, and quartzites are approximately equal in abundance. The upper part of the section consists predominantly of quartzites and quartzite breccias.



DESCRIPTION

stream deposits of sand and gravel, colluvium yellowish blow sand, and talus. 150 feet.

dark-gray to black, dense, vesicular, basaltic andesite flows. 150 feet.

poorly to moderately indurated, poorly sorted, heterolithic sands and gravels. 200 ft.

late Tertiary intrusives composed of andesites to granites and monzonite dikes.

light-gray to pink, multiple-flow, compound cooling unit of moderately to densely welded, moderately crystal-rich ash-flow tuffs. 700 feet.

gray to purple, multiple-flow, compound cooling unit of moderately to densely welded, crystal-poor, ash-flow tuffs with a distinctive botryoidal pumice tuff near the base. More lithic-rich near base. Cooling break occuppied by thin sandstone bed. Deposition controlled by paleovalley. 1400 feet.

purplish-gray, aphanitic, platy, basaltic andesite flows with distinctive secondary hematite banding. 400 feet (?).

purple, fluidal-banded, contorted, simple cooling unit of densely welded, crystal-poor ash-flow tuffs. Deposition controlled in part by paleovalleys. 1000 feet.

pink to purple-gray, multiple-flow, simple cooling unit of densely welded, massive, blocky, crystal-rich, ash-flow tuffs (lithic-rich near base). 800 feet.

purplish, compound cooling unit of moderately to densely welded, crystal-rich ash-flow tuffs. 600 feet.

dark-gray-black, porphyritic, dense andesite flows and dark-purple, latitic to andesitic mudflow breccias and conglomerates. 800 ft.

light-pink, multiple-flow, compound cooling unit of poorly to densely welded, sometimes lithic-rich ash-flow tuffs with interbedded porphyritic andesite flows. Medium-gray, coarsely porphyritic, amygdaloidal andesite flow at base. 500 feet.

dark purple, latitic to andesitic mudflow breccias, conglomerates, and sandstones (greenish-gray when propylitized). 1100 feet.

red-brown (bleached to gray to green in thesis area), fine-grained, thin-bedded quartz arenites and siltstones with abundant, thin laminations; interbedded limestone pebble conglomerates and quartzite breccias. Thickness unknown.

Thick sequence of gray micrites and thin, medium-grained siltstones. Not exposed in thesis area. 1500' interval not shown.

Green-gray to brown, medium- to coarse-grained quartzites and gray to black, sandy carbonaceous shales and siltstones with thin beds of gray crinoidal limestones.

Figure 2. Generalized stratigraphic column of rocks in the Tres Montosas-Cat Mountain area. Thicknesses indicated are maximums estimated from structure sections.

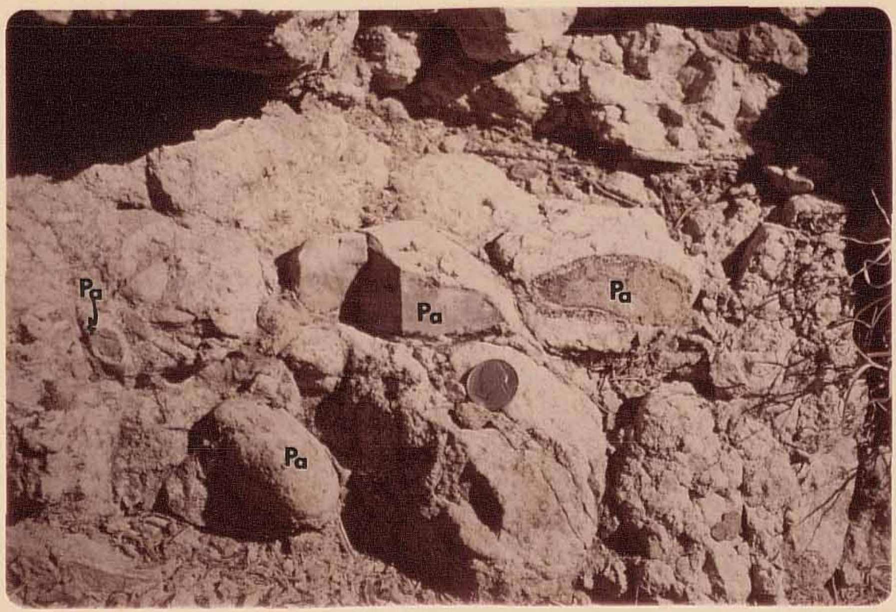


Figure 3. Clasts from the Abo Formation (Pa) enclosed in the overlying volcaniclastic sedimentary rocks of the Spears Formation. This, along with the nature of the contact, shows that the Abo outcrops were a paleotopographic high during Spears deposition and not a fault block. The light color is due to pervasive propylitic alteration. The outcrop is located along the northern contact of the Abo Formation.

The quartzites are calcareous, fine-grained rocks with some appearing almost aphanitic. The color varies from gray in very-fine-grained rocks to shades of brown and olive-green in coarser grained rocks. Much of the lighter color is the result of the oxidation of disseminated pyrite. On weathered surfaces these rocks are all shades of grays and browns. Fine laminations and cross laminations are readily visible in some beds. Several of the beds show grading of the sand particles over several feet.

Petrographically, the quartzites are very-fine-grained (0.2 mm) to medium-grained (0.7 mm), moderately to well-sorted, angular to subround, almost pure quartz sandstones with some carbonate cement. Feldspar accounts for less than one percent in several slides and there is a trace of mica in the others. Point contacts are dominant over line and concave-convex contacts. All slides show some evidence of alteration. Disseminated pyrite, oxidized to hematite or limonite, and epidote in disseminated patches and veinlets are most common. Garnet, wollastonite, secondary quartz veinlets, and chlorite veinlets are also present in some thin sections. In most thin sections, calcite replaces the quartz grains to varying degrees. In some sections the matrix is very-fine-grained quartz which may be diagenetic or the result of hydrothermal alteration.

The quartzite breccias are composed of poorly sorted, angular to subround, reddish to gray quartzite clasts in a carbonate cement. The clasts are usually small, one to two inches in diameter, but may reach nine inches in diameter. In some of the breccia beds, and in some of the clasts themselves, thin laminations are visible. The quartzite clasts are very similar to the quartzites described above suggesting that previously deposited Abo is being eroded and redeposited as quartzite breccias. C.T. Smith (oral commun., 1975) has seen similar features in the Abo Formation in the Los Pinos Mountains.

The quartzite breccias consist of fragments of quartzite in a carbonate cement. In some, the cement is coarse, crystalline spar with scattered sand grains and in others the carbonate is very fine grained.

The silty beds are as much as six inches thick, partly calcareous, fine siltstones. They exhibit a poorly developed shaly parting and are visible only in prospect pits where they have not been subjected to weathering. Their color is the same as that of the quartzites.

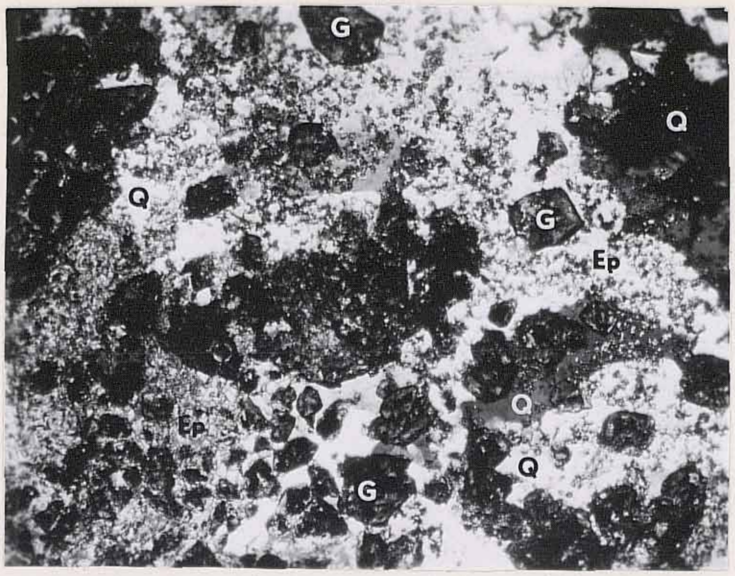
The limestone pebble to boulder conglomerates form beds from one to eight feet thick. They contain poorly sorted, round to subround, light-gray to dark-bluish-gray limestone clasts in a coarsely crystalline spar cement. The size varies from less than one inch to as much as four feet in diameter. The clasts are uniformly nonfossiliferous with only a few showing some fossil fragments. The only sedimentary structure observed is the imbrication of some of the larger clasts. The average strike and dip of imbricated clasts at one locality was N 85° W, 27° E (flow direction from east to west). (See Fig. 4).

Several samples of the clasts sent for fossil identification were identified as molluscan-brachiopod-peloid wackestones to packstones, brachiopod-ostracod mudstones, and micropelletoid, possibly algal wackestones to packstones (Armstrong, written commun., 1971). Fossils are generally fragmented and poorly preserved due to recrystallization.

One noteworthy observation is that in the quartzite breccias there are very few limestone clasts and in the limestone conglomerates there are very few quartzite clasts.

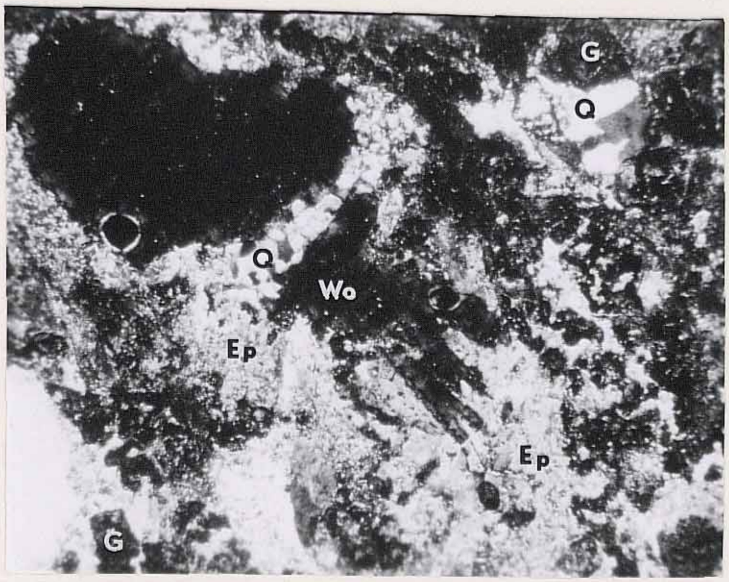
Several hand specimens and thin sections showed evidence for varying degrees of contact metasomatism with the most intense alteration developed in the carbonate rocks. Almost all of the thin sections showed scattered, small patches of calcite and epidote replacing quartz grains but the most definite contact metasomatic assemblage was observed in a thin section of a limestone conglomerate. Epidote, as distinct crystals and crystal aggregates; garnet as individual euhedral crystals; and wollastonite as elongate crystals in radial aggregates pervade the thin section (see Figs. 5-A and 5-B). Chamberlin (1974) and the author have observed garnets in some thin sections of the Spears Formation around the eastern edge of the Tres Montosas stock. These contact metasomatic effects are undoubtedly the result

Figure 4. Outcrop of a limestone pebble conglomerate unit in the Abo Formation. Note the imbrication of some of the larger limestone clasts. A thin quartzite bed is visible just above the hammer. The outcrop is located in a large arroyo in the eastern part of the Abo outcrops.



0.5 mm.

Figure 5-A. Photomicrograph of contact metasomatic minerals in a limestone pebble conglomerate from the Abo Formation. Abundant euhedral garnet (G) and small epidote (Ep) crystals pervade the rock. (Q = quartz, X-nicols, x60 magnification.)



0.5 mm.

Figure 5-B. Photomicrograph of contact metasomatic minerals in a limestone pebble conglomerate from the Abo Formation showing a radial group of wollastonite (Wo) crystals in quartz (Q), epidote (Ep), and garnet (G). Both samples are from the northern margin of the Abo outcrops. (X-nicols, x60 magnification.)

of the proximity of the Abo section to the stock; the metasomatism may increase with depth.

The existence of this sedimentary section has been known for many years but its exact stratigraphic position is still not definitely known due to poor exposures and no visible upper or lower pre-Tertiary contacts. It is necessary to know the stratigraphic position to predict drilling depths to favorable limestone units. These sedimentary rocks are close to and affected by the Tres Montosas stock which creates the possibility of replacement-type deposits in favorable limestones at depth.

Kottlowski (1960) mentioned these sedimentary rocks and stated, "No fossils were found, but the beds are similar to parts of the Pennsylvanian in the Magdalena Mountains." Slawson and Austin (1962) mentioned the "brecciated limestones" but made no attempt to work out the stratigraphy. Siemers (1973) measured a section, conducted petrographic studies, and compared these sedimentary rocks with the Pennsylvanian and Permian Formations. He concluded that they were too dissimilar to the Sandia quartzites to be correlative but that a reasonable correlation could be made with the Abo Formation, based on lithologies and sedimentary structures. Loughlin and Koschmann (1942), Kottlowski and others (1956), and Jaworski (1973) all noted limestone pebble conglomerates in the basal parts of the Abo Formation.

Limestone clasts containing fossil material were sent to the U.S. Geological Survey for identification. Bernard L. Mamet (written commun., 1975) recognized the following three genera of foraminifera: BISERIELLA sp., EOLASIODISCUS sp., and ORTHOVERTELLA sp. He placed an age of Middle Pennsylvanian or slightly younger (Madera Limestone) on at least some of the limestone clasts; therefore, the conglomerates and quartzites must be younger than Middle Pennsylvanian.

The identification of this section was based upon several independent lines of evidence, none of which are diagnostic alone. When taken together, however, they strongly suggest that these rocks are part of the Abo Formation, probably in the basal part.

Sedimentary Rocks of Unknown Age

The last 289 feet of the Banner drill hole penetrated a sequence of carbonaceous, calcareous siltstones and sandstones. Because no pre-Tertiary contacts were encountered, the age of these rocks is unknown. The Banner Mining Company interpreted these rocks as Mesozoic sedimentary rocks and stopped drilling. The data presented here suggests that these rocks may be part of the Sandia Formation.

In hand specimen, these rocks are black to dark gray to medium-gray brown, calcareous siltstones to fine-grained sandstones. They are often laminated and contain plant fragments along carbonaceous partings. The only other fossils observed were sparse foraminifera.

In thin section, these rocks are very fine-grained, calcareous sandstones to siltstones. They are composed of poorly- to well-sorted, angular to subround quartz grains which vary from 0.01 to 0.4 mm in diameter. Silica and calcium carbonate are the principal cements and the quartz grains are slightly embayed by the carbonate cement. Siemers (written commun., 1973) examined the thin sections and suggested that the depositional environment was a low to moderate energy marine environment. Alteration, in the form of disseminated pyrite and quartz-calcite and pyrite veinlets, occurs throughout the section.

This section of rocks is similar to the middle Sandia Formation of Pennsylvanian age in the Magdalena Mountains where it consists of carbonaceous shales, siltstones, and fine, quartzitic sandstones, although the rocks from the drill hole are finer-grained. Siemers (oral commun., 1975) has interpreted the Pennsylvanian rocks east of the Rio Grande as a deltaic sequence grading into a marine environment to the southwest. There would be a progressive deepening of the marine basin toward the Tres Montosas area and facies changes would cause the clastic sedimentary rocks to be finer grained.

Mesozoic clastic rocks are generally feldspathic, cherty sandstones (Kottlowski, oral commun., 1975) which contrasts with the section in the drill hole. The rocks in the core are clean, quartz sands and silts in which feldspar is almost entirely absent. This suggests that these rocks do not belong in the Mesozoic section but belong somewhere in the Paleozoic section.

As discussed on page 92, the thesis area is on the northern flank of a Laramide uplift which has been beveled by the Eocene erosion surface. This erosion surface has caused rocks of progressively older ages to be exposed southward. Where Mesozoic rocks are preserved in the Gallinas Mountains, the Baca Formation of Eocene age always overlies them. To the south, the Baca Formation apparently disappears and the Abo Formation (Permian) is exposed two miles north of the Banner drill hole. This suggested progression indicates that the siltstones and sandstones in the drill hole could be the Sandia Formation.

Several samples of the core containing fossils were sent to the U.S. Geological Survey and the University of Pennsylvania for identification. Armstrong (written commun., 1971) identified two foraminifera (TURBERITINA sp. and GLOBIOVALVULINA sp.) and stated, "... the total fauna suggests to me an Atoka (Pennsylvanian-Permian) or slightly younger age." Kosanke (written commun., 1974) stated, "Because of this (poor preservation) it has not been possible to make any identifications with certainty. None of the spores or pollen grains resemble Paleozoic taxa. Bob Tschudy examined several slides and it is our guess that a few of the specimens suggest a similarity to Mesozoic taxa." Pfefferkorn (written commun., 1974) stated, "Seeds and the leaf fragment indicate only that the material is Upper Devonian or younger. The preservation is so bad that the material could come from any of the Mesozoic systems or even from the Tertiary."

There is no direct evidence at this time to place these rocks with any certainty in the stratigraphic section. The lithologies and structural setting suggest a Paleozoic age, probably the Sandia Formation. Although the paleontological data is not diagnostic, it does not eliminate the possibility that these rocks may be the Sandia Formation.

Tertiary Volcanic Rocks

Volcanic rocks comprise the great majority of the exposures in the map area. Welded ash-flow tuffs and lava flows predominate with interbedded volcaniclastic sedimentary rocks subordinate. From Figure 2, a maximum total thickness of 6300 feet can be estimated for the Oligocene rocks.

Spears Formation

The earliest volcanic rocks exposed in the Tres Montosas area are a thick sequence of volcaniclastic sedimentary rocks and interbedded ash-flow tuffs and lava flows called the Spears Formation. The Spears type section was described by Tonking (1957) and named the Spears Member of the Datil Formation. Weber (1971) raised the Datil Formation to Group status and Chapin (1971-a) raised the Spears to Formational status. A latite tuff breccia in the Joyita Hills (45 miles northeast of Tres Montosas), which has been correlated with the Spears Formation, yielded a K-Ar age date of 37.1 m.y. (Weber, 1963, 1971).

The Spears Formation comprises the largest outcrop area and exhibits the poorest outcrop characteristics of any of the rock units mapped. It occurs as low, rounded hills and slopes covered with distinctive float. Most of the central portion of the map area is underlain by Spears which is well-exposed only rarely in roadcuts and arroyo bottoms.

Brown (1972) and Chamberlin (1974) subdivided the Spears Formation into two members: a lower member composed of latitic, epiclastic, volcanic sandstones and conglomerates and minor autobrecciated latite flows and an upper member composed of latitic ash-flow tuffs, andesite-latite flows, and minor volcanic breccias and sedimentary rocks. The break between the lower and upper members occurs at the appearance of a "turkey track" andesite which underlies the tuff of Nipple Mountain, an excellent stratigraphic marker within the Spears. This convention will be followed in this report.

The Spears Formation in the map area has been subdivided into three mappable units: Ts - undivided Spears which includes the lower and the upper volcaniclastic rocks and andesite flows; Tsn - the tuff of Nipple Mountain; and Tsg - the tuff of Granite Mountain, a distinctive latitic ash-flow tuff at the top of the Spears Formation.

Lower Spears. The lower Spears Formation is very poorly exposed and much mapping was done from float. An excellent stratigraphic section of the lower Spears has been obtained from core from a hole drilled by the Banner Mining Company in Sec. 6, T. 3 S., R. 5 W. The hole collared in the tuff of Nipple Mountain and drilled through almost 1100 feet of the lower Spears Formation to its contact with pre-Tertiary sedimentary rocks.

The rocks of the lower Spears consist predominantly of latitic conglomerates with clasts as much as two feet in diameter, thin volcaniclastic sandstones, and minor autobrecciated latite flows. When fresh these rocks are typically maroon, purple, or red-brown, but pervasive propylitic alteration has given them a greenish to gray color. A few samples from the drill core are relatively fresh, but most of the core and most outcrops are altered. The clasts vary in color from green to gray to red-brown. They, too, have been affected by the alteration and, in many cases, it is difficult to tell where the contact between clast and matrix is. The grain size of the matrix varies from silt to broken feldspar crystals as much as 6 mm in length. Plagioclase and sanidine are the predominant minerals in both matrix and clasts with minor hornblende and biotite. Clasts are typically well-rounded and vary in diameter from 6 mm to 61 cm. The clasts are heterolithic, comprised of various andesitic and latitic rocks and, near the base, clasts of the underlying sediments (see Fig. 3).

The propylitic alteration has made identification and percentage estimates difficult. In the matrix, plagioclase (0.1 to 2.5 mm) and sanidine (0.1 to 0.9 mm in diameter) are the predominant minerals with plagioclase usually the most abundant (10 to 30 percent). Occasionally sanidine is more abundant than plagioclase, but it usually varies from 5 to 25 percent of the rock volume. The feldspars are altered in varying degrees to calcite, clay, and minor chlorite. Plagioclase compositions were measured on sixty-six grains using the Fouque method; the compositions ranged from An_6 to An_{39} with an arithmetic mean of An_{22}. Tonking (1957) found a similar range from An_{10} to An_{30}.

Hornblende and biotite are present in amounts up to seven percent. The hornblende is always altered to magnetite, calcite, and epidote with the magnetite outlining original grain boundaries and fractures. Apatite and quartz are very minor constituents.

The clasts, many of which show a trachytic alignment of feldspar and hornblende in a cryptocrystalline groundmass, are also characterized by plagioclase (oligoclase) and sanidine as the dominant phenocrysts. Alteration has made the identification of minerals and the estimation of relative percentages difficult. Hornblende and biotite are minor constituents. Three types of clasts were observed: 1. andesitic to latitic rocks; 2. tuffaceous rocks - crystal-poor with devitrified groundmass; and 3. Paleozoic sedimentary rocks - limestone and siltstone. The clasts of Paleozoic sedimentary rocks occur only near the bottom of the section and are derived from the underlying formations.

Tuff of Nipple Mountain. The tuff of Nipple Mountain is an informal name used by Brown (1972) and Chapin (1974-b) for a pink, moderately to densely welded, crystal-poor, ash-flow tuff which separates the upper and lower members of the Spears Formation. It is an excellent marker unit within the Spears, not only in the vicinity of Tres Montosas, but within the entire Magdalena area. Accordingly, it has been mapped as a separate unit. Chamberlin redefined the tuff of Nipple Mountain to include the "turkey track" andesite flows commonly found below it. His reasons for the change were "the occurrence of andesitic (and latitic) lavas which are interbedded in the ash flow tuffs that form the main body of the unit and the common stratigraphic and spatial association of the turkey track lavas with these tuffs" (Chamberlin, 1974, p. 16). Similar observations have been made in the Tres Montosas area and Chamberlin's definition has been adopted by the author.

The only available section of the tuff of Nipple Mountain in the Tres Montosas area is from the Banner drill hole mentioned earlier. The hole collared in the tuff of Nipple Mountain and gave a minimum thickness of 71 feet plus 21 feet for a basal "turkey track" andesite (total minimum thickness 92 feet). However, cross sections indicate a minimum thickness of 500 feet through several sections.

The tuff of Nipple Mountain is a multiple flow, compound cooling unit with the cooling breaks occupied by thin andesitic to latitic lava flows. There is an apparent gradation from fine-grained, extremely crystal-poor ash-flow tuffs near the bottom to densely welded, crystal-poor, ash-flow tuffs at the top similar to those described by Brown

(1972). The "turkey track" andesite is observed only in the drill hole and in a small exposure in the eastern part of Section 15, T. 3 S, R. 6 W.

The tuff of Nipple Mountain has an outcrop area of approximately one square mile; the great majority of the exposures are limited to a north-trending belt along the eastern edge of the Gallinas uplift. The tuff is everywhere altered and is intensely silicified in and around the Cobb prospect. Where silicification is less intense, the tuff of Nipple Mountain crops out poorly and is often visible only as float-covered slopes. But where silicification is intense, the outcrops are prominent and in some cases cliff-formers. The light color of the bleached and highly silicified outcrops leads to easy identification on aerial photographs.

In a fresh hand specimen, the tuff of Nipple Mountain is characteristically pink, but because of alteration, specimens in the Tres Montosas area show a wide variety of light colors. It is a fine- to medium-grained, unwelded to densely welded rock with 3 to 10 percent phenocrysts. The dominant phenocrysts are sanidine and plagioclase. Dark, latitic lithic fragments are present in amounts ranging from 0 to 5 percent by volume. They are most common in the medium-grained ash-flow tuffs.

In thin sections, the tuff of Nipple Mountain is porphyritic with a totally devitrified and/or altered (silicified) groundmass. Glass shards are well preserved in some sections and generally show some degree of compaction. However, in a few sections they are undistorted. The groundmass in most thin sections is devitrified and intensely silicified with veinlets and patches of silica common. Outlines of glass shards are preserved in some sections with axiolites and spherulites developed in some.

Sanidine is the most abundant phenocryst (2 to 10 percent) in some thin scetions while plagioclase (not mentioned by Brown, 1972) is most abundant in others (2 to 8 percent). The high degree of alteration makes it difficult to distinguish between sanidine and plagioclase in many thin sections. The sanidine occurs in euhedral to subhedral crystals 0.2 to 2.0 mm in diameter which are normally altered to clay and calcite. Some grains show microperthitic unmixing. Plagioclase is typically altered to clay minerals also, but enough fresh grains are available to obtain fairly consistent composition measurements of An_{23} to An_{35} (Fouque method, 15 grains, average of An_{27}). The plagioclase occurs as euhedral to subhedral crystals 0.2 to 2.0 mm in length. Euhedral quartz grains are very minor constituents.

The "turkey track" andesite is a porphyritic, vesicular lava flow with abundant, large plagioclase crystals. It is gray to black when fresh and weathers to a brownish-gray color. A small prospect pit was dug in the "turkey track" andesite in Section 15, T. 3 S, R. 6 W, apparently after a green mineral which was identified as celadonite and fills vesicles and holes left by weathering feldspar. The thickness of the "turkey track" andesite in the Banner drill hole is 21 feet. In thin section, the "turkey track" andesite contains 15 to 20 percent euhedral to subhedral plagioclase phenocrysts 0.75 to 10.7 mm in length with a composition of $An_{27.5}$ (Rittmann zone method, 3 grains). Minor anhedral pyroxene, 0.1 to 0.75 mm in diameter is the only other phenocryst. The groundmass is composed of trachytically aligned plagioclase microlites, magnetite, pyroxene, and minor apatite.

Upper Spears. The upper part of the Spears Formation is composed predominantly of andesitic and latitic flows with minor, poorly bedded volcaniclastic sedimentary rocks. Exposures are poor and because the upper volcaniclastic rocks are difficult to distinguish from the lower volcaniclastic rocks, the upper and lower Spears Formation has been mapped as a single map unit, Ts.

The number of individual andesite or latite flows and their thicknesses are not known; however, their thickness is much greater than the 200 feet reported by Chamberlin (1974) immediately to the north in the Council Rock area. A minimum thickness of 600 feet has been estimated in the Cat Mountain area. The andesites are generally dense, gray to almost black rocks which usually form low, rounded hills.

They are typically porphyritic with plagioclase as the dominant phenocryst. However, several flows have large phenocrysts of pyroxene as much as 6.0 mm in diameter. In some of these flows, the pyroxene grains are partly altered to reddish iron oxides. In places, the dense flows exhibit hematite banding along joints and fractures and an occasional dark-brown lithic fragment is observed in some. The weathered surfaces are usually some shade of brown. Near the Tres Montosas stock, the andesites are extremely dense due to baking by the stock and exhibit a waxy luster on fresh surfaces.

Petrographically, the andesites are porphyritic rocks with a felty to trachytic alignment of groundmass microlites. Many of the thin sections show glomeroporphyritic clots of plagioclase and/or pyroxene. Euhedral plagioclase grains, 0.1 to 4.0 mm in length, are the dominant phenocryst accounting for 10 to 30 volume percent of the rock. Alteration in some slides, especially those from near the Tres Montosas stock, is intense and the plagioclase may be completely altered to calcite, epidote and chlorite. Pyroxene, in euhedral grains up to 6.6 mm, accounts for 0 to 15 percent of the rock. The pyroxene is well zoned and is probably pigeonite (2V approx. 30° to 45°). Hornblende and sanidine are minor constituents varying from 0 to 4 percent by volume. Some of the hornblende grains are extremely large, as much as 6.6 mm in length. They are generally altered to opaque iron oxides with identification being made from grain outlines. The groundmass is composed of plagioclase microlites and small pyroxene grains. In intensely altered thin sections, the groundmass is completely obscured.

Measurements of plagioclase compositions indicate that there are some variations within the andesite flows. Specifically, they may be grouped compositionally into three categories: An_{30-32}, three flows; An_{41-48}, five flows; and An_{55}, one flow. A similar mineralogic variation is manifested. Those flows with compositions ranging from An_{41-55} are pyroxene-bearing rocks while flows with more sodic plagioclase are hornblende- and biotite-bearing rocks. How these variations are related stratigraphically is unknown because of the lack of exposures of a complete section of the upper Spears Formation.

There appear to be two different types of latitic flows. The first has a dark purplish gray matrix with large (up to 12.0 mm) chalky feldspar phenocrysts. Several hand specimens exhibit a faint alignment of the long axes of the feldspar crystals. Pyroxene, biotite, and magnetite are the other visible minerals. These rocks usually weather to shades of green and brown. The second type is lighter in color, gray to light purplish gray, with a more crowded, finer grained appearance. They are feldspar- and biotite-rich rocks which weather to a light-gray color.

The latites are porphyritic rocks. some of which exhibit a poorly developed alignment of biotite and feldspar phenocrysts. The principle phenocrysts are euhedral to subhedral grains of plagioclase ranging from 0.1 to 4.0 mm in length. Compositions range from An_{22} to An_{31} with an average of An_{27} (Fouque method, 5 grains). Sanidine accounts for as much as 15 percent by volume of the rock in grains as much as 1.9 mm in diameter. In rocks that are altered, it is especially difficult to distinguish sanidine from plagioclase. Biotite, in grains 0.1 to 1.5 mm long, accounts for 3 to 5 percent by volume, and is usually altered to reddish iron oxide and opaques. Apatite (0.1 mm) is a minor accessory mineral.

The upper Spears volcaniclastic rocks are similar to those in the lower part of the section, but thin sections of rocks from near outcrops of the Abo Formation contain lithic fragments of quartzite. Similar clasts are visible in outcrop (see Fig. 3).

Rocks of the upper Spears Formation in close proximity to the stock have been affected in varying degrees by thermal metamorphism. The dense andesites show few effects beyond some secondary quartz in the groundmass but several thin sections of the clastic rocks show pervasive metasomatism by minerals indicative of contact metamorphism: calcite, epidote, quartz, and euhedral garnet grains. No wollastonite, as observed in the Abo Formation, was observed here. Chamberlin (1974) observed similar mineral assemblages in the metamorphosed "turkey track" andesite below the tuff of Nipple Mountain immediately to the north of the outcrops of the Abo Formation.

<u>Tuff of Granite Mountain</u>. The tuff of Granite Mountain is an informal name proposed by Chapin (1974-b) for the crystal-rich, quartz-poor ash-flow tuffs near the top of the Spears Formation. Variations in the degree of welding and the amounts of pumice indicate that these tuffs form a multiple-flow, compound cooling unit. The Hells Mesa Tuff is similar, but there are some recognizable differences:

1. The tuff of Granite Mountain contains 1 percent or less quartz as opposed to 5 - 15 percent quartz in the Hells Mesa Tuff.

2. They both have similar outcrop characteristics, but where the tuff of Granite Mountain is overlain by the Hells Mesa Tuff, there is a slight break in slope at the contact with the gentler slope on the tuff of Granite Mountain.

The tuff of Granite Mountain has an outcrop area of approximately one square mile with the principal outcrops on Tres Montosas, Gray Hill, and in the south-central portion of the map area. Outcrops are relatively fresh, but along fractures and near the upper and lower contacts narrow zones of more intense propylitic alteration are observed. To the north in the Council Rock area, Chamberlin (1974) observed a maximum thickness of 300 feet. However, on Tres Montosas and Gray Hill there is a maximum of 600 feet of the tuff of Granite Mountain, an abrupt thickening to the south.

The lower contact is exposed on Gray Hill where the tuff of Granite Mountain rests on Spears andesites and on Tres Montosas where it rests on a thin, poorly welded ash-flow tuff. The upper contact is not as easily established. In the area northeast of Magdalena, Brown (1972) described a hematite-stained conglomerate, 0 to 40 feet thick at the top of the Spears Formation. Chapin (oral commun., 1975) has mapped this conglomerate in the Granite Mountain area where it thickens to 200 feet. However, in the Tres Montosas area, the Hells Mesa Tuff rests directly on the tuff of Granite Mountain and the contact is placed at the first appearance of abundant quartz, a feature which is readily observable in hand specimen and occurs over a very narrow range. This change in quartz content coincides with a slight break in slope which is visible on aerial photographs. On Gray Hill, the tuff of Granite Mountain forms a prominent ridge. On Tres Montosas, however, talus from the overlying Hells Mesa obscures much of the tuff of Granite Mountain. Where it does outcrop, the lower part forms blocky, massive outcrops similar to much of the Hells Mesa. As the upper contact is approached, the tuff of Granite Mountain becomes lighter in color and the outcrops become platy.

In fresh specimens, the tuff of Granite Mountain varies from light-pinkish-purple to dark-purple with the weathered surfaces showing darker, browner colors. When altered, it is a light-pinkish-gray. The tuff of Granite Mountain is a medium-grained, moderately to densely welded, crystal-rich latitic ash-flow tuff. The predominant phenocrysts are plagioclase, sanidine, and coppery biotite. Minor clinopyroxene and quartz are occasionally present. Lithic fragments are present throughout the unit. Dark, andesitic fragments are most common, but lesser amounts of tuffaceous fragments and light-colored, equigranular igneous rock fragments are also present. Pumice is present in amounts varying from 0 to 5 volume percent.

In thin section the rock is porphyritic, seriate with phenocrysts varying from 40 to 45 percent by volume. Plagioclase, varying from 10 to 20 percent, is the most abundant phenocryst. It occurs in euhedral to anhedral, irregularly embayed grains 0.2 to 2.4 mm in length. Alteration to calcite with minor epidote and clays ranges from incipient to complete. Plagioclase compositions range from An_{31} to An_{36} with an average from six measurements of An_{34} (Fouque method). Albite twinning is the most common with subordinate Carlsbad twins. Normal zoning is well developed in some phenocrysts.

Sanidine varies from 10 to 15 percent as subhedral to euhedral, irregularly embayed grains 0.2 to 2.0 mm in diameter. Some grains show incipient alteration to calcite, epidote, and clays while other grains are completely altered to these products. Biotite, varying from 4 to 7 volume percent, occurs as euhedral to subhedral, pleochroic grains 0.3 to 1.5 mm in length. Some crystals are fresh but most show at least incipient alteration to dark red and opaque iron oxides. Opaque grains, probably magnetite, account for 1 to 3 percent of the rock. Minor quartz and clinopyroxene may be present. Quartz occurs as large, embayed, anhedral crystals 0.7 to 1.4 mm in diameter and clinopyroxene as euhedral crystals 0.3 to 0.4 mm in diameter altered to calcite and iron oxides. The groundmass consists of partially to completely devitrified glass stained dark-reddish-brown by finely disseminated hematite dust. Outlines of extremely compacted glass shards wrapping around phenocrysts are indicative of dense welding.

The tuff of Granite Mountain around the Tres Montosas stock has been greatly affected by the intrusion. It is difficult to determine in hand specimen if a particular rock is part of the stock or part of the tuff of Granite Mountain. Only upon close examination are features of ash-flow tuffs, such as lithic fragments, pumice cavities, and faint eutaxtic textures observed. The metamorphosed tuff of Granite Mountain has a darker color than the fresh rock and a waxy appearance on a freshly broken surface. Recrystallization of the groundmass has given the hornfels derived from the tuff of Granite Mountain a faint sugary texture.

Petrographically, the effects are more apparent. The baking has resulted in a distinct recrystallization of the groundmass into 0.4 to 0.8 mm feldspar grains and the introduction of abundant, small pyroxene grains has given the rock its darker color. The increase in temperature caused by the intrusion and then slow cooling has caused exsolution of potassium feldspar from the plagioclase. Graphic intergrowths of quartz and feldspar were observed in two thin sections. Despite the effects of metamorphism, the rock still retains its pyroclastic texture.

Hells Mesa Tuff

The Hells Mesa Tuff was restricted by Chapin (1974-b) to include only a quartz-rich, densely welded, multiple-flow simple cooling unit of quartz latite to rhyolite ash-flow tuffs occurring widely throughout the Magdalena district, the San Mateo, Gallinas and Lemitar Mountains, and east of the Rio Grande. It is the equivalent of the lower, quartz-rich portion of Tonking's (1957) Hells Mesa Member of the Datil Formation and to Brown's (1972) tuff of Goat Springs in the Hells Mesa Formation. A K-Ar age date of 30.6 ≠ 2.8 m.y. (Weber & Bassett, 1963) was obtained for the base of this formation. Dates of 32.1 m.y. and 32.4 m.y. (Burke and others, 1963) for crystal-rich tuffs in the Gallinas Mountains and the Joyita Hills correlated with the Hells Mesa Tuff are in better agreement with other dated units (the Spears Formation and the A-L Peak Tuff)

The Hells Mesa Tuff covers about three square miles of the map area and is most prominent in the northwest where it forms the high part of Tres Montosas. Because of poor exposures, a good stratigraphic section is not available. However, from cross sections it appears that the thickness varies from as great as 800 feet on Tres Montosas to as little as 150 feet on Gray Hill.

Just south of Tres Montosas, in a roadcut along Highway 60, a carmel-colored vitrophyre of Hells Mesa is exposed, but the outcrops cannot be traced away from the roadcut. The lower contact with the tuff of Granite Mountain is present on Gray Hill but is obscured by talus. The upper contact with the A-L Peak Tuff is well-exposed in a roadcut on Gray Hill where the two formations are separated by a one- to two-foot-thich, gray-green, friable bentonite layer. Brown (1972) reports a "turkey track" andesite occurring at this break in the Bear Mountains.

On Tres Montosas, the Hells Mesa forms prominent, massive cliffs which extend to the west as dip slopes and project under the sand cover. Elsewhere, the outcrops typically form low, rounded, talus-covered hills with little relief. Several cliff-forming outcrops are exposed in the central portion of the map area. The Hells Mesa typically weathers into large rounded blocks bounded by joints, but it may also weather as flat, platy outcrops.

In fresh hand specimen, the Hells Mesa is pink to brownish-purple, although most of the outcrops in the central area are bleached to a pink-cream color. Weathered surfaces yield buff to dark purple colors. The Hells Mesa is a medium-grained, densely welded rock with crystals and crystal fragments accounting for 40 to 55 percent by volume. The major phenocrysts are sanidine, plagioclase, quartz, and coppery-colored biotite. Lithic fragments typically account for 0 to 4 percent of the rock, but one part of the section contains as much as 20 percent dark, andesitic but do occur in some sections.

In thin section, the samples are porphyritic with a continuous gradation of particles from 0.1 to 3.0 mm giving a seriate texture. The groundmass is composed of small crystal fragments, glass shards, fine magnetite dust, and devitrification products. The dense welding is evidenced by highly compacted glass shards and pumice preserved in some samples.

Sanidine is the most abundant phenocryst and varies from 10 to 25 percent of the rock volume. It occurs in subhedral to euhedral, irregularly embayed grains ranging from 0.1 to 3.3 mm in diameter. Some grains show microperthitic unmixing with the development of patchy exsolved albite-twinned plagioclase. Most samples show incipient alteration along cracks and cleavage planes to chlorite, sericite, calcite, and hematite, and in some the sanidine is completely altered.

Plagioclase varies from 50 to 20 percent of the rock as subhedral to euhedral, irregularly embayed, lath-shaped crystals 0.1 to 3.0 mm in diameter. Alteration to clays and calcite varies from incipient to complete replacement. The plagioclase compositions were measured by the Fouque method; the composition varied from An_{26} to An_{29} with an average from 7 grains of An_{27} (olgioclase). Albite twinning is the most common twin form in plagioclase but Carlsbad twins are also present. Both normal and reverse zoning are well developed in some phenocrysts. In some, the Ca-rich cores reach a composition of An_{48} (andesine).

Quartz accounts for 5 to 15 percent of the rock as large, rounded grains varying from 0.1 to 3.3 mm in diameter. Grains as much as 6.5 mm in diameter were observed. Most grains are embayed, some very deeply, and filled with groundmass glass and small crystal fragments. Bronzy biotite occurs as euhedral phenocrysts from 0.2 to 1.6 mm long and varies from 2 to 6 percent of the rock volume. The grains are pleochroic with colors ranging from light-brownish-green to dark-reddish-brown and are partially to completely altered to iron oxides. In some thin sections, the biotite laths are bent and broken. Hornblende occurs as a minor constituent (as much as 1 percent) in euhedral grains 0.2 to 1.2 mm in diameter. Incipient alteration to magnetite is developed along some cleavage planes and around the borders of the crystals minor pyroxene and apatite are also present. In several thin sections, cubic-shaped holes filled with limonite have been left by the alteration of pyrite.

The groundmass is brownish-gray and normally devitrified with spherulitic aggregates of cristobalite and feldspar common. The spherulites are so abundant in some thin sections that they obscure the groundmass texture. Outlines of glass shards are well preserved in some thin sections and can be observed wrapped around phenocrysts and lithic fragments. Fine iron oxide dust makes up the remainder of the groundmass.

Lithic fragments vary from 0 to 4 percent in the majority of the formation. Near the base there is a zone containing as much as 20 percent lithic fragments. The fragments are typically dark-gray-brown, porphyritic, andesitic fragments probably derived from the Spears. In thin section, they consist of an opaque, hematized groundmass containing altered plagioclase phenocrysts. Lithic fragments range in size from 5 mm to 5 cm. Where the lithic fragments weather out of the lithic-rich zone, they give the false impression of Spears float. Pumice is uncommon but in some thin sections it is observed compacted around phenocrysts.

On Gray Hill, a paleovalley has been cut through the Hells Mesa. The Hells Mesa outcrop ends abruptly against the younger A-L Peak Tuff. Within the paleovalley, the A-L Peak Tuff is in depositional contact with the tuff of Granite Mountain. The vitrophyre at the base of the A-L Peak Tuff is continuous around Gray Hill to the north.

Where the Hells Mesa Formation is in contact with the Tres Montosas stock, there is only slight recrystallization of the groundmass. The phenocrysts are not affected as they are in the tuff of Granite Mountain. In hand specimen, the Hells Mesa does exhibit a dull, waxy luster on fresh surfaces.

A-L Peak Tuff

The A-L Peak Rhyolite is the name proposed by Deal and Rhodes (in press) for "gray-to-purple, crystal-poor ash-flow tuffs that are widely distributed in southwestern Socorro County." This formation was formerly called the tuff of Bear Springs by Brown (1972), who described it as a member of the Hells Mesa Formation. Brown (1972) and Simon (1973) were able to subdivide the A-L Peak into six mappable units; only one unit was observed in the Tres Montosas area. A fission track age date of 31.8 ± 1.7 m.y. was obtained by Smith and others (in press) for the formation.

The A-L Peak Tuff is a multiple-flow, compound cooling unit which, in the map area, consists only of the densely welded, flow-banded unit with a two- to three-foot-thick, brown vitrophyre at the base. The lower portion of the flow banded member is purple to pink in color with fresh or slightly chalky sanidine phenocrysts and highly compacted pumice which gives a streaky or banded appearance. The upper part of the formation contains abundant pyrite (1 to 3 percent) which upon oxidation has given the rock a buff to white color and has completely altered the sanidine to clay and given the rock a chalky appearance.

Except for two small exposures in the northeast corner of the map area, the A-L Peak is restricted to the extreme southwest corner where the total outcrop area is less than one square mile. It typically forms low, rounded hills covered by angular fragments with few good outcrops. On Gray Hill, the A-L Peak forms platy, rubble-covered slopes.

The A-L Peak Tuff rests directly on the underlying Hells Mesa Tuff on Gray Hill, but on the small hill in Section 14, only one mile away, a thin "turkey track" andesite separates the two tuffs. The upper contact is drawn at the base of a thin sequence of volcaniclastic sedimentary rocks which separate the A-L Peak Tuff from the overlying tuff of Gray Hill. On Gray Hill, where both contacts are exposed, the A-L Peak varies from 300 to 1000 feet in thickness.

In hand specimen, the A-L Peak Tuff varies from brown in the vitrophyre to purple in fresh samples. When altered by the oxidation of pyrite it has a buff color. The A-L Peak Tuff is crystal-poor with 5 to 10 percent phenocrysts of sanidine and quartz. The sanidine is generally euhedral, varying from clear to chalky-white when altered; the quartz forms small rounded grains. Scattered, small honey-colored crystals of titanite are visible in hand specimen, although none were observed in thin sections. The lower portion of the tuff contains as much as 20 percent highly compacted pumice which decreases in abundance toward the top. The pumice is dark-brown to gray and completely devitrified with the degree of compaction decreasing toward the top. Extreme examples of compaction around lithic fragments and phenocrysts are observed near the base (see Fig. 6). The A-L Peak Tuff contains as much as 10 percent andesitic and tuffaceous lithic fragments.

Petrographically, tuffs of the A-L Peak are fine-grained, porphyritic rocks containing euhedral to anhedral, partially resorbed phenocrysts of sanidine, quartz, plagioclase, and biotite. Sanidine is the dominant constituent and varies from 3 to 5 percent of the rock volume. It typically forms euhedral grains 0.1 to 3.3 mm in diameter and is commonly microperthitic. The sanidine is usually altered to clays. Quartz, in partially resorbed, rounded grains as much as 2.0 mm in diameter, accounts for 2 to 3 percent of the rock. Plagioclase and biotite are minor constituents occurring in very small grains, each accounting for less than 1 percent of the rock volume. The composition of the plagioclase, as determined on two grains using the Fouque method, was An_{29}.

The groundmass is completely devitrified with some well-preserved outlines of compacted glass shards. The devitrified groundmass consists of fine-grained quartz and feldspar, often as axiolites and spherulites. Finely disseminated iron oxide gives the groundmass a reddish-brown color.

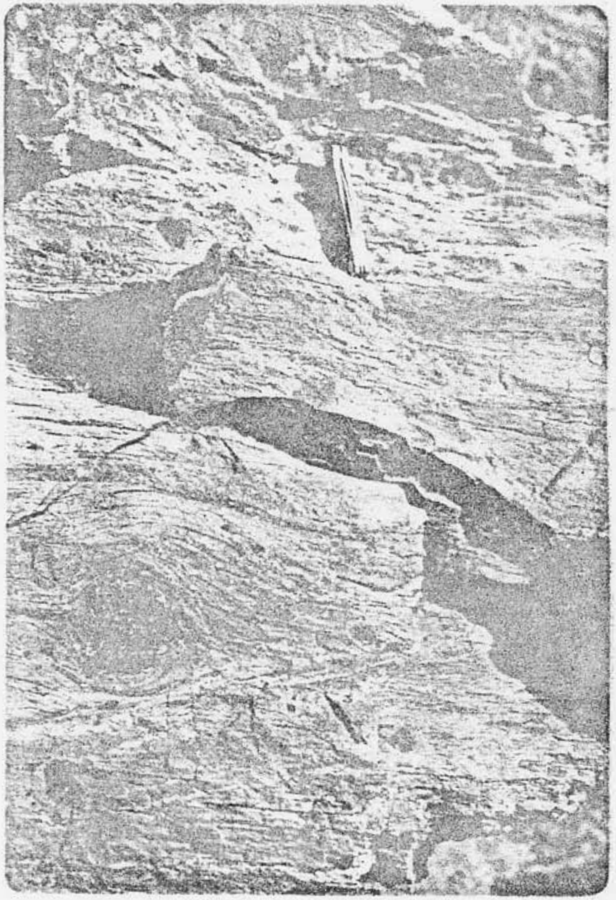


Figure 6. Cross-sectional view of the flow-banded member of the A-L Peak Tuff in a roadcut on Gray Hill. Note the fluidal banding caused by extreme compaction and elongation of pumice during primary welding. A well-developed lineation (not visible in photograph) is present on the foliation planes.

The distribution and thickness of the A-L Peak Tuff is controlled by a large, northeast-trending paleovalley which was cut through the Hells Mesa Tuff and the tuff of Granite Mountain prior to eruption of the A-L Peak (see Fig. 7). This accounts for the dramatic thickening of the unit within less than one-quarter of a mile.

A pronounced feature of the paleovalley is the tendency of the foliation to steepen as the valley wall is approached; attitudes change from those shown on Plate I to nearly vertical within short distances. This line of vertical foliation is interpreted to be the paleovalley wall and varies in trend fron N 30° E to N 55° E. Measurements of lineated pumice (which should parallel the direction of flow) vary from N 16° E to N 50° E. Secondary flow folds along the wall of the paleovalley were observed in the outcrops and the axis of one such fold had a N 38° E trend. So there is a marked parallelism of vertical flow foliation, pumice lineations, and secondary fold axes. Lowell and Chapin (1972) and Chapin and Lowell (1975) have described similar structures in paleovalleys in Colorado. Evidence of divergent foliation, interpreted as masses of hot tuff slumping down the valley wall and becoming welded to subsequently deposited tuff, is common in the outcrops.

Deal and Rhodes (in press) suggested that the Mt. Withington cauldron was the source of the A-L Peak Tuff.

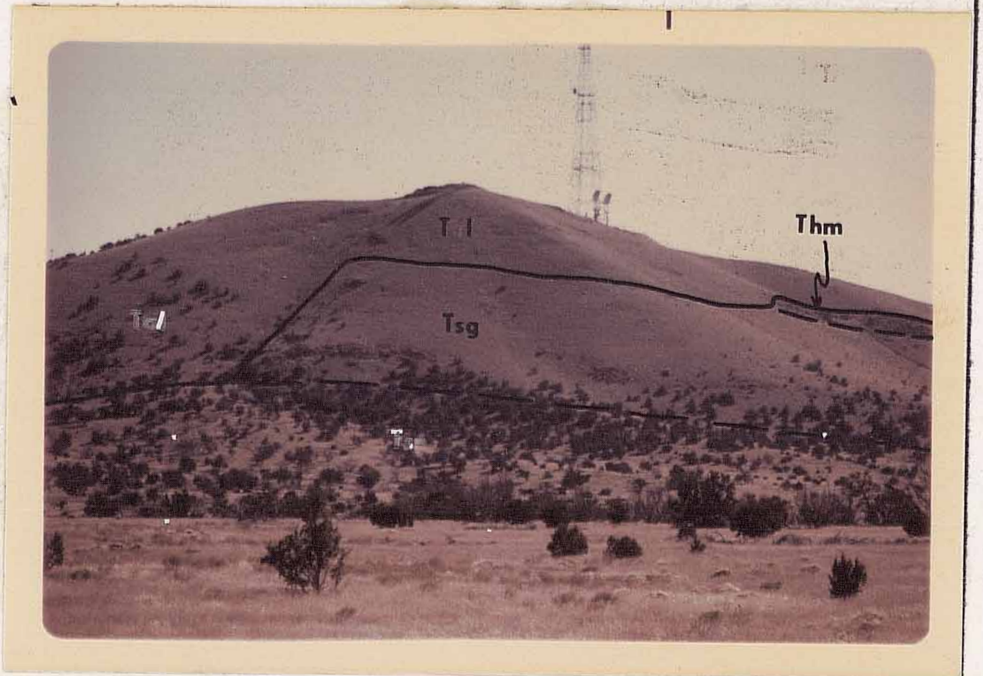


Figure 7. View of Gray Hill from the northwest showing a major paleovalley filled with the A-L Peak Tuff. From right to left, the A-L Peak rests on progressively older units towards the deepest part of the valley. (Thm = Hell Mesa Tuff; Tsg = tuff of Granite Mountain; Tsp = volcaniclastic rocks of the Spears Formation; solid line = outline of the paleovalley.)

This source is consistent with the trend of the paleovalley on Gray Hill and with the azimuths of lineation measured by Brown (1972), Deal (1973), Simon (1973), Chamberlin (1974), Blakestad (1976), and the author. Deal and Rhodes (op. cit.) measured 1800 to 2100 feet of the A-L Peak Tuff within the cauldron.

Andesite of Landavaso Reservoir

The andesite of Landavaso Reservoir is the informal name given by Chapin (1974-b) to a highly variable series of porphyritic basaltic-andesite flows cropping out about four miles east of the study area. Chamberlin (1974) mapped a local vent for these lavas in the Council Rock area to the north. The occurrence of these andesites east of the range-bounding fault north of Cat Mountain, and in juxtaposition with the Spears Formation southwest of Cat Mountain, provides a clue to the minimum displacement along the range-bounding fault.

Exposures of the andesite of Landavaso Reservoir consist of platy to massive lavas which cover an area of less than one-quarter square mile. The maximum thickness is unknown due to poor and widely scattered outcrops, but cross sections indicate a minimum thickness of about 400 feet. The lower contact is not exposed in the map area. On Cat Mountain, the andesite of Landavaso Reservoir is overlain by a sequence of younger ash-flow tuffs correlated in this report with the Potato Canyon Tuff.

In hand specimen, the andesite of Landavaso Reservoir is a dense, gray to reddish-gray, porphyritic rock with phenocrysts of plagioclase, pyroxene, and biotite. Flow banding is well developed in some areas and secondary hematite banding is a common feature of the unit. In most samples, there are distinct hematite alteration aureoles around the ferromagnesian minerals.

Petrographically, the lavas are porphyritic with a felty to pilotaxitic groundmass and occassionally contain glomeroporphyritic clots of pyroxene and plagioclase. Plagioclase is the dominant phenocryst and comprises 15 to 20 percent of the rock volume. It occurs in euhedral to subhedral grains 0.4 to 4.5 mm in length. Normal and oscillatory zoning are commonly observed. The plagioclase phenocrysts are typically fresh but many show incipient alteration to clays and calcite. The composition of the plagioclase ranges from An_{44} to An_{60} with an average of An_{54} (Rittmann Zone Method, 25 grains), suggesting that the lavas are basaltic-andesites.

Pale green clinopyroxene was observed in all thin sections and comprises 1 to 5 percent of the rock as euhedral to subhedral grains 0.4 to 1.9 mm in diameter. It is typically altered in varying degrees to hematite and magnetite.

Biotite occurs in all thin sections in grains 0.3 to 2.5 mm in length and comprises 1 to 4 percent of the rock volume. It is almost always altered to hematite but two thin sections contain fresh, brown, plechroic grains. Apatite, in grains as much as 0.4 mm in length, and magnetite are common accessory minerals.

The groundmass is typically composed of a felty to pilotaxitic arrangement of plagioclase microlites with interstitial pyroxene and magnetite. Some glassy groundmass was observed in several thin sections.

Tuff of Gray Hill

The tuff of Gray Hill is the name proposed in this report for a thick sequence of crystal-poor to moderately crystal-rich, rhyolitic ash-flow tuffs occurring between the A-L Peak Tuff and the Potato Canyon Tuff on Gray Hill. In most other areas, this break is occupied by the andesite of Landavaso Reservoir. The lower contact is exposed in a roadcut on Gray Hill where the A-L Peak Tuff is separated from the tuff of Gray Hill by a lense of volcaniclastic sedimentary rocks.

These sedimentary rocks are included in the tuff of Gray Hill. The contact of the tuff of Gray Hill with the overlying Potato Canyon Tuff is exposed in the southwest corner of the map area. The tuff of Gray Hill is probably correlative with Simon's (1973) crystal-poor upper tuffs which overlie the andesite of Landavaso Reservoir. The age of the tuff of Gray Hill is closely bracketed by a 31.8 ± 1.6 m.y. fission track date on the underlying A-L Peak Tuff and a 30.3 ± 1.6 m.y. fission track date on the overlying Potato Canyon Tuff (Smith and others, in press).

The tuff of Gray Hill has a minimum thickness in excess of 1000 feet as estimated from cross sections. The only exposure of the upper contact is separated from the main part of the formation by a fault with unknown displacement, so the maximum thickness is not known. Exposures of the tuff of Gray Hill are restricted to the extreme southwestern corner of the map area where they form high, rounded hills. The tuffs weather to rounded blocks; hill slopes are covered with small, angular fragments.

Simon's (1973) convention of dividing the crystal-poor tuffs into two parts, a basal unit and an upper unit, is followed in this report. The basal unit is composed of gray-to-purple, chalky, moderately to poorly welded tuffs characterized by small, botryoidal pumice. A similar unit containing botryoidal pumice has been observed as far away as the Luis Lopez district south of Socorro (Chapin, oral commun., 1975). Some of these tuffs contain (15 to 20 percent) small, andesitic and tuffaceous lithic fragments. The basal unit erodes as low valleys, separating the A-L Peak Tuff from the more densely welded upper unit.

The upper unit is separated from the lower by a thin, medium-grained volcaniclastic sandstone composed of moderately-sorted grains of quartz, sanidine, and plagioclase in a fine-grained siliceous matrix. The upper unit consists of gray to purplish-gray, moderately to densely welded tuffs characterized by small, banded rhyolitic lithic fragments.

Petrographically, the tuffs are porphyritic with a devitrified, microcrystalline groundmass. The phenocryst content varies from 5 to 25 volume percent. Sanidine, occasionally exhibiting microperthitic intergrowths, is usually the most abundant phenocryst and accounts for 2 to 15 percent of the rock. It is often completely altered to clays and calcite. Quartz is rarely more abundant than sanidine and accounts for 2 to 13 volume percent. It occurs as rounded, slightly embayed grains as much as 3.0 mm in diameter. Plagioclase is almost absent in the basal unit but increases to as much as five percent near the top of the upper unit. Compositions range from An_{28} to An_{32} with an average of An_{30} (Fouque method, 7 grains). Biotite, usually altered to opaques or hematite, comprises about one percent of the rock volume in the upper part of the section.

The groundmass is completely devitrified to microcrystalline aggregates of potash feldspar and quartz with spherulitic and axiolites textures developed in some thin sections. Outlines of glass shards are typically well-preserved in the upper unit.

Lithic fragments are common throughout the tuff of Gray Hill, accounting for 0 to 30 volume percent. They are generally small, ranging from 6 mm to 5 cm in diameter. Several distinct types were observed: 1.) gray to black, fine-grained andesitic fragments; 2.) brown to gray tuffaceous fragments; 3.) crystal-rich Hells Mesa-type fragments; and 4.) pinkish-gray, banded rhyolitic fragments.

The outcrop of distribution, thickness, and local extent of the tuff of Gray Hill suggest that it was deposited in the paleovalley previously filled by the A-L Peak Tuff. The sedimentary rocks between the two formations, and local uncomformities between the tuff of Gray Hill and the vertical foliation in the A-L Peak Tuff, suggest that the paleovalley was re-entrenched and then filled by the tuff of Gray Hill.

Such a process could also explain the absence of the andesite of Landavaso Reservoir between the two formations in spite of its presence just to the west of the paleovalley wall.

Potato Canyon Tuff

The Potato Canyon Rhyolite is the name proposed by Deal and Rhodes (in press) for a thick section of moderately crystal-rich ash-flow tuffs in the Mt. Withington cauldron. Subsequent mapping (Woodward, 1973; Spradlin, 1975) has shown that the Potato Canyon Tuff occurs as far east as the Lemitar Mountains and the Joyita Hills. Smith and others (in press) obtained a fission track date of 30.3 $\pm$ 1.6 m.y. from a sample near the base of the formation. In the study area exposures of the Potato Canyon Tuff are restricted to Cat Mountain and to the mesa in the southwest corner.

Deal (1973) divided the Potato Canyon Tuff into two informal units: a lower unit of gray, densely welded tuffs and an upper "moonstone tuff" unit. The exposures in the southwest corner of the study area correlate with his lower unit. Here, the Potato Canyon Tuff is very thin (100 feet), consisting of a gray, densely welded tuff with 15 to 20 percent chatoyant sanidine and smokey quartz. Its base is a depositional contact with the tuff of Gray Hill and the upper contact is an erosional surface on which the basalt of in a reddish-brown groundmass. Lithic fragments account for 0 to 25 volume percent with the following types observed: 1.) small brown aphanitic fragments; 2.) gray to brown tuffaceous fragments; and 3.) black andesitic fragments. Pumice varies from 10 to 30 percent of the rock volume.

In thin section, the tuffs are porphyritic with a devitrified groundmass in which spherulitic textures are occasionally developed. The phenocryst content varies from 5 to 30 volume percent. Sanidine is typically the most abundant phenocryst and comprises 2 to 15 percent of the rock volume as euhedral to subhedral grains. Some grains exhibit microperthitic unmixing of plagioclase. Plagioclase accounts for 1 to 10 percent and is occasionally more abundant than sanidine. Compositions were measured on seven grains (Fouque method) and ranged from An_{22} to An_{27} with an average of An_{25}. Quartz accounts for 0 to 15 percent as rounded, slightly embayed grains as much as 3.0 mm in diameter. Biotite, typically altered to opaques and hematite, varies from 0 to 2 volume percent.

Tertiary Intrusive Rocks

Latite Dikes

Latite dikes are present in two distinct parts of the map area: around the periphery of the Tres Montosas stock and in the Cat Mountain mining district. Those dikes near the stock are radially distributed about the stock for a distance of as much as two miles. There are two varieties

Council Rock was deposited. Outside the study area, the Potato Canyon Tuff normally overlies the A-L Peak Tuff or the andesite of Landavaso Reservoir.

The section exposed on Cat Mountain is composed mainly of densely welded, crystal-rich, quartz-rich tuffs with some unwelded pumiceous tuffs and fluidal-banded, crystal-poor tuffs which correlate with Deal's (1973) uppermost "moonstone tuff" unit. This section is very similar to the section exposed in Monica Canyon, north of Mt. Withington. Stratigraphic boundaries are ambiguous due to poor exposures, but it appears that the Potato Canyon Tuff on Cat Mountain overlies the andesite of Landavaso Reservoir. It is unconformably overlain by the basalt of Council Rock. These exposures may be correlative with Simon's (1973) crystal-rich upper tuffs, but poor and discontinuous exposures in both areas prohibit any certain correlation. The Potato Canyon Tuff on Cat Mountain has a minimum thickness of 700 feet.

The Potato Canyon Tuff is gray to pink on fresh surfaces and weathers to gray to dark reddish-brown. The tuffs vary from crystal-poor to crystal-rich and are typically densely welded, although several samples are only slightly welded. The dominant phenocrysts are sanidine (which may be chatoyant), colorless to smokey quartz, plagioclase, and biotite. Two of the crystal-rich tuffs have distinct white, flattened pumice of dikes, both latites. The first is a dark greenish-black, porphyritic rock with a fine-grained, aphanitic to phaneritic matrix. This variety occurs as a dike six to eight feet wide and 2100 feet long with a distinct vertical alignment of plagioclase phenocrysts. It also occurs as several short dikes cutting the wall rocks of the stock. The dikes weather to a reddish-brown color.

In thin section, the dike rock is porphyritic-phaneritic with a pilotaxitic groundmass. Plagioclase phenocrysts as much as 1.8 cm in length comprise 20 to 25 volume percent. Compositions range from An_{40} to An_{42} (Rittmann zone method, 3 grains) with an average of An_{41}. Clinopyroxene and apatite are minor accessories accounting for 1 and 2 percent, respectively. The groundmass consists of altered plagioclase microlites with interstitial clinopyroxene and orthoclase. This rock is very similar to the border facies of the stock, the only difference being a slightly finer grained matrix in the dikes.

The second type of latite occurs as dikes eight to ten feet wide and as much as one and three quarters mile long. It is a yellowish-brown rock with a fine-grained, phaneritic matrix with fewer and smaller plagioclase phenocrysts than the first type. In thin section, it is porphyritic-phaneritic with a trachytic groundmass of plagioclase microlites and interstitial orthoclase. Most of the phenocrysts were plucked out during cutting of the thin section, but plagioclase was probably the only kind present. The compositions of the dikes and their proximity to the stock suggests that they have a genetic relationship to the stock.

In the southeastern part of the map area, in the Cat Mountain mining district, a dike swarm crops out over an area one and one-half miles wide and two miles long. The dikes trend NNW to NNE with steep dips fluctuating to either side of vertical. These dikes are as much as ten feet wide and two can be traced for one mile or more. Where observed, they have no chilled margins and there are no contact metamorphic effects on the country rocks. Some of the dikes contain fresh inclusions of the wall rocks.

Fresh dike rocks are dark greenish-black, porphyritic with aphanitic to fine-grained phaneritic groundmass. They form poor outcrops, often traceable only as lines of distinctive float. Most of the dikes are altered due to the oxidation of contained pyrite and this imparts a brown or buff color to the outcrops. On some weathered surfaces, feldspar crystals as much as 2.0 cm long stand out in relief.

In thin section, the latites are porphyritic with phenocrysts of plagioclase and orthoclase in a pilotaxitic groundmass of plagioclase microlites. Euhedral plagioclase phenocrysts, as much as 6.2 mm in diameter, are the dominant phenocryst accounting for 5 to 20 volume percent. Compositions range from An_{27} to An_{45} with an average of An_{33} (Rittman zone method, 14 grains). Orthoclase phenocrysts, as much as 2.2 mm in diameter, comprise 2 to 4 volume percent. Euhedral apatite grains, as much as

1.4 mm long, account for 2 to 4 percent and clinopyroxene may occur in amounts up to 2 percent. The groundmass is composed of plagioclase microlites with interstitial orthoclase and apatite.

The occurrence of this dike swarm, in association with extensive quartz veining and hydrothermal alteration, may indicate the presence of a pluton buried beneath the Cat Mountain mining district. Several workers in the Magdalena district (Brown, 1972; Krewedl, 1974; Blakestad, 1976; and Chapin, pers. commun., 1975) have noted the correlation of mafic and porphyritic felsic dikes with known intrusives. They showed that the dikes are concentrated in the roof zone and extend only within a two-mile radius of the stocks. Chamberlin (1974) and the author noted a similar correlation of latite dikes with the Tres Montosas stock. Witkind and others (1970) reported the correlation of felsic dikes and plugs with a gravity outlined stock in the Little Belt Mountains, Central Montana. Therefore, it appears that the presence of a dike swarm is a valid geologic indicator of a buried intrusive.

Further evidence in support of the presence of a buried intrusive is the existence of a magnetic low on the low-level aeromagnetic map (USGS, Residual Magnetic Intensity Map, Area 4-3N, SW New Mexico) centered over the area of the dike swarm (see Fig. 8 and Plate II).

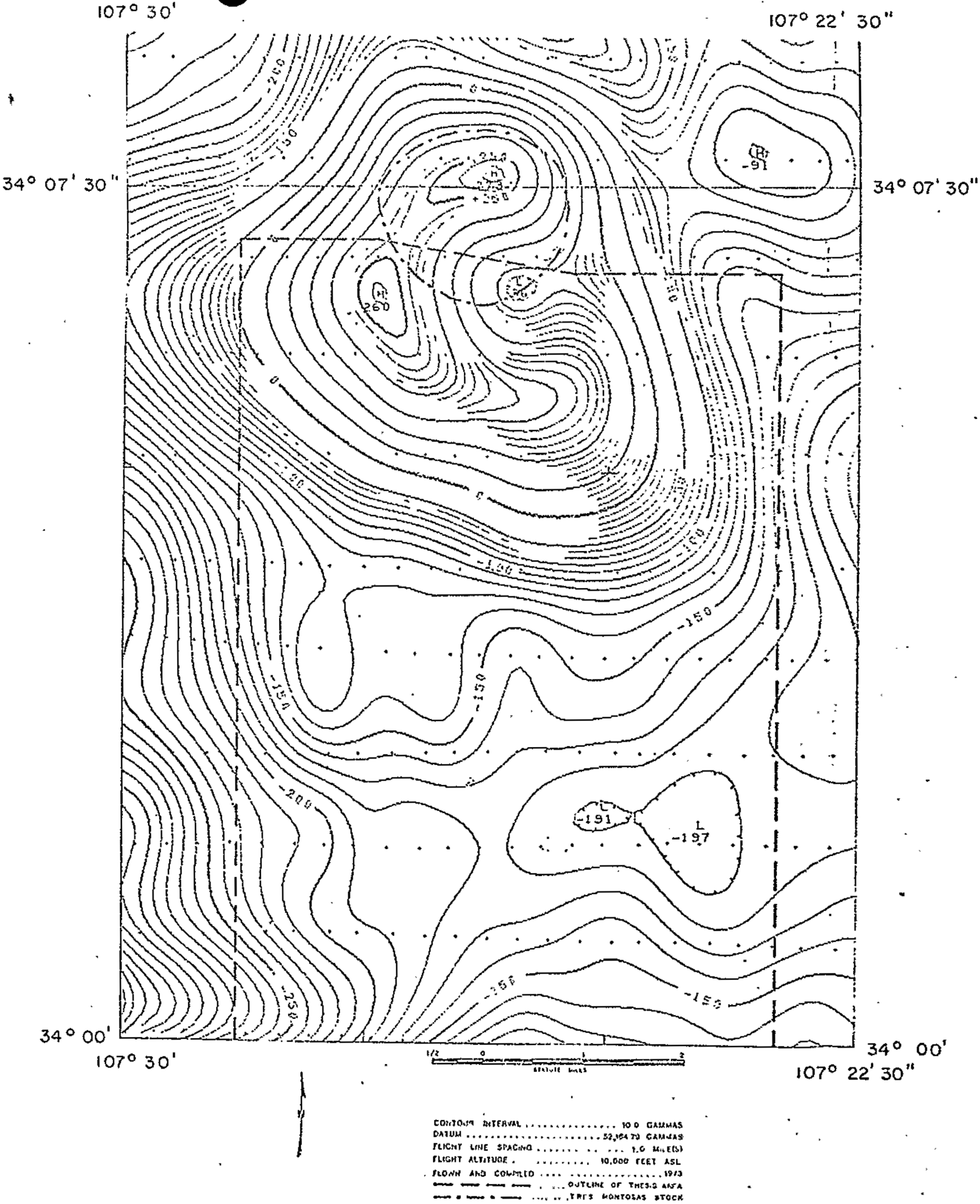


Figure 8 . Residual magnetic intensity map of the Tres Montosas quadrangle and part of the Gallinas Peak quadrangle showing the anamoly centered over the Tres Montosas stock (from U.S.G.S. Open File Map, Area 4-3 N, SW New Mexico).

Tres Montosas Stock

Two stocks are exposed in the map area. The largest of these occurs as a roughly circular body approximately two miles in diameter located along the northern boundary of the study area. It is a composite body consisting of three facies: andesite to granodiorite, latite to quartz monzonite and granite. Chamberlin (1974) named it the Tres Montosas stock for it proximity to Tres Montosas, three prominent peaks between the San Mateo and Gallinas Mountains. The majority of the Tres Montosas stock is mantled by blow sand and gravel; but the outcrop pattern, topographic expression, and a corresponding aeromagnetic high (see Fig. 8) indicate that it is a continuous, cupola-like body beneath the surface.

The Tres Montosas stock intrudes rocks ranging in age from the lower Spears Formation to the A-L Peak Tuff, and thus has a maximum age of 31.8 m.y. (fission track date by Smith and others, in press, on the A-L Peak Tuff). This age is in good agreement with K-Ar ages of the Nitt and Anchor Canyon stocks of the Magdalena District (28.0 ± 1.4 m.y. and 28.3 ± 1.4 m.y., respectively, Weber and Bassett, 1963) and suggests that the Tres Montosas stock is of a similar age. Chamberlin (1974) collected a sample from the Big John mine for K-Ar dating. A whole-rock analysis by Geochron Laboratories Inc., yielded a date of 33.9 m.y., an age greater than the youngest rock intruded by the stock. Subsequent petrographic examination of the sample revealed that it contained as much as 10 percent pyroxene, which according to Damon (1968, p. 14) commonly yields high ages due to excess argon. Based on the above data, the author assumes an age similar to the Nitt and Anchor Canyon stocks for the Tres Montosas stock.

Most outcrops of the stock occur along the stock-country rock contacts, but there are a few isolated outcrops in the central part of the stock. Exposures in the central core form low, rounded hills completely surrounded by blow sand and gravel. Better outcrops occur around the periphery where the border facies are "held up" by the more resistant metamorphosed country rocks.

The stock-country rock contact is quite sharp (see Fig. 9) and is exposed in two places; elsewhere it is covered by soil and colluvium. Chamberlin (1974) reported that the contact between quartz monzonite and the Hells Mesa Tuff was exposed along the west margin. He estimated a dip of about 30 degrees to the west at this location and used this figure to calculate that the roof of the stock was approximately 1500 feet above the present erosion level. However, along the south margin the contact between monzonite and the tuff of Granite Mountain strikes N 63° W and dips 60° N. Any prediction based on only these two data points would of necessity be tentative, but the shape of the aeromagnetic anomaly indicates that the stock has a moderately shallow, outward dip. Therefore, Chamberlin's (op. cit.) estimate of the depth of erosion is reasonable. Local variations in the dip of the contact are to be expected.

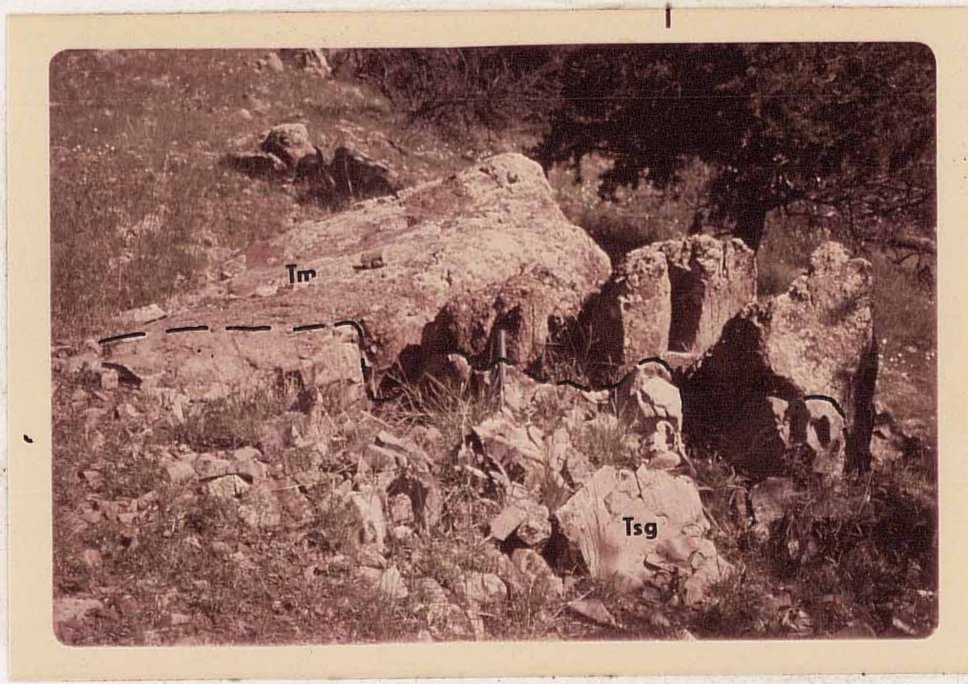


Figure 9. Outcrop showing the contact between the monzonite facies of the Tres Montosas stock (Tm) and hornfels derived from the tuff of Granite Mountain (Tsg). The outcrop dips 60° toward the stock (into the picture). The outcrop is located along the southwestern margin of the stock.

Chamberlin (1974) suggested that the Tres Montosas stock was forcefully intruded into the country rocks but data obtained from subsequent mapping indicated that passive intrusion was probably the most important mechanism. There is little or no doming of the country rocks except along the northwestern margin of the stock. The steep eastward dips along the eastern margin are the result of a monoclinal structure described by Chamberlin (op. cit.). The occurrence of quartzite xenoliths in the stock indicates that piecemeal stoping was operative at some time during intrusion. Figure 10 shows xenoliths of Spears andesite in the chilled margin of the monzonite facies. Further evidence of stoping was observed along the southern margin where a granite dike intrudes the Spears andesites (see Fig. 11). Small "fingers" of the dike have begun to block out and incorporate fragments of the andesite. Concentric faulting is well-developed around the periphery with the sense of movement down toward the center of the stock. The fact that the dips on the monoclinal structure decrease toward the stock and the scarcity of concentric and radial dikes suggest that the concentric faulting represents collapse over the stock due to subsidence of magma pressure. If forceful intrusion played a dominant role, doming should be more apparent and the radial and concentric faults would be expected to contain more dikes. The above data do not exclude forceful intrusion, but suggest that passive intrusion was the dominant mechanism.

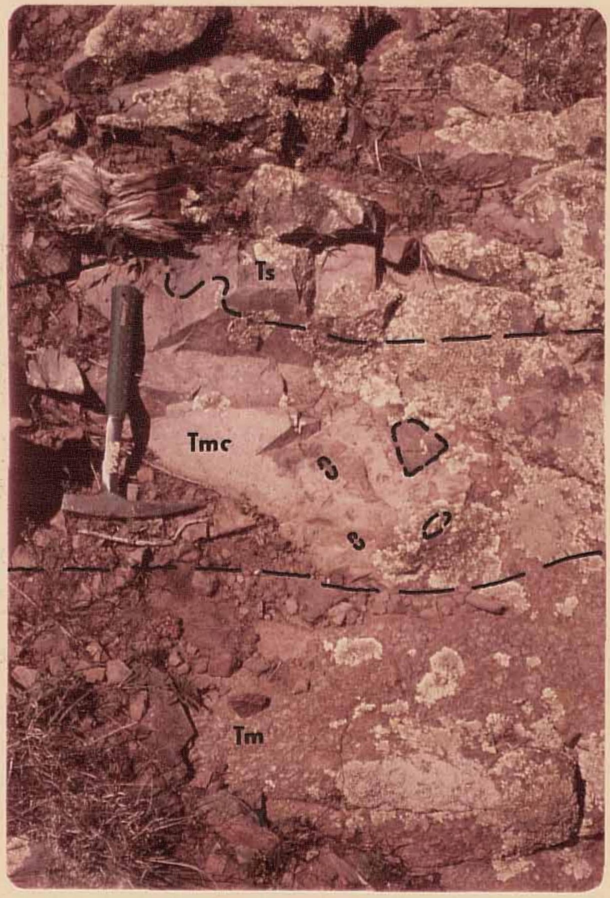


Figure 10. Exposure of the contact between the monzonite facies of the Tres Montosas stock (Tm) and andesites of the Spears Formation (Ts) showing a thin, chilled margin of the stock (Tmc). The outlined, dark fragments in the chilled zone are xenoliths of the Spears andesites. The outcrop is located along the southern margin of the stock.

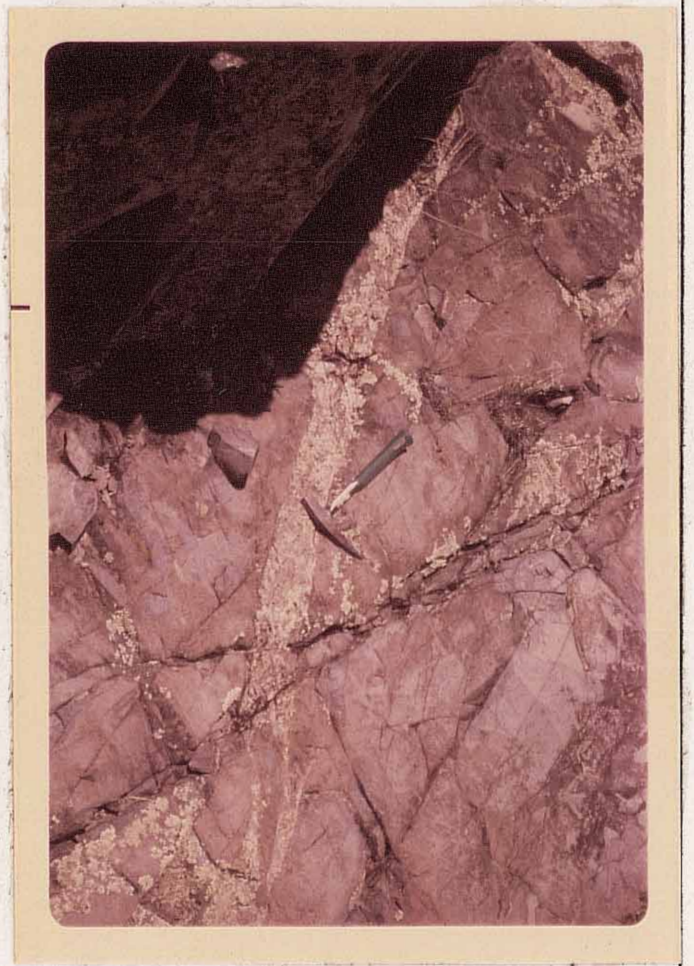


Figure 11. Outcrop of andesites in the Spears Formation intruded by a granite dike from the Tres Montosas stock. Note the thin "fingers" of the dike surrounding and incorporating fragments of the andesite. The outcrop is located along the southern margin of the stock.

Reconstruction of the stratigraphic section indicates that the Tres Montosas stock was intruded to within 2000 feet of the Oligocene ground surface.

Facies. The Tres Montosas stock is composed of three principal facies: andesite to granodiorite, latite to quartz monzonite, and granite. The inferred distribution of facies is illustrated in Figure 12 (modified after Chamberlin, 1974, p. 59); lack of exposures along the eastern margin makes that part of the illustration highly speculative. Sample locations of the stock rocks are also plotted on the figure. The undifferentiated mafic rocks shown by Chamberlin (op. cit.) along the southern border have been shown by subsequent mapping to be metamorphosed hornfelsed Spears Formation.

The andesite and granodiorite were not observed in the map area, but Chamberlin (1974) mapped rocks of this type as the outermost facies along the northern margin of the stock. "Andesites form a chilled sheath about the outer surface of the stock at the northwest . . . . margin. Near the Big John mine, andesite porphry is apparently gradational into fine- to medium-grained granodiorite." (op. cit., p. 60).

Latites and quartz monzonites form the border facies along the western and southern margins where they are in contact with the Hells Mesa and Spears Formations, respectively. Along the southern margin there are several latite dikes cutting the wall rocks in a radial pattern and Chamberlin

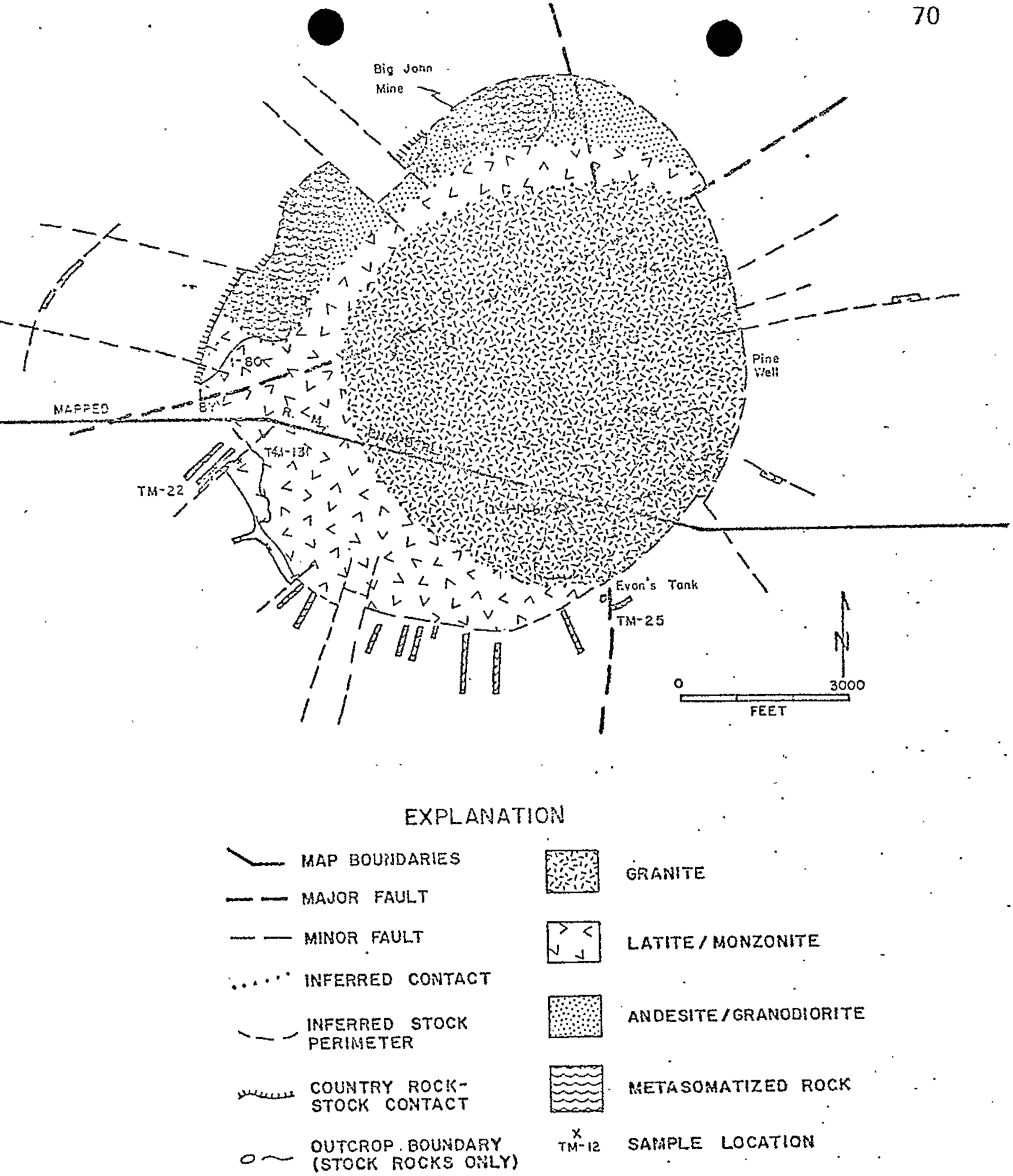


Figure 12. Inferred distribution of the principal rock types in the Tres Montosas stock. Metasomatized rocks are chiefly hedenbergite syenites. (Modified after Chamberlin, 1974.)

(1974) reported that latite intrudes granodiorite near the Big John mine.

The latites are distinctly porphyritic with large plagioclase phenocrysts as much as 1.9 cm long in a black-to-gray, aphanitic groundmass. They typically form poor outcrops along float-covered slopes. Zoning of the large plagioclase phenocrysts is visible in hand specimen. In thin section, the latites consist of large, euhedral plagioclase phenocrysts in a pilotaxitic groundmass of plagioclase microlites with interstitial orthoclase. Plagioclase compositions range from An_{40} to An_{45} with an average of An_{42} (Rittman zone method, 3 grains). Magnetite and apatite each account for 1 percent of the rock volume. The groundmass minerals consist of plagioclase (30 percent), orthoclase (30 percent), magnetite (10 percent), pyroxene (5 percent), and apatite (2 percent).

The quartz monzonite is a porphyritic, fine-grained phaneritic rock with phenocrysts of plagioclase and biotite. The plagioclase, accounting for 6 volume percent, occurs as glomeroporphyritic clumps and as single crystals as much as 2.5 cm long. Alteration was too intense to determine plagioclase compositions but Chamberlin (1974) reported that compositions for the quartz monzonite average An_{37}.

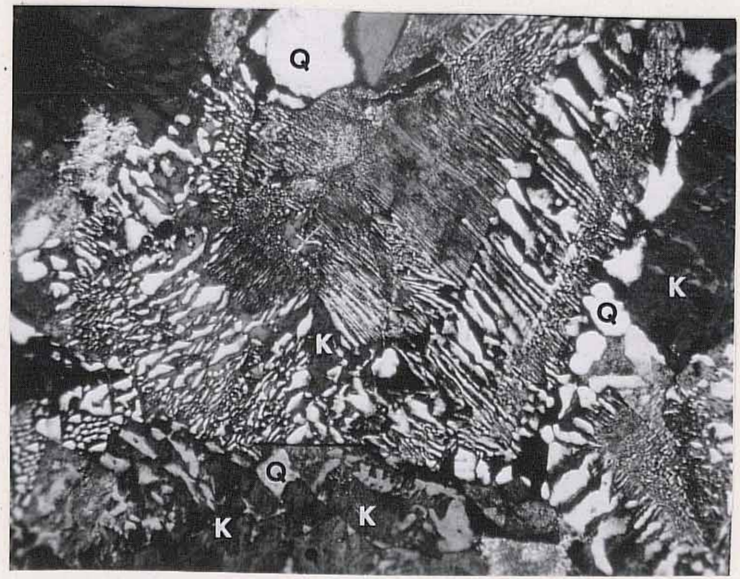
Biotite accounts for 4 volume percent. The groundmass consists dominantly of granophric intergrowth of quartz and orthoclase (20 percent and 42 percent, respectively) and approximately 20 percent plagioclase laths. Biotite, apatite, and magnetite are minor accessory minerals. Chamberlin (1974) and the author observed orthoclase mantling high temperature plagioclase in the above border facies rocks.

Granite and granite porphry occupy the central portion of the Tres Montosas stock. Granite was observed cutting andesites of the Spears Formation (see Fig. 11) and according to Figure 12 it presumably cuts the latite-monzonite border facies along the southern margin. Most of the granite is distinctly porphyritic with large, pinkish orthoclase phenocrysts as much as 3.8 cm long in a very coarse crystalline matrix of quartz and orthoclase, but one sample is equigranular. The granite is usually altered with most samples containing a few percent of oxidized pyrite.

In thin section the granite is typically a coarse-grained rock with textures varying from hypidiomorphic- to allotriomorphic-granular and from porphyritic-phaneritic to equigranular. The dominant constituents are orthoclase (52 to 60 percent), quartz (16 to 38 percent), and plagioclase (0.4 to 20 percent). Orthoclase typically occurs as clouded, anhedral to subhedral grains as much as 2.5 cm in diameter. Granophyric intergrowths of orthoclase and quartz are common in all samples of the granite and are especially well-developed in some (see Fig. 13) Chamberlin (1974) reported that the alkali-feldspar of one sample (I-14) was sanidine instead of orthoclase.

Quartz occurs in two forms: as rounded, partially resorbed grains as much as 4.8 mm in diameter and as granophyric intergrowths averaging about 0.4 mm in diameter. One thin section shows early quartz grains being replaced by orthoclase along grain boundaries.

Plagioclase is more abundant in the granitic dikes near the margin of the stock where it occurs as euhedral to subhedral grains as much as 2.0 cm long (see Table 1). In these dikes, it is the only phenocryst and accounts for as much as 20 volume percent. Here it is mantled by orthoclase (Chamberlin, 1974). In the coarser grained granites from the center of the stock, plagioclase accounts for 3 percent or less of the rock volume. Compositions of plagioclase from the dikes ranged from An_{32} to An_{47} and averaged An_{39} (Rittman zone method, 10 grains), compositions from the central granite ranged from An_{28} to An_{36} (Rittman zone method, 6 grains) (Chamberlin, 1974).



0.5 mm.

Figure 13. Photomicrograph of granophyric texture developed in granite from the central portion of the Tres Montosas stock. Note the different zones of granophyric intergrowths. (X-nicols, x50 magnification, Q = quartz, K = potassium feldspar.)

Table 1. Representative modal analyses of principal rock types from the Tres Montosas stock.

Rock type	Quartz Monzonite	Granite	Granite Dike
Sample no.	CR-I-80*	S-1	TM-22
plagioclase	27.7 #	0.39	18.7
	An_{36}	An_{29-36}	An_{36}
K-feldspar	48.7+	59.1	52.6
quartz	14.7	38.2	20.9
pyroxene	0.35	0.79	5.46
hornblende	3.67	-----	-----
biotite	-----	0.08	-----
opaques	2.36	tr	2.26
groundmass	-----	-----	-----
totals	100.0	100.0	100.0

*collected by R.M. Chamberlin
#volcanic (high temperature)
+plutonic (low temperature)

Pyroxene is generally a very minor constituent, but may account for as much as 5 volume percent as small (0.1 mm) rounded grains. Hornblende, magnetite and rutile are other minor constituents.

Chamberlin (1974) described a hedenbergite syenite from near the Big John mine, on the northwestern margin, which he attributed to ferro-potassic metasomatism of the granodiorite. He describes magnetite comprising 5 to 25 volume percent of the rock in veinlets as much as 5 cm wide.

Contact metamorphism and metasomatism occur in an aureole as much as one mile in width around the stock. The tuff of Granite Mountain and andesites of the Spears Formation were baked and recrystallized. The Abo Formation is baked and the carbonate rocks in the Abo may be altered to wollastonite, garnet, and epidote. Chamberlin (1974, p. 73) described the metasomatism of a "turkey track" andesite in the Spears Formation. The reader is referred to the descriptions of these specific formations for more details.

Several features observed during mapping and petrographic examinations provide clues concerning the petrogenesis of the stock. A shallow depth of intrusion is indicated by reconstruction of the stratigraphic section and born out by several petrologic features. Granophyric textures, interpreted by Barker (1970) as resulting from ". . . relatively rapid simultaneous growth of alkali feldspar and quartz from a melt, vapor, or devitrifying glass." are well developed in the granites and some of the border facies rocks. The occurrence of high-temperature plagioclase in the border facies and sanidine in the granite also indicates that the stock was emplaced near the surface and cooled too rapidly for conversion from high temperature to low temperature feldspars.

The extreme paucity of hydroxyl minerals and the lack of alteration that can be attributed to the stock suggests that it was a very dry magma at the time of intrusion. Holland (1972) presents data that suggests siliceous and intermediate magmas require 2 to 4 weight percent water before biotite and hornblende begin to crystallize. The lack of these hydroxyl minerals indicates a low water content in the Tres Montosas magma.

Chamberlin (1974) invoked the process of alkali metasomatism to account for the formation of the granitic core. It is evident that such a process occurred, but the water for the metasomatism must have come from another source at some time after the initial intrusion of the magma. Several observations support alkali metasomatism: 1.) granophyric orthoclase replacing early quartz and

Table 2. Modal analyses of fresh and metamorphosed tuff of Granite Mountain showing the chemical changes accompanying metasomatism.

	Fresh	Hornfels	
sample no.	average	TM-27	CR-I-55*
plagioclase	10 - 20	29.00	00.20
	An_{26}	An_{34}	An_{32}
K-feldspar	10 - 15	42.00	44.00
quartz	tr	5.00	0.30
biotite	4 - 7	tr	---
magnetite	1 - 3	tr	---
clinopyroxene	tr	22.00	31.00

*collected by R.M. Chamberlin

plagioclase, 2.) different mineralogies between granitic core and granitic dikes, and 3.) the enrichment of alkalis in the metamorphosed tuff of Granite Mountain (table 2). Because of the lack of evidence for a high water content as proposed by Chamberlin (1974), the author does not think that the granite is the result of in-situ alkali metasomatism but of differentiation of the parent magma. Several observations support differentiation from the parent magma: 1.) the existence of basic to silicic facies, 2.) cross-cutting relationships which suggest separate intrusions of each of the facies, and 3.) plagioclase becomes more sodic toward the center -- latite An_{40-45}, monzonite An_{37}, and granite An_{26-36}. More data, both chemical and petrologic, along with better sample control, are needed before a reliable petrogenetic model can be proposed for the Tres Montosas stock.

Monica Canyon Pluton

The Monica Canyon pluton is a small intrusive body located in the extreme southwestern part of the map area where it forms a small, conical hill about 800 feet in diameter. It is probably in intrusive contact with the basalt of Council Rock, the Potato Canyon Tuff, and the tuff of Gray Hill but the actual contact is obscured by piedmont gravels and talus. The pluton is intensely sheeted in a north-south direction and to a lesser extent along a N 85° W direction. The Monica Canyon pluton is significant in that it is the third exposed intrusive along the Gallinas uplift and may be an apophysis from a larger stock occurring beneath the piedmont gravels.

The Monica Canyon pluton is a dark gray, fresh, porphyritic rock of monzonitic composition. It contains large plagioclase and fresh, black pyroxene phenocrysts in a pinkish-gray, sugary matrix. It is a dark, brownish-gray color on weathered surfaces.

In thin section the Monica Canyon pluton is a porphyritic-phaneritic, hypidiomorphic-granular rock with glomeroporphyritic clumps of plagioclase and clinopyroxene. Plagioclase accounts for 15 percent of the rock volume as subhedral to euhedral grains 0.74 to 6.0 mm long. They are typically fresh and most are rimmed by thin rinds of potassium feldspar. The plagioclase compositions range from An_{39} to An_{47} with an average of An_{44} (Fouque method, 3 grains). Zoning is well developed with oscillatory and normal zoning the most common types. Clinopyroxene accounts for approximately 5 percent of the rock volume as anhedral to euhedral grains 0.3 to 1.5 mm in diameter. It is usually fresh but may show incipient alteration to iron oxides.

The groundmass is dominantly composed of very small plagioclase and potassium feldspar grains which comprise

34 and 20 percent of the rock volume, respectively. Clinopyroxene and magnetite each account for approximately 10 volume percent. Quartz and apatite occur as minor accessory minerals.

Post-Oligocene Rocks

Piedmont Gravels

Piedmont gravels, sloping westward and southward into the San Augustin graben and eastward into the Mulligan Gulch graben, cover about one-third of the map area and constitute the oldest surficial deposits. The maximum thickness is not known but one drill hole within one mile of the eastern exposures of bedrock was still in basin-fill sediments when it bottomed at 1000 feet. The piedmont gravels are poorly to moderately indurated and poorly sorted with particle sizes ranging from sand to boulders as much as four feet in diameter. The clasts are dominantly of the Datil volcanics exposed in the map area, both fresh and altered, but in the northeast corner, clasts of granite and the Permian sedimentary rocks are also present. The gravels are presently being dissected by streams with the amount of dissection sometimes in excess of 100 feet. Because the piedmont gravels represent filling of grabens formed by Basin and Range faulting, a Miocene or younger age is inferred.

Basalt of Council Rock

The youngest volcanic rocks in the Tres Montosas area are a series of thin lava flows capping piedmont gravels to the east and ash-flow tuffs of the Potato Canyon Tuff on Cat Mountain. The outcrop area is less than one-half square mile within the map area. The lava flows attain their maximum thickness on Cat Mountain where there are four individual flows with a total thickness of 75 feet. The outcrop patterns suggest a much greater thickness but this is due to the attitudes of the flows and to slumping along the edges. A Pliocene age is inferred for these lava flows.

In hand specimen the lava flows are dense, fine-grained, porphyritic, gray-to-black, vesicular rocks with plagioclase, olivine, and pyroxene phenocrysts. The alteration of olivine to iddingsite is readily visible in hand specimen. Some of the vesicles are flattened and drawn out and some are filled with calcite and drusy coatings of quartz. The rock weathers to a brownish-gray color.

Petrographically, the lava flows are glomeroporphyritic rocks with plagioclase, olivine and pyroxene as the only phenocrysts. Plagioclase grains 0.5 to 3.0 mm in length comprise 10 percent of the rock. Their compositions range from An_{44} to An_{60} with an average of An_{54} (Rittmann zone method, 18 grains). Normal zoning is common with some very small compositional changes (An_{47} to An_{44}; core to rim).

In several well-zoned crystals, there was no measurable compositional change from the core to the rim. Olivine constitutes 3 to 6 percent of the rocks as grains 0.1 to 0.6 mm in diameter. All of the olivine shows some degree of alteration to iddingsite. The alteration occurs predominantly along grain boundaries and fractures where there is a gradation from iddingsite to fresh olivine near the centers of the grains. Several of the olivine phenocrysts are zoned.

Two types of pyroxenes occur in the lava flows, clinopyroxene and hypersthene. Clinopyroxene is the most abundant, 1 to 4 percent, occurring as neutral, non-pleochroic grains 0.3 to 3.0 mm in diameter. Chamberlin (1974) observed this clinopyroxene to be endiopside ($2V_z = 50° \pm 2°$, z AC = 38°). Hypersthene accounts for 1 to 2 percent of the rock as euhedral to subhedral grains 0.3 to 3.0 mm in diameter. It occurs as neutral, slightly plechroic grains often associated with the clinopyroxene. The groundmass exhibits a trachytic-intergranular texture and is composed of microlites of plagioclase (75 percent), clinopyroxene (10 percent), magnetite (10 percent) and minor apatite (1 percent) and iddingsite (5 percent). The groundmass plagioclase has a composition of An_{47} (Fouque method, 2 grains).

Samples were collected from the four flows on Cat Mountain for chemical analysis (X-ray fluorescence and atomic absorption). The results are listed in Table 3 and the normative compositions are listed in Table 4. On traditional plots, such as Kuno's (1960) Al_2O_3 vs. $Na_2O + K_2O$, the lavas plot as alkali basalts. However, on Church's (1975) triaxial variation plot, they fall on the line of intersection of the basalt and andesite fields (see Fig. 10) indicating that they are not true basalts or andesites. Based on the classification scheme of Rittmann (1952), these lava flows are classified as alkali-trachyte to trachy-andesites.

The values of the solidification index [Kuno, 1960, defined as (SI + MgO) x 100/MgO + FeO + Fe_2O_3 + Na_2O + K_2O)] are low (21 to 24) indicating a high degree of differentiation. An additional indication of differentiation is illustrated in Figure 15. Here the average plagioclase phenocryst compositions are plotted for each flow vs. heighth in the section. A distinct trend toward more calcic plagioclase is indicated by the first three flows with the fourth falling off the trend line. The trend of the first three samples is the reverse of a normal differentiation trend and can be explained in two ways: tapping a differentiated magma chamber in the middle and draining upward or by

Table 3. Chemical analyses of the basalt of Council Rock in weight percent. *indicates samples analyzed by atomic absorption, #indicates samples analyzed by weight loss in a furnace, and the remainder were analyzed by X-ray fluorescence.

	TMC-1-1	TMC-1-2	TMC-1-3	TMC-1-4
SiO_2	54.43	53.46	54.41	54.91
TiO_2	1.45	1.46	1.43	1.44
Al_2O_3	14.48	15.51	15.63	15.48
*FeO	3.02	3.09	2.73	2.33
*Fe_2O_3	5.76	5.99	6.36	6.22
MgO	5.07	4.93	5.17	4.62
CaO	6.76	7.28	6.83	6.76
MnO	0.12	0.12	0.10	0.11
K_2O	2.06	2.12	2.11	2.32
Na_2O	5.93	4.91	5.28	5.86
#H_2O^+	0.20	0.94	0.09	0.78
#H_2O^-	0.47	0.20	0.14	0.65
totals	99.75	100.01	100.38	101.48

Table 4. Normative compositions of the basalt of Council Rock calculated according to the C.I.P.W. system from the chemical analyses in Table 3. Values are in weight percent.

Normative Mineral	TMC-1-1	TMC-1-2	TMC-1-3	TMC-1-4
ilmenite	2.74	2.74	2.74	2.74
orthoclase	12.23	12.79	12.23	13.90
albite	42.71	41.08	43.96	41.87
anorthite	6.67	13.90	13.34	8.90
magnetite	6.03	6.26	4.87	3.71
hematite	1.44	1.44	2.72	3.52
diopside	20.95	17.28	15.98	19.22
olivine	2.10	3.01	3.85	1.89
nepheline	4.12	0.17	0.31	4.29
totals	98.99	98.67	100.00	100.04

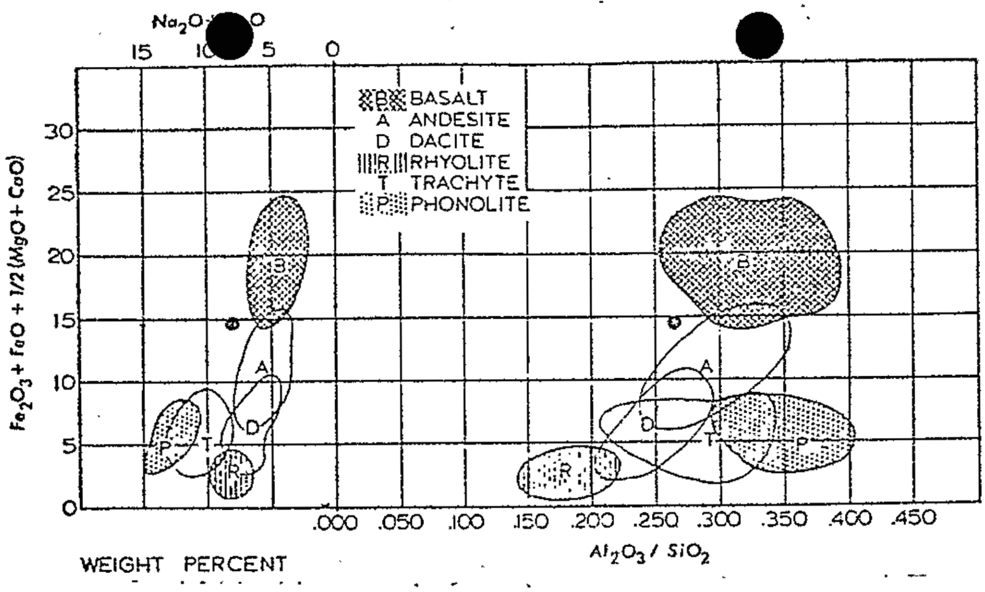


Figure 14. Classification of the basalt of Council Rock after the method of Church (1975). The solid circles represent the chemical compositions of the basalt of Council Rock.

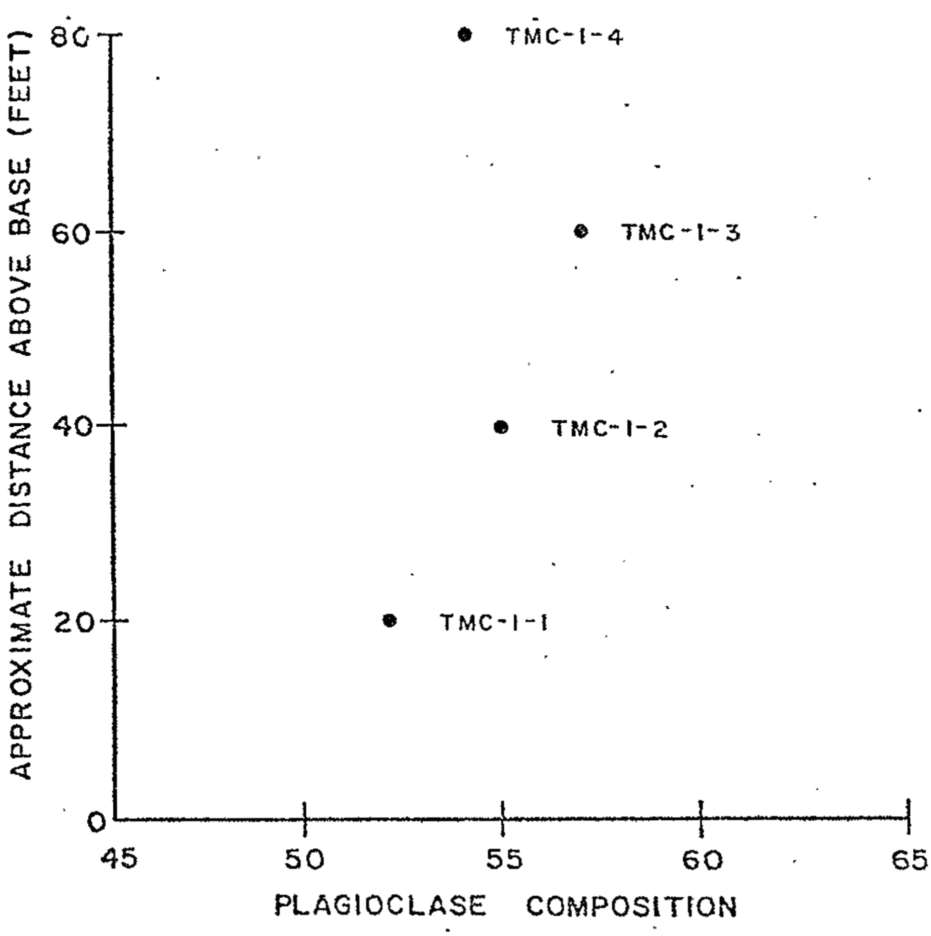


Figure 15. Variations of the plagioclase compositions in the basalt of Council Rock.

progressive partial melting of the crust. Because the solidification index indicates a high degree of differentiation, the first explanation is probably more reasonable.

Lipman (1970) suggested that the Miocene-Pliocene period of basaltic eruptions was approximately coincident in time with the formation of the Rio Grande rift. However, Chapin and Seager (1975) showed that Lipman's model was too simple and that the transition from middle Cenozoic calc-alkalic volcanism to basaltic volcanism occurred over a 10 to 15 million year interval beginning approximately 30 m.y. ago. Chapin (1971-b) proposed a bifurcation of the Rio Grande rift southwestward along the San Augustin lineament into Arizona. These ideas suggest that the basalt of Council Rock is a product of crustal extension along the San Augustin lineament and not a product of the parent magma of the Datil volcanic field as implied by Chamberlin (1974). The compositional differences between the Miocene-Pliocene and Oligocene andesites and basaltic-andesites support this interpretation.

Quarternary Deposits

Talus and Colluvium. In several areas the slopes are steep enough to allow significant accumulations of angular debris derived from mass wasting of resistant units overlying less resistant, slope-forming units. Extensive talus deposits are formed on Tres Montosas where the resistant Hells Mesa Tuff overlies the Spears Formation and on Cat Mountain where a resistant basaltic-andesite caps older ash-flow tuffs. The talus slopes have been stabilized by the growth of grasses and small trees but in places they are being eroded by small gullies which expose patches of the underlying rock units.

Colluvium is mapped where stratigraphic contacts are obscured by thin, unconsolidated deposits of angular rock debris on gentler slopes.

Eolian Sand. An extensive veneer of windblown sand surrounds Tres Montosas and the Tres Montosas stock. Along the northeastern boundary sand fills arroyos and low depressions. The yellowish to beige sand was carried northeastward by prevailing southwest winds blowing from the San Augustin Plains. A large pluvial lake occupied these plains in Wisconsin times and much of the sand was derived from the desication and deflation of the lake basin.

Areas of eolian sand are easily distinguished on aerial photographs by their light color and by the much more abundant growths of juniper and pinon trees than on the piedmont surfaces. Where there are thick deposits of sand filling arroyos, small stands of large Ponderosa pine trees grow. Evidently the sand can retain enough moisture to support these large trees.

Alluvium. In this study alluvium is used to indicate recent stream deposits in the larger drainages and deposits of deeply weathered gravels which occur as valley fill. The stream deposits consist dominantly of sand and gravel. When they occur together, alluvium generally fills channels cut into the eolian sand, but some sand blows into drainages during dry periods.

STRUCTURE

Regional Structure

A detailed regional structural analysis of west-central New Mexico has yet to be undertaken. Hunt (1974), in his physiographic study, included the Magdalena area in the Mexican Highland section of the Basin and Range province. The Tres Montosas area is situated on a north-northwest-trending uplifted block bounded on the east by the Mulligan Gulch graben and on the west by the North Lake graben. The area has been affected by two major periods of deformation: Laramide (Late Cretaceous and early Tertiary) and middle to late Cenozoic.

During Laramide time, the prevolcanic rocks were uplifted and deformed into a series of large open folds and thrust belts (Kelly and Wood, 1946; Tonking, 1957). Early investigators attributed the Laramide structures to compressive forces, but Eardley (1962) attributed them to the expansion of a column of magma due to partial melting. Coney (1971) viewed the deformation as the result of compressive stresses due to "massive westward cratonic underthrusting" and Chapin (1974-a) reported that Laramide structures were characterized by east-northeast directed compression.

During Eocene time, the Laramide uplifts were beveled by an erosion surface (Epis and Chapin, 1975) which exposed the cores of the uplifts. The Magdalena area is situated on the northern flank of such an uplift. Erosion was to the north into the Baca basin (Eocene) with progressively older rocks exposed to the south.

During late Eocene-early Oligocene time, west-northwest-trending faults were active along the Capitan lineament (Chapin and others, 1974). This zone has been documented in the Magdalena Range (Krewedl, 1974; Blakestad, 1976), in the map area, and in the Datil Mountains (Lopez, 1975).

During early to middle Oligocene time, a thick epiclastic apron of latitic detritus and voluminous ash-flow tuff eruptions covered the area to depths of 4000 to 5000 feet. Some of the ash flows filled northeast-trending paleovalleys which were structurally controlled by the Morenci-Magdalena lineament (Chapin and others, 1974). This ignimbrite plateau was then broken by a broad, north-trending extensional fault zone which controlled the emplacement of numerous stocks and dikes (28 m.y., Weber and Bassett, 1963) and "ushered in the Basin and Range epoch" (Chapin, 1974-a).

Late Cenozoic, north-trending faults related to the development of the Rio Grande rift (Chapin, 1971-a) were superposed on the earlier developed structural patterns. Southwest bifurcation of the Rio Grande rift along the San Augustin Plains (op. cit.) developed in the late Miocene. The cause of rifting has been interpreted by Eardly (1962) and Chapin (op. cit.) as the result of the northwest pulling away of the Colorado Plateau.

Local Structure

Structures in the map area are part of a complex system of several periods of faulting and folding. Figure 16 illustrates the relationship of these structural trends to major structures of the Magdalena region. The effects of the Mt. Withington cauldron near Cat Mountain are readily apparent as are the major north- and northeast-trending fault zones which probably represent older basement structures that have been reactivated during one of the several periods of deformation. The major periods of faulting occurred during the Oligocene and Miocene, but there is indirect evidence for faulting as old as the Permian.

A structural interpretation must explain several anomolous features of the map area: 1.) the low topographic relief compared to the high structural relief of the area; 2.) the abrupt eastward dips of the Oligocene volcanic rocks toward the Mulligan Gulch graben; and 3.) the high topographic relief of the Tres Montosas peaks. Figure 17 shows the low,

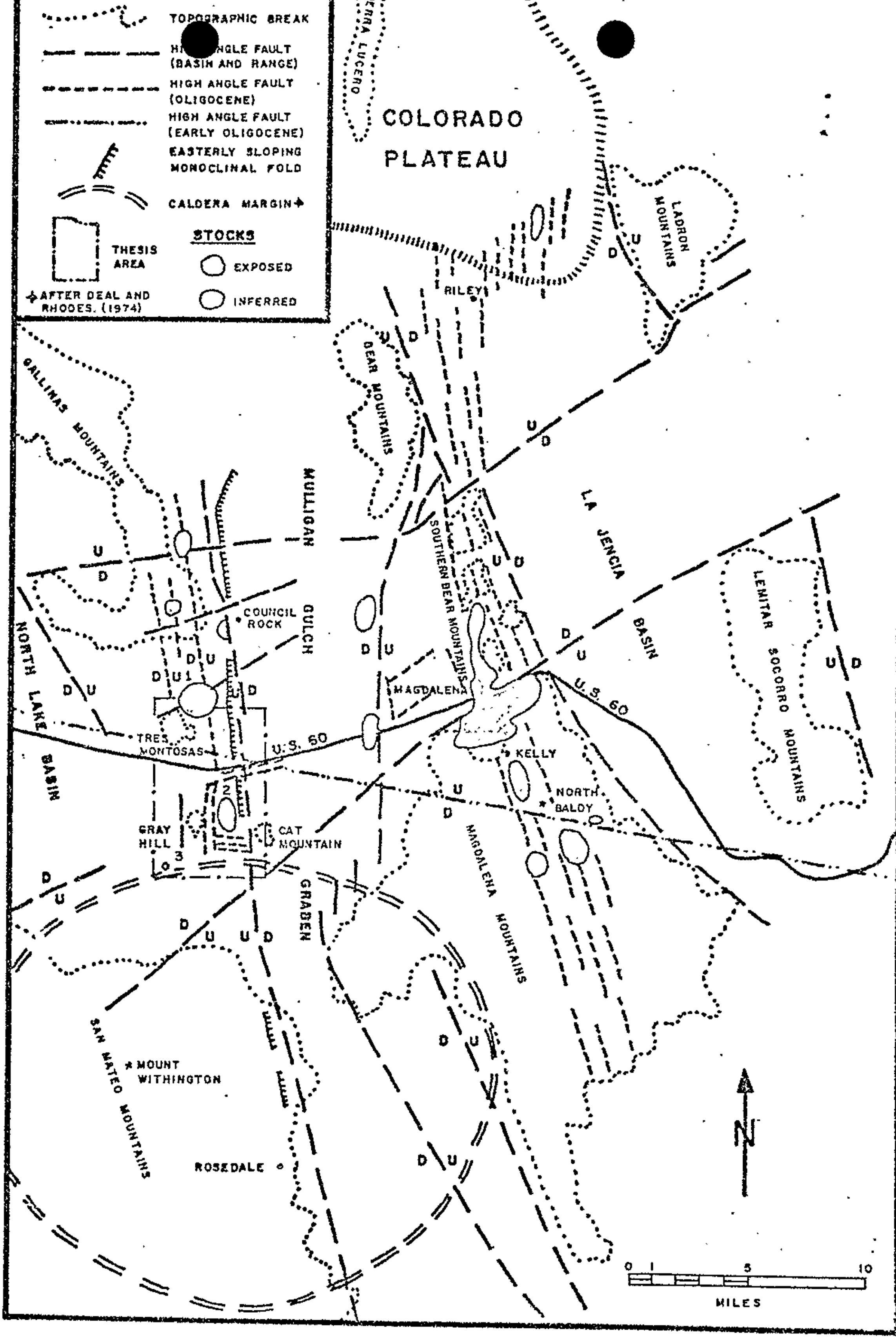


Figure 16. Generalized sketch map of the major structural features in the Magdalena region with respect to the thesis area. Exposed or inferred stocks within the thesis area: 1. Tres Montosas; 2. Cat Mountain; 3. Monica Canyon. (Modified from NMBMMR Open File Report No. 47).

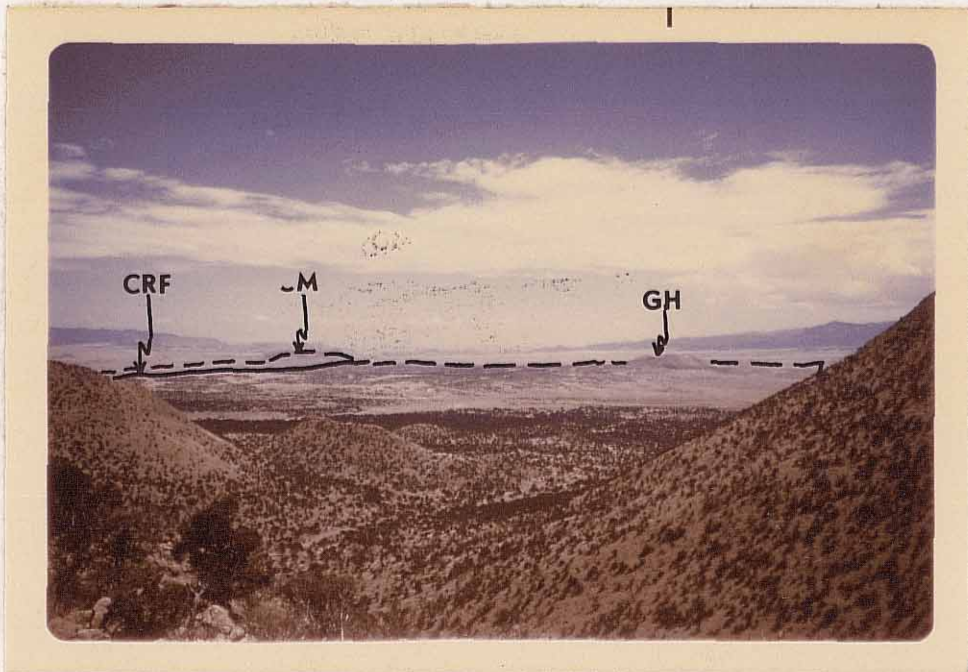


Figure 17. Overall view of the thesis area from the top of Tres Montosas. Note the low, undulating topography between Tres Montosas and Gray Hill (GH) and Cat Mountain (CM). The Magdalena Mountains are in the left background and the San Mateo Mountains are in the right background. (Dashed line = outline of the thesis area, CRF = southern extension of the Council Rock fault.)

undulating topography between Tres Montosas on the north and Cat Mountain and Gray Hill on the south.

Paleozoic Faults

The occurrence of limestone conglomerates and quartzite breccias in the Abo Formation suggests that uplift, possibly accompanied by faulting, occurred at the time of Abo deposition with the Madera Limestone exposed on the uplifted block. The existence of large limestone boulders (as much as four feet in diameter) in the Abo indicates a nearby source. A single azimuth measured on imbricated cobbles yielded N 85° W with the imbrication indicating transport from east to west. The elongation of the uplift was probably north-south, perhaps outlined by an older fault system which influenced the late Cenozoic north-trending faults.

Oligocene Tectonics

Late Eocene-Early Oligocene Transverse Faults. A N 80° W-trending fault zone along the Capitan lineament was active during the late Eocene-early Oligocene. This zone was mapped by Krewedl (1974) and Blakestad (1976) in the Magdalena Range as a down-to-the-south fault zone with about 1400 feet of displacement. The fault displaces the Spears Formation but not the Hells Mesa Tuff.

The evidence for this zone in the map area is its expression on the aeromagnetic map and in stratigraphic relationships from surface and drill hole data. In the Banner drill hole, the lower Spears Formation rests on carbonaceous siltstones thought to be the Sandia Formation but only two miles to the north the tuff of Nipple Mountain and the upper Spears Formation rest on the Abo Formation. The tuff of Nipple Mountain does not thicken across the zone so movement must have predated deposition of the tuff. This indicates that at the time of deposition of the tuff of Nipple Mountain, the displacement across the Capitan lineament was approximately 1300 feet down-to-the-south. If the sediments in the drill hole are assumed to be Mesozoic in age, then there must be approximately 5000 feet of down-to-the-south displacement, an unrealistic figure in terms of the available data.

The westward continuation of the Capitan lineament has been documented in the Datil Mountains by Lopez (1975). Along its projection he mapped an abrupt westward-curving of north-trending faults together with similar age relationships and direction of displacement along faults paralleling this zone.

<u>Development of the Mt. Withington Cauldron</u>. The development of the Mt. Withington cauldron has been discussed by Deal (1974) and Deal and Rhodes (in press). The tectonic

effects of the cauldron on the Magdalena area as a whole are small but the southern part of the Tres Montosas-Cat Mountain area has been greatly affected. The approximate position of the cauldron margin is shown on Plate I and in Figure 18 . The initial doming of the cauldron resulted in the development of radial and concentric faults which are well-developed in the Cat Mountain mining district. Most of the faults appear to be approximately contemporaneous but some of the radial faults have been displaced by concentric faults.

Doming was followed by the eruption of ash-flow tuffs beginning with the A-L Peak Tuff at 31m.y. and ending with the Potato Canyon Tuff at 30 m.y. (Smith and others, in press). Deposition of the A-L Peak Tuff, tuff of Gray Hill, and Potato Canyon Tuff was controlled in part by northeast-trending paleovalleys (Woodward, 1973; Simon, 1973; Blakestad, 1976; this paper) following the Morenci-Magdalena lineament (Chapin and others, 1974), an assumed northeast-trending basement structure. Chamberlin (1974) described a north-trending fault which was contemporaneous with the deposition of the Hells Mesa and lower A-L Peak Tuffs.

After deposition of the ash-flow tuffs, a graben formed in the south-central part of the map area which downdropped the tuff of Granite Mountain, Hells Mesa Tuff, and A-L Peak Tuff and preserved them as a north-trending outcrop belt.

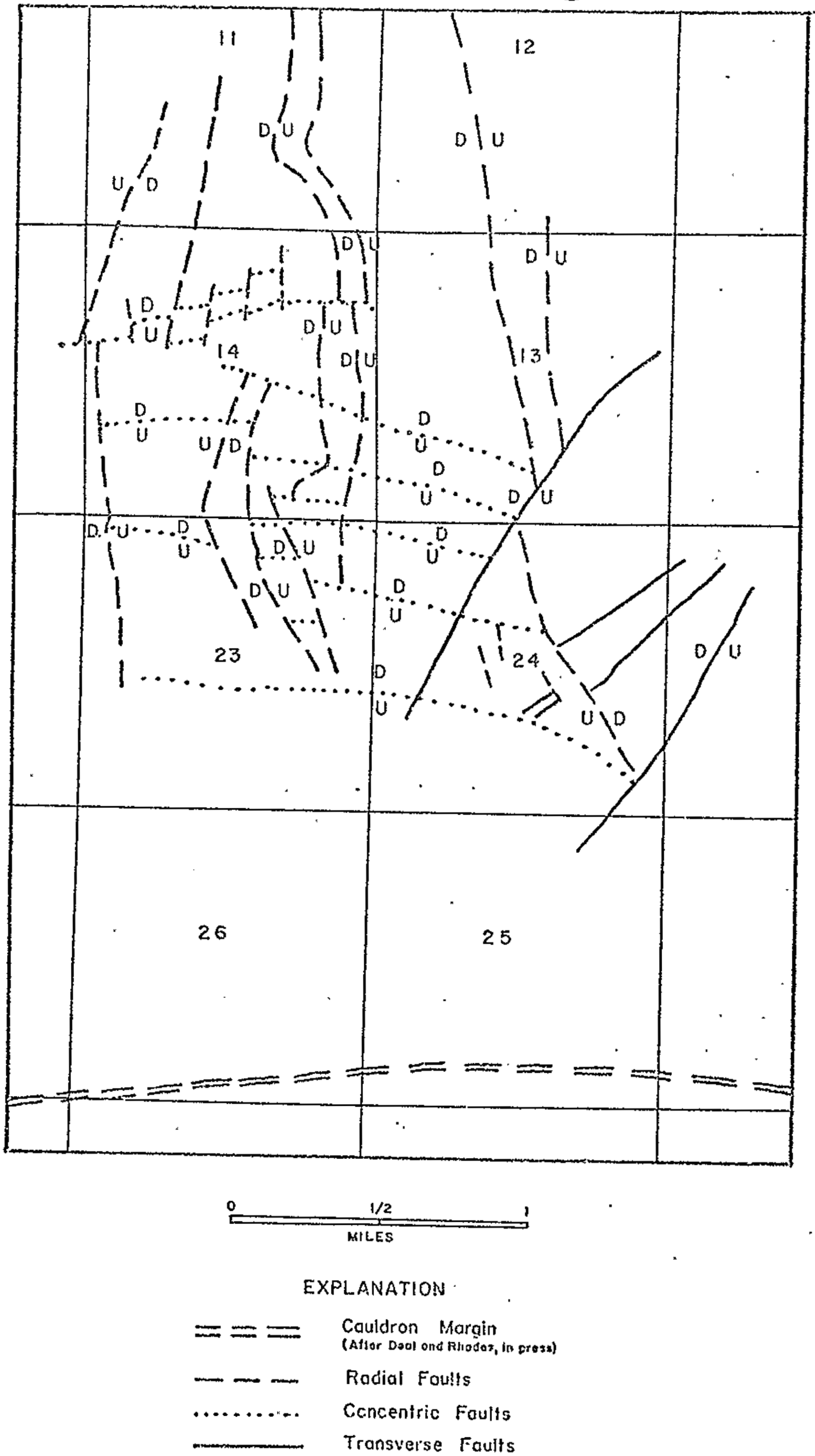


Figure 18. Relationship of faults in the Cat Mountain district to the Mt. Withington cauldron.

The graben probably formed during collapse of the cauldron, similar to the formation of grabens around the Creede caldera (Steven and Ratte, 1960). Also associated with cauldron collapse are a series of transverse faults (Schwartz, 1968) which cut the radial and concentric faults at high angles (see Fig. 18). Deal (1974) believes that catastrophic collapse did not occur until after the eruption of the Potato Canyon Tuff; this interpretation agrees with the timing cited above. Dike intrusion and mineralization in the Cat Mountain district followed and utilized radial and transverse faults as passageways.

Northest-Trending Faults. Late Oligocene faults with a northeast trend are especially evident just south of Highway 60 where the Hells Mesa Tuff has been preserved in a northeast-trending graben less than one mile wide. North-trending faults crossing this graben show changes in attitude from N 30° W south of the zone to N 20° E north of it. Simon (1973) mapped a northeast-trending graben along the eastern projection of this structure which controlled deposition of the tuff of La Jencia Creek. Differences in the level of erosion between these two areas accounts for the different rock associations. Chapin (oral commun., 1975) suggested that parts of the Spears Formation (the tuffs of Nipple Mountain and Granite Mountain) were controlled by northeast-trending paleovalleys in the Magdalena area and Chamberlin

(1974) mapped northeast-trending faults of Oligocene age in the Council Rock area.

If all of the above faults represent the same system, then the northeast faulting began during deposition of the Spears Formation (37 m.y.). The graben south of Highway 60 is offset by north-trending faults which in turn are offset by slightly younger, northeast faults. Veins, which apparently postdate the intrusives (28 m.y.) are not offset along this zone. Therefore, these faults were probably active during deposition of the Oligocene volcanic rocks but ceased just after 28 m.y.

This northeast trend may be related to northeast-trending basement structures. The Precambrian in the Magdalena area (Woodward, 1973; Chamberlin, oral commun., 1975) and in the Southwest as a whole, has a predominant northeasterly grain. These structures were probably reactivated in the Oligocene, perhaps by increasing pressure from the intrusion of batholiths which must have preceeded the Oligocene volcanic activity.

North-Trending Faults. During the late Oligocene, N 10° W high-angle faulting dominated the beginning of regional estension. Chapin (1974-a) ascribes this feature to changes from convergent to transform motion along the west edge of the American plate. This broad zone of north-trending faults broke the ignimbrite plateau and controlled the emplacement of numerous stocks and dikes. The zone extends from Tres Montosas eastward to the Ladron Mountains and from Ryan Hill Canyon in the South Baldy quadrangle northward to Riley, an area about 20 miles wide by 40 miles long. The timing of this period of faulting is well-bracketed by radiometric dates on the youngest ash-flow tuff deposited prior to faulting and on several intrusives emplaced along the faults (see Table 5).

Chamberlin (1974) discussed the structures related to the intrusion of the Tres Montosas stock. The main faults cutting the Tres Montosas peaks were first activated as radial faults during intrusion of the stock. Several other radial and concentric faults occur around the stock but they are not as well expressed as in the Council Rock area.

Folding. Along the eastern boundary of the map area, a narrow band of steep eastward-dipping Oligocene volcanic rocks, as much as one mile wide, extends from Abbey Springs through Cat Mountain, a distance of about 20 miles. A similar occurrence of dipping volcanic rocks along the eastern edge of the San Mateo Mountains may be a continuation of this zone. Chamberlin (1974) defined this zone of eastward dips as the anticlinal crest of an east-sloping monoclinal fold and assigned a late Oligocene age to it. He attributed its formation to the widespread intrusion of magma along

Table 5. Radiometric dates which bracket the age of the Oligocene north-trending faults.

Unit Dated	Age	Source
Nitt stock	28.0 ± 1.4 m. y.	Weber and Bassett, 1963 (K-Ar)
Monzonite dike northeast of Riley	28.1 ± 1.2 m. y.	Chapin and others, 1974 (K-Ar)
Anchor Canyon stock	28.3 ± 1.4 m. y.	Weber and Bassett, 1963 (K-Ar)
Water Canyon stock	30.5 ± 1.2 m. y.	Chapin and others, 1974 (K-Ar)
Lucero Mesa laccolith	27.1 ± 1.0 m. y.	Chapin (unpublished date)(K-Ar)
PERIOD OF NORTH-TRENDING FAULTS		
Potato Canyon Rhyolite (youngest ash-flow tuff involved in intrusion and faulting)	30.3 ± 1.6 m. y.	Smith and others, (in press) (Fission track)

north-trending basement fractures (see Fig. 19). Chapin and Seager (1975) suggested that this monoclinal fold forms the western boundary of the basin into which the La Jara Peak Andesite and Popotosa Formation were deposited. This would explain why the La Jara Peak Andesite has not been observed on the Gallinas uplift.

The conspicuous north-south alignment of intrusives (see Fig. 16) supports the idea of formation of the monocline by magma intrusion. Three plutons are exposed and three more are inferred over the distance from Abbey Springs to Cat Mountain. The greatest intensity of alteration in the study area and in the Council Rock area (Chamberlin, 1974) is also concentrated along the moncline.

Basin and Range Faults

Longitudinal Faults. If the formation of fanglomerate deposits is a valid criterion for evaluating the onset of Basin and Range faulting, then the first such evidence in the Magdalena area is the unit of Arroyo Montosa dated at 25 m.y. (Simon, 1973). Faulting of this period is related to the formation of the Rio Grande rift and resulted in the development of north-trending, block-faulted horsts and grabens which dominate the present topography. The Magdalena-Bear Mountains and Gallinas Ranges were uplifted

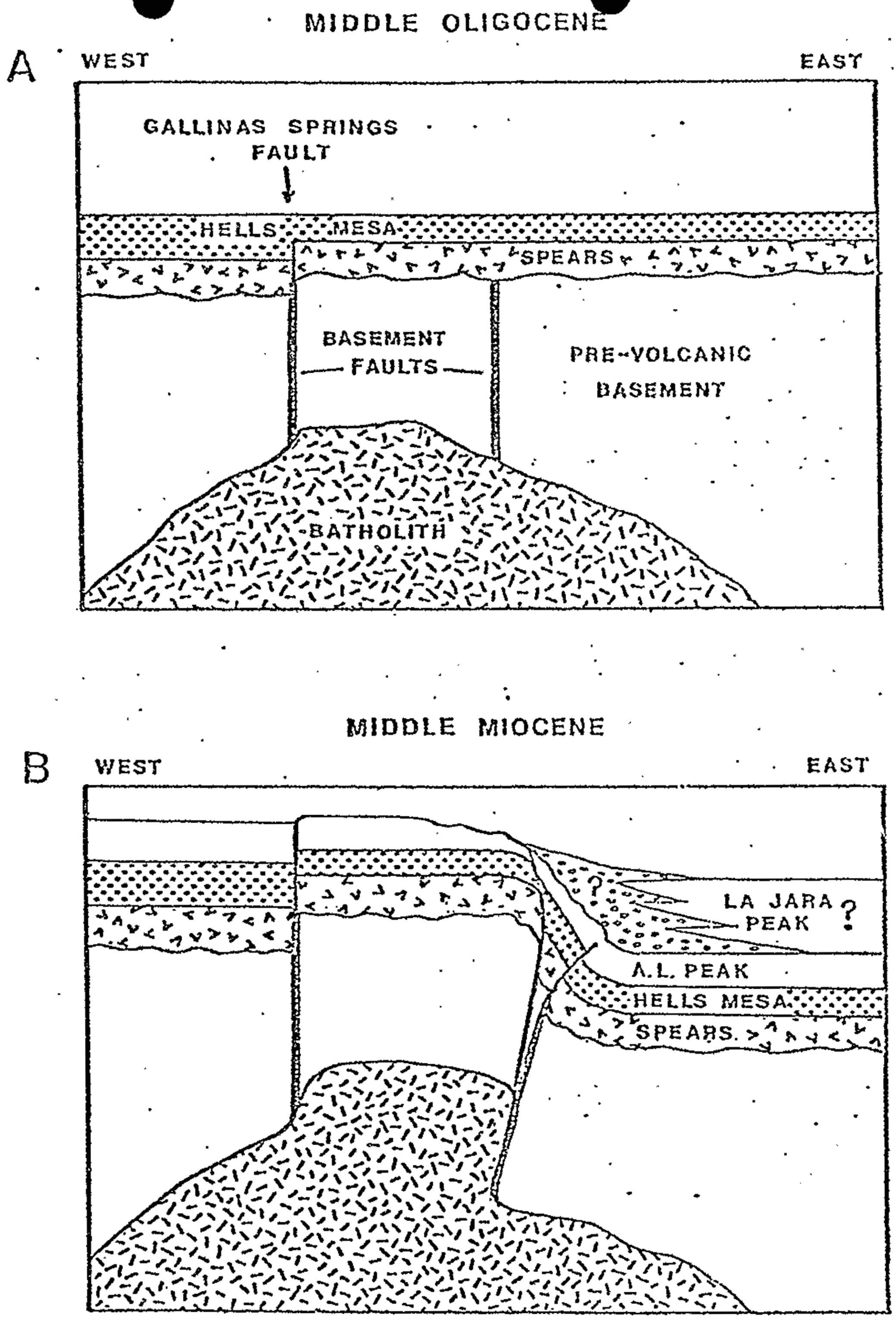


Figure 19. Diagrammatic east-west cross section at the approximate latitude of Gallinas Canyon (Gallinas Peak quadrangle) illustrating the development of the intrusive monocline along the eastern edge of the Gallinas uplift (from Chamberlin, 1974).

and the La Jencia, Mulligan Gulch, and North Lake grabens were downdropped during this period.

The major fault of the Basin and Range period is the southern extension of the Council Rock fault (Chamberlin, 1974) which forms the eastern boundary of the Gallinas uplift. It is marked by a distinct scarp with low topographic relief. This fault extends the entire length of the map area and probably forms the eastern margin of the San Mateo Mountains (see Fig.16).

Along most of the Council Rock fault, Oligocene and older rocks crop out against piedmont gravels but at Cat Mountain, Oligocene rocks are exposed on both sides. Here, rocks of the upper Spears Formation are juxtaposed against the andesite of Landavaso Reservoir and the Potato Canyon Tuff; this gives a minimum displacement in excess of 2000 feet. A drill hole just east of the map area and south of Highway 60 was still in gravels when it bottomed at 1000 feet. Chamberlin (1974) estimated a throw of 800 to 1500 feet in the Council Rock area and Chapin (oral commun., 1975) reports a small exposure of the A-L Peak Tuff about two miles southeast of Council Rock, near the center of the graben. These observations suggest that the depth of the Mulligan Gulch graben varies considerably.

Along the western boundary of the map area, numerous shorter segments of a similar north-trending fault drop blocks of the volcanic rocks down to the west into the North Lake graben. The great topographic relief of the Tres Montosas peaks is due to reactivation of late Oligocene north-trending faults and to westward tilting of greater than normal thicknesses of the Hells Mesa Tuff.

The North Lake graben exerts a greater influence on the drainage and structure of the Gallinas uplift than the Mulligan Gulch graben. This is illustrated in several places where the westward drainage penetrates to within one mile of the Mulligan Gulch graben. In the Council Rock area, away from the influence of the Mt. Withington cauldron, normal faults with their west sides down toward the North Lake graben extend to within two miles of the Mulligan Gulch graben. Little is known about the depth of fill in the North Lake graben. A complete section of the Oligocene volcanic rocks was encountered in the Sun No. 1 drill hole drilled on a structural saddle between the North Lake and San Augustin grabens. A minimum displacement of 3700 feet between this saddle and the Gallinas uplift is indicated, so displacement is probably much greater in the deeper parts of the graben.

The occurrence of young north-trending fault scarps cutting the alluvium on the La Jencia Plain indicates that this north-trending Basin and Range faulting is still active.

The basalt of Council Rock is also displaced by north-trending faults in the Mulligan Gulch graben.

Transverse Faults. Late Cenozoic faults with a northeast trend were observed by Brown (1972) and Chapin and others (1974) in the Magdalena area where they form a graben four to six miles wide with a vertical offset approaching 2000 feet and left-lateral offset of 0.8 miles. Chapin (1971-a) interpreted this zone as a southwest bifurcation of the Rio Grande rift along *en echelon* grabens extending through the San Augustin Plains and into the Blue Range of Arizona. There is little expression of this sense of movement in the map area. Chamberlin (1974), however, mapped transverse faults in the Council Rock area which were expressed by downfaulted piedmont gravels and a northeast-trending basaltic dike along the northern half of the Tres Montosas stock. The graben defined by Brown (1972) and Chapin and others (1974) widens considerably to the west and passes to the north and south of the Council Rock and Tres Montosas areas respectively, and on into the San Augustin Plains. The south bounding fault passes through Estaline Canyon in the San Mateo Mountains and the north-bounding fault passes through Deep Well Canyon about three miles north of Council Rock (see Fig. 16).

Chapin and others (1974) inferred a maximum age of latest

Miocene for the development of the San Augustin bifurcation. Rhyolite flows, dated at 14.3 m.y. (Weber, 1971), erupted from the dome at Magdalena Peak and flowed to the south. If the graben had formed earlier, there would have been a depression to the north into which these lava should have flowed.

The positions of the graben bounding faults combined with other structural elements help to explain why the Gallinas uplift has such a high structural relief but low topographic relief when compared to the Magdalena Range and Bear Mountains. The Gallinas uplift was formed during the initial Basin and Range faulting. It remained structurally high and formed the western margin of the basin into which the La Jara Peak Andesite and Popotosa Formation were deposited. Considerable debris in the Popotosa was derived from the Gallinas uplift. The Magdalena Range underwent further uplift during deposition of the Popotosa Formation and again during the breakup of the Popotosa Basin when the range was uplifted 3000 to 5000 feet while the Gallinas uplift remained relatively stable. The Gallinas uplift was already a structurally complex block (formation of the Mt. Withington cauldron, late Oligocene faults, and stock intrusions) which favored relatively rapid erosion. Superimposing the San Augustin bifurcation on the uplift added further to the complexity and to the low topographic relief.

ECONOMIC GEOLOGY

Mineralization in the map area is restricted to a zone about one mile wide along the eastern margin. The mineralization has been divided into two separate categories to facilitate discussion: vein mineralization in the Cat Mountain mining district and in the Abo Formation and disseminated mineralization at the Sixty copper prospect.

The Cat Mountain mining district is a small district operated around 1900 for gold. It consists of two intersecting vein trends with the most extensive workings located at the point of intersection. Lasky (1932) reported that the average of the assays of 58 samples was $6.85 per ton, but he collected samples from under the stamp mill which assayed 0.06 oz. gold and 0.46 oz. silver per ton. A 20-stamp mill was erected in 1902 but was shut down in 1903. Jones (1904) reported that the ore was mainly a refractory ore and that the operation ceased due to the inability to recover the metals. No production figures are available.

The veins in and around the Abo Formation were presumably worked at about the same time as the Council Rock district three miles to the north. Reports from the Council Rock district indicate that some of the ore averaged $250 per ton (Lasky, 1932). The workings are represented by three shafts, a short adit, and several prospects. No production figures are available.

The Sixty prospect is located in Sec. 6, T. 3 S., R. 5 W., just south of Highway 60. It is a small oxide copper body with mineralization disseminated in highly silicified and fractured tuff of Nipple Mountain. The predominant minerals are malachite, chrysocolla, and mottramite; minor chalcocite and azurite have been observed. The workings consist of a shaft and several open cuts, one of which is about 100 yards long. Figure 20 shows the mineralization in one of these open cuts. Total production was 356 tons which averaged 3.01 oz. silver per ton and 0.81 percent copper. As much as 1.33 percent lead and a trace of gold have been reported (Thurmond, 1951).

Mineralogy

Veins

Although the veins are located in two separate districts, they are similar mineralogically and will be described together. Two differences do exist between the two groups: veins in the Cat Mountain district are more quartzose and were worked for gold, whereas the other veins were worked for lead and silver.

Two major trends are readily apparent: north-south to

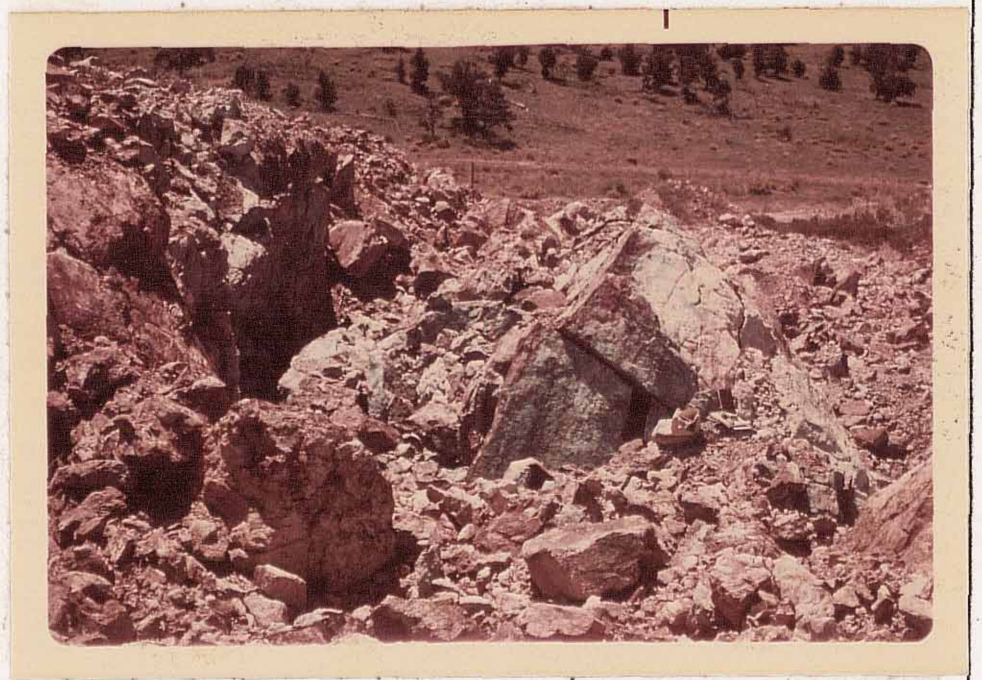


Figure 20. Overall view of the mineralization in the open cut at the Sixty prospect. Hematite is the predominate mineral, but copper silicates and oxides are common. View is looking south.

N 30° W and N 50° E. The veins dip very steeply with dips rarely less than 60°. They vary in width from veinlets a few millimeters across to veins eight feet across. Pinching and swelling of the veins is common which leads to much discontinuity. Several veins, however, were followed for more than a mile. The pinching and swelling probably also occurs in vertical section; few shafts exceed 100 feet in depth so either the values cease or the veins pinch.

Textures of the vein minerals indicate that the veins filled open spaces. Most contain evidence of brecciation or slickensiding of the wall rocks so they apparently filled spaces opened due to faulting. One vien is a composite of small quartz veinlets filling a narrow shear zone. Veins are typically slightly sinuous in plan.

The veins are associated with only two rock units in the map area: the Spears and Abo Formations. Chamberlin (1974) shows a similar association in the Council Rock district, but whether there is a real stratigraphic control or it is the result of the level of erosion is not known.

The veins are predominantly quartz and black calcite; one or the other is always present. The quartz is generally white occurring as massive veins of intergrown crystals or cementing brecciated wall rocks. Occasionally amethystine quartz is present. Late-stage quartz fills cavities throughout the veins as a drusy coating of clear crystals. Black calcite forms masses of intergrown crystals typically occurring as alternating bands with quartz. The contacts between quartz and calcite bands are generally very sharp. The black color is due to arborescent and reniform inclusions of manganese and iron oxides; when these inclusions are not present, the calcite is clear. In many districts throughout the Southwest, the manganese oxides in calcite are argentiferous (Hewett and Radtke, 1957). A sample of black calcite was analyzed for manganese and silver by emission spectrophotometry; manganese was present, but silver was not. This does not rule out the possibility that some of the silver values may be contained in the manganese oxides, but most is present in galena (assay). Late-stage calcite is clear and forms small, platy crystals filling vugs scattered throughout the veins.

Barite and fluorite are the next most abundant gangue minerals. Barite occurs as large, white, bladed crystals filling cavities in the black calcite and occasionally in the quartz. It may occur as scattered crystals or as solid, vein-like masses. Fluorite occurs as purple, green, or clear octahedral and cubic crystals filling vugs in quartz and calcite. When barite and fluorite occur together, fluorite covers barite crystals or fills open spaces within pods of barite.

The veins contain minor amounts of minerals characteristic of the oxidized zone. Cerussite, mimetite, wulfenite, and anglesite have been identified from several veins. Cerussite was identified by microchemical tests and a sample of suspected mimetite was analyzed for arsenic with positive results. These minerals typically occur as microscopic crystals filling cavities. Black manganese oxides and brown iron oxide are also present, generally as inclusions in calcite and as stains. In one sample manganese oxide was observed filling fractures in barite.

Near the southern margin of the Tres Montosas stock a small quartz vein was found with disseminated magnetite crystals. Chamberlin (1974) described magnetite veining on a much larger scale around the northern margin of the stock.

The only sulfides ovserved in the veins were pyrite and galena. Pyrite occurs as small cubes within the veins and in the wall rocks, where it is generally oxidized to hematite and limonite. Galena occurs sparingly throughout the veins as isolated crystals and as shiny, spongy masses coated with cerussite. In the calcite and fluorite, galena ofter occurs as tiny blebs contained within the crystals and aligned along cleavage planes. Galena is usually fresh but may show oxidation rinds to anglesite.

Figure 21 represents the paragenetic sequence observed in the vein minerals. It represents only the relative times of deposition, not the amounts deposited.

Disseminated Deposits

The Sixty prospect is a small, disseminated copper prospect occurring in highly silicified and fractured tuff of Nipple Mountain. The important minerals, in decreasing order of abundance, are: chrysocolla, mottramite, malachite, tenorite, cuprite, azurite, and chalcocite. Chrysocolla, mottramite, and malachite account for 98 percent of the mineralization, with cuprite, azurite, and chalcocite making up the rest. Chalcopyrite, as relict cores within chalcocite, was reported by Thurmond (1951) but was not observed by the author.

The chrysocolla, malachite, and chalcocite occur disseminated throughout the rock as tiny blebs, as pseudomorphs after feldspar phenocrysts, and as fracture coatings (see Fig. 22). A similar occurrence of copper mineralization replacing feldspar phenocrysts was described by Clement (1968) in the Copper Canyon intrusive in Nevada. Mottramite, tenorite, and azurite occur strictly as fracture coatings or filling vugs. Cuprite occurs as distorted octahedral crystals associated with tenorite. The most intense

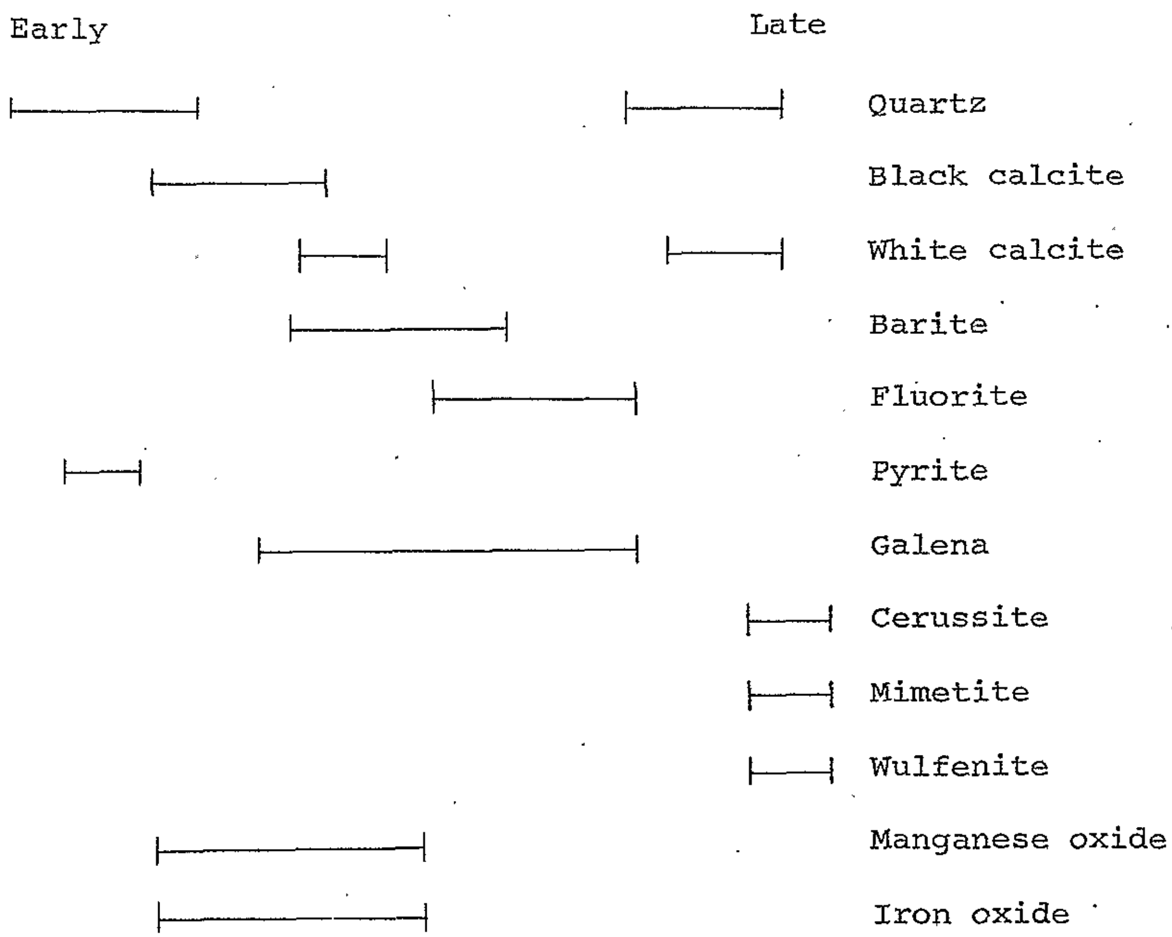


Figure 21. Paragenetic sequence for vein minerals in the Tres Montosas-Cat Mountain area. The diagram represents only the relative times of deposition, not the amounts deposited.

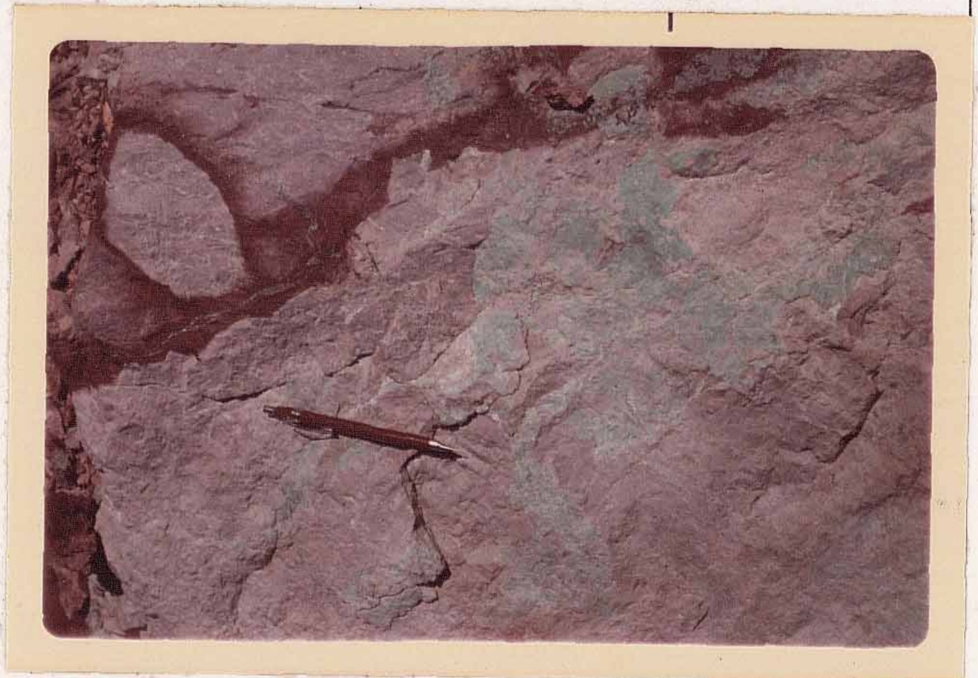


Figure 22. Photograph showing the occurrence of chrysocolla as fracture fillings, veinlets, and disseminated blebs in the silicified tuff of Nipple Mountain. Note the hematite banding along one of the veinlets. Outcrop is in the open cut at the Sixty prospect.

mineralization occurs along fractures where the copper minerals have apparently been remobilized and redeposited by circulating groundwater. Copper mineralization is not readily apparent on weathered surfaces but only a few inches beneath the surface the mineralization is present.

Hematite is a common alteration mineral at the Sixty prospect as fracture fillings. Waves of hematite staining are often visible moving away from the fractures with decreasing intensity along micro-fractures or around grain boundaries (see Fig. 23).

Mottramite is an unusual occurrence and deserves some discussion. It occurs as yellow, dark green, or black botryoidal fracture fillings (see Fig. 23). It was apparently the last mineral deposited since it coats hematite, although locally remobilized copper minerals may coat mottramite. The silver and lead values in the assays are probably contained in the mottramite so it is a potential ore mineral. Figure 24 represents the paragenetic sequence of mineralization at the Sixty prospect.

The mineralization is restricted to one outcrop only of the tuff of Nipple Mountain, although similarly altered and fractured exposures of the tuff exist close by. The boundaries of mineralization are fairly well known. The south and east sides are bounded by faults. The eastern

Figure 23. Photograph showing a wave of hematite banding moving away from a fracture in the silicified tuff of Nipple Mountain. The boundary of the hematite band with unaltered rock is sharp except along microfractures. The outcrop is in the open cut at the Sixty prospect. The olive to dark green mineral on the fracture surface is mottramite, $PbCu(VO_4)(OH)$.

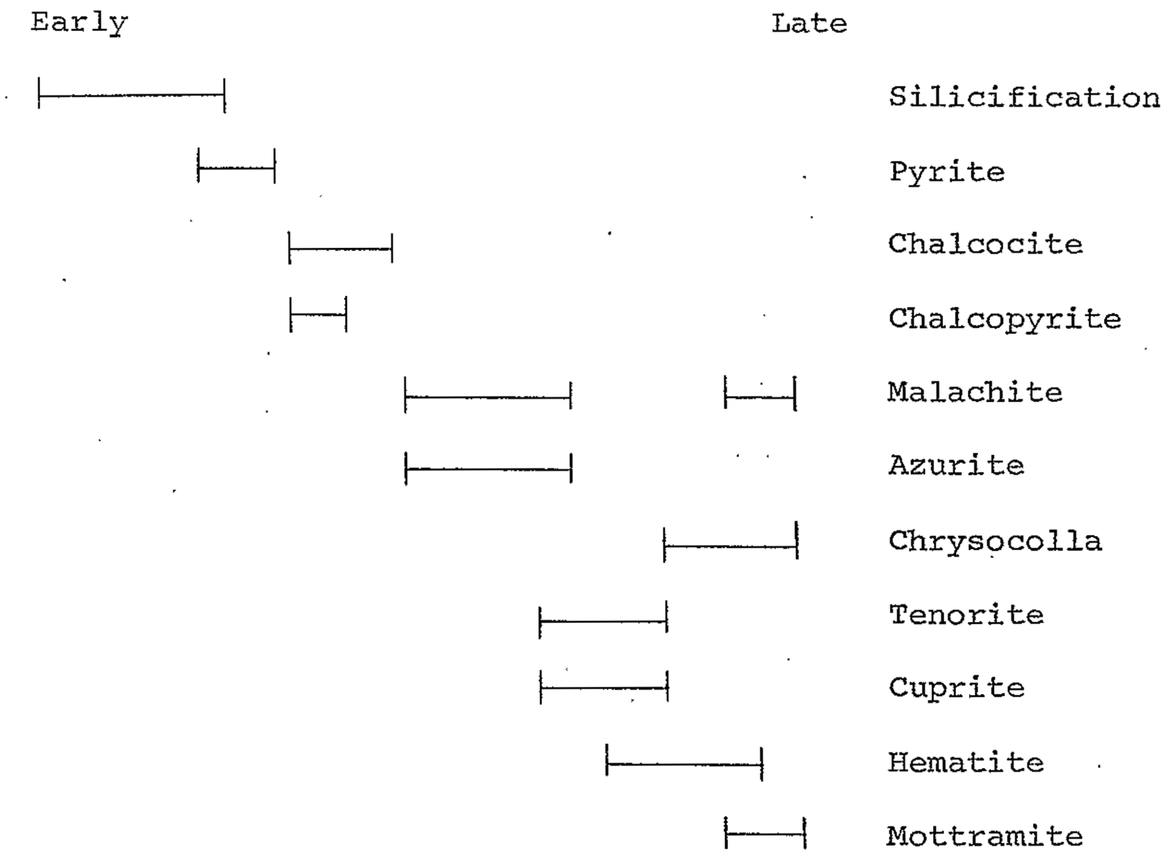


Figure 24. Paragenetic sequence for mineralization at the Sixty copper prospect. The diagram represents only the relative times of deposition, not the amounts deposited.

fault is upthrown to the east so the tuff of Nipple Mountain is repeated but no copper mineralization is present. Part of the west side is bounded by a fault although a drill hole west of this fault is mineralized. The northern extension is indefinite due to poor exposures and soil cover. The vertical extent is moderately well known from several drill holes. A northeast-southwest line of five drill holes along line A-B on Plate II penetrated the mineralization. Figure 25 is a cross section of the mineralized zone along line A-B. The Banner drill hole just south of this line collared in mineralized rock but contained little mineralization throughout the tuff of Nipple Mountain.

The mineralized zone is an irregularly shaped blanket about 800 feet long by 500 feet wide. The bottom of the zone closely follows the contour of the surface. The relief on the top probably represents areas of intense fracturing from which the copper has been leached. Along the fault east of the ore body, the repeated tuff of Nipple Mountain is underlain by a small slice of the "turkey track" andesite. Brunson (oral commun., 1975) reported that assays of this andesite yielded high silver values, but the type of mineralization is not known.

In 1968, the Banner Mining Company put down a diamond drill hole to 1622 feet which bottomed in what they interpreted

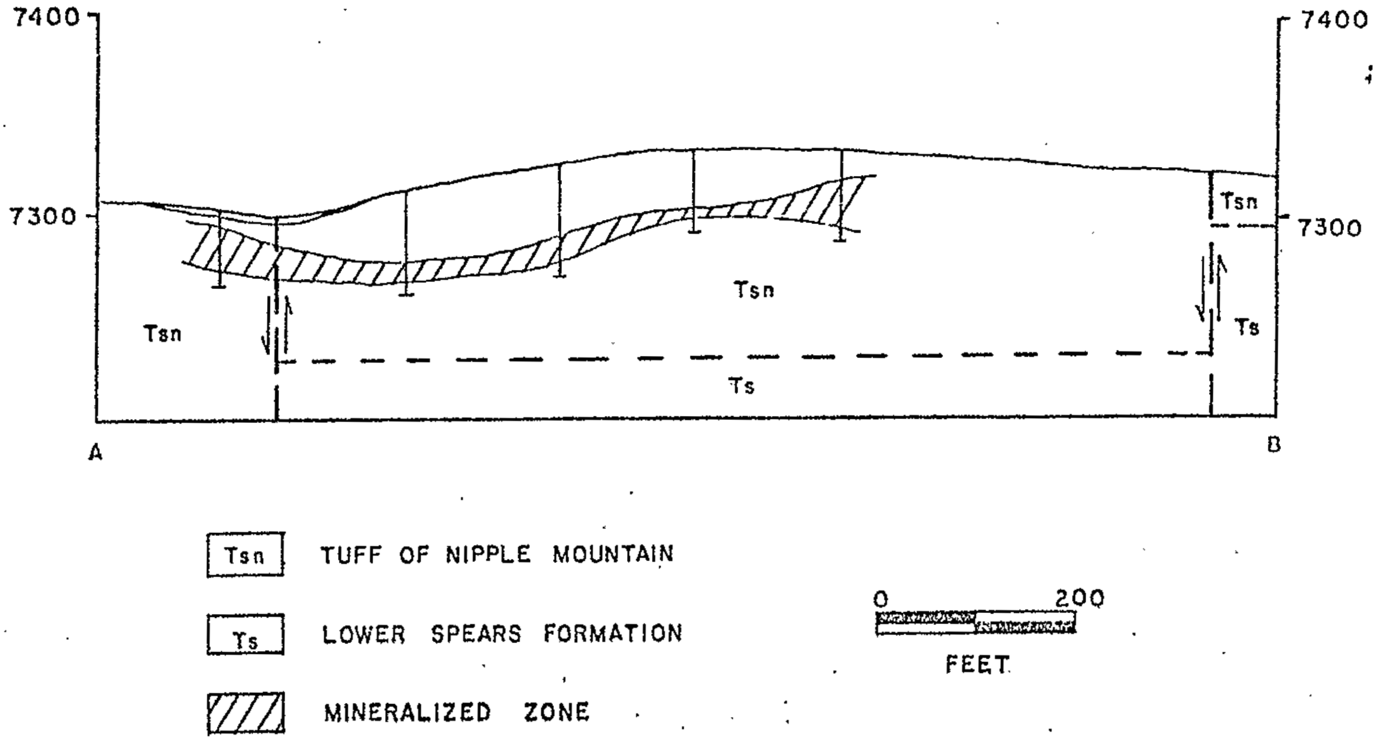


Figure 25. Cross section through the Sixty copper prospect showing the shape of the mineralized zone (based on drill cuttings furnished by W. Brunson, Magdalena, New Mexico).

as Mesozoic sedimentary rocks. Subsequent work indicated that these carbonaceous siltstones are probably the Sandia Formation. Propylitic alteration was pervasive throughout the hole with abundant fresh and oxidized pyrite. The pyrite occurs as disseminated cubes, veinlets, and in quartz-calcite veinlets in amounts ranging from 0 to 4 percent. Below about 1330 feet quartz-calcite-epidote veinlets become more abundant. Normally they contain only pyrite, but five samples from the last 100 feet contain small amounts of pyrite plus chalcopyrite, sphalerite, and galena. They occur as discrete grains in the veinlets with occasional exsolved blebs of chalcopyrite in sphalerite. One such veinlet was approximately one inch wide.

Alteration

Alteration of various types is widespread within the map area and along the Gallinas uplift. No overall zonal relationships were observed but it does appear that the distribution of the alteration is controlled in part by faults and in part by stratigraphy. Most of the alteration is concentrated near faults with the lateral extent controlled by the permeability of the wall rocks. Certain volcanic units, the tuff of Nipple Mountain and the A-L Peak and Hells Mesa Tuffs, are more permeable and contain alteration over a wider area than others. No pervasive alteration pattern related to the exposed portion of the Tres Montosas stock was observed.

Five different types of alteration were recognized during mapping and petrographic examinations: propylitic, pyritic, argillic, silicic, and lime silicate. Each will be discussed separately, although several types of alteration may be present in the same rock.

Propylitic Alteration

Propylitic alteration is the most widespread form of alteration in the map area and in the Magdalena area as a whole (Chapin and others,1974). It is characterized by the alteration of ferromagnesian minerals to carbonate, chlorite, and epidote. The conglomerates of the Spears Formation show the most pronounced effects of propylitization. They are characteristically purple to reddish-brown when fresh, but the alteration changes the color to greenish-gray. This type of alteration occurs along the Council Rock fault from Cat Mountain through the Sixty prospect and the area of the outcrops of the Abo Formation but appears to diminish northward in the Council Rock district. The propylitic alteration is probably related to solutions moving along the Council Rock fault.

Pyritic Alteration

The areas of pyritic alteration approximately coincide with those of propylitic alteration and may in part be related to it. There are areas where pyrite, with its attendant bleaching, is the only alteration observed. Pyrite occurs fairly extensively as disseminated cubes and veinlets. It is especially conspicuous in outcrops of the tuff of Nipple Mountain and the A-L Peak and Hells Mesa Tuffs where they are bleached to a much lighter color than normal. Some of these pyritized and bleached areas are visible on aerial photographs. This type of alteration also appears to be fault controlled with the lateral extent controlled by the permeability of the wall rocks. Pyritization is relatively continuous at depth to at least 1622 feet in the Banner drill hole.

Oxidation of the pyrite released iron into the groundwater which was then redeposited as limonite or hematite along joints and fractures. This staining is especially visible in the tuff of Nipple Mountain in and around the Sixty prospect.

Silicic Alteration

Silicic alteration occurs by the addition of SiO_2 as microcrystalline quartz to the groundmass and as quartz veinlets. Silicification is dominantly restricted to the tuff of Nipple Mountain but some occurs in clastic rocks of the Spears Formation and in andesites adjacent to quartz-calcite veins. The copper mineralization at the Sixty prospect is contained entirely in silicified tuff of Nipple Mountain. However, several other areas of intensely silicified tuff of Nipple Mountain exist with no copper mineralization.

Argillic Alteration

Argillic alteration is not so widespread and is generally restricted to outcrops of the tuff of Nipple Mountain. It occurs as the replacement of feldspar by clays and as patches of clays in the groundmass. Argillic alteration of feldspar provided sites for copper deposition at the Sixty prospect.

Lime Silicate Alteration

The occurrence of a limited amount of lime silicate alteration in the Abo Formation was discussed in a previous section (p.17). Small amounts of garnet, wollastonite, epidote, and quartz were observed replacing calcareous portions of the Abo Formation. Because of poor exposures, no zonation was observed but the alteration occurs mostly along the western and northern edges of the outcrops. Some garnets were also observed in a thin section of the Spears Formation along the northern edge of the Abo outcrops.

Chamberlin (1974) described a similar assemblage from the Council Rock area in the "turkey track" andesite at the base of the tuff of Nipple Mountain. He noted the presence of andradite, wollastonite, ferrosalite, diopside, magnetite, and biotite and suggested that they were the result of the recrystallization of hematitic calcite amygdules common in the andesites. Both of these areas are near the margin of the Tres Montosas stock and probably reflect the effects of thermal metamorphism during its intrusion.

Discussion of Mineralization

Veins

The overall geologic setting of the veins in the Tres Montosas-Cat Mountain area is very similar to that of Creede and other mining districts in the San Juan Region of Colorado. Mineralogically and structurally the veins are similar to the epithermal deposits discussed by Lindgren (1933). He believed the hydrothermal solutions were derived from intrusive rocks. Utilizing oxygen and hydrogen isotope data, several researchers have been able to demonstrate the importance of meteoric ground water in some hydrothermal systems. Taylor (1973, 1974) has shown that meteoric ground waters predominate in some Tertiary, epithermal deposits in volcanic terranes (the San Juan Mountains, Colorado; the western

Cascade Range, Oregon; and three gold-silver districts in western Nevada). Shepard and Taylor (1974) examined the Butte, Montana ore deposits and found that meteoric ground water was the dominant component. O'Niel and Silberman (1974) examined twenty Tertiary, epithermal gold-silver deposits in the Great Basin, Nevada, and demonstrated ". . . the dominance and probable exclusivity of meteoric water in the hydrothermal fluids of such deposits."

Although this data appears overwhelming for Tertiary epithermal veins in volcanic terranes, it does not eliminate the involvement of magmatic hydrothermal solutions. In fact, some magmatic hydrothermal components were observed by the above authors (Pasto Bueno and Casapalca, Peru, and probably Providencia, Mexico). Oxygen and hydrogen isotope data are needed before any single deposit can be interpreted. It appears reasonable, however, that Tertiary, epithermal, precious metal veins in volcanic terranes in the southwestern United States can be interpreted to have formed from hydrothermal solutions with dominant meteoric ground water components.

A small amount of geochemical data is available and several tentative conclusions can be deduced from it. A sample of fluorite from a vein in the Abo outcrops was prepared for fluid inclusion analysis. Homogenization temperatures were measured to get the temperature of formation and the freezing temperature was measured to calculate the salinity in NaCl equivalents. A sample of the fluid from the primary inclusions (procedure described in Appendix I) was prepared for atomic absorption analysis. The results are listed in Table 6.

Table 7 is a compilation of lead isotope data obtained by Slawson and Austin (1962) from the Council Rock district. The first sample is from a vein in brecciated volcanics and the second from brecciated limestone. The sample from the brecciated limestone may be from the outcrops of the Abo Formation. J-ness is the sum of ^{206}Pb plus ^{207}Pb plus ^{208}Pb divided by ^{204}Pb and provides a measure of the mixing of normal and radiogenic leads. 73.5 is the value at which the lead age is zero. Higher values represent anamolous or J-type leads and those lower represent normal leads.

The fluid inclusion and lead isotope data verify that the veins are epithermal and were deposited from saline solutions which contained sufficient quantities of lead to deposit galena. The lead isotope values are near the boundary between normal and J-type leads and indicate either mixing of primeval and radiogenic leads, or a primary isochron.

Based on oxygen and hydrogen isotope data from similar deposits in other regions, the author believes that the

Table 6. Geochemical data obtained from fluid inclusion analyses in fluorite and calcite.

Sample no.	Homogenization Temperature (press. corr.)	Freezing Temp.	Salinity NaCl equivalents	$\frac{K}{Na}$	Na ppm	K ppm	Pb ppm	Ba ppm
P-50 fluorite	186° C	-11.4° C	3.07 m	$10^{-.17}$	42435	47775	6200	7865
P-50 calcite	226° C							
P-49 fluorite	181° C							

Table 7. Lead isotopes from the Council Rock district (after Slawson and Austin, 1962).

Sample	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	J-ness
brecciated volcanics	1.344 % 1.000	25.30 % 18.83	21.10 % 15.70	52.25 % 38.88	73.4
brecciated limestone	1.336 % 1.000	25.33 % 18.96	21.08 % 15.77	52.25 % 39.11	73.8

hydrothermal solutions involved in forming the veins in the thesis area were dominantly heated meteoric ground water driven by intrusives. Geological and geophysical evidence indicate the presence of an intrusive beneath the Cat Mountain district and Chamberlin (1974) postulated a buried intrusive beneath the Council Rock district; these two intrusions plus the Tres Montosas stock would have provided the energy necessary to heat the ground water and set up the hydrologic flow system.

Beane (1974) and Allmendinger (1974) conducted a much more detailed study of the barite-fluorite-galena deposits in eastern Socorro Co., which includes the Hansonburg district, based upon the same kinds of geologic and geochemical data presented in this paper. They concluded that the hydrothermal solutions were 2 to 3 molal NaCl solutions at temperatures between 140° and 200° C. Tertiary dikes and sills were postulated by these authors to have heated the ground water; the mineral-forming constituents were thought to have been derived from Permian arkosic sedimentary rocks.

The K/Na ratio observed in the Tres Montosas sample can be explained by the albitization of potassium feldspar to albite, a reaction which releases K^+ into solution and takes Na^+ out of solution. A second effect of albitization is the release of lead and barium which commonly substitute in the potassium feldspar lattice. The volcanic rocks contain potassium feldspar but Precambrian granites and arkosic sedimentary rocks (i.e. Abo and Baca Formations) within the ground water flow pattern would provide much more feldspar. As more potassium feldspar is albitized, the concentration of lead and barium in solution increases. The K/Na ratio from the Tres Montosas sample is higher than those observed by Beane and Allmendinger in the Hansonburg district.

The lead isotopes from the Council Rock district are closer to normal leads than those from the Hansonburg district and lead is slightly more concentrated in the fluid inclusions from the Tres Montosas veins. The leaching of nonradiogenic lead requires higher temperatures than the leaching of radiogenic lead. Non radiogenic lead is held in the lattice of feldspar, whereas radiogenic lead occurs as interstitial fillings in the rocks. The interstitial lead is easily leached by warm water, whereas the lead in the lattice requires higher temperatures to be leached. Since the isotopic ratios of samples from Council Rock contain more nonradiogenic lead than those from Hansonburg, higher heat or a given heat over a longer period of time is implied. The occurrence of numerous stocks in the Magdalena area indicates a higher heat flow that lasted for a longer time than that associated with the smaller dikes and sills at Hansonburg. Thus, more lead and more normal mixtures of lead were available in the hydrothermal solutions in the Tres Montosas-Council Rock districts.

Walker (unpub. data, 1975) analyzed barite from veins in the Tres Montosas-Cat Mountain district for trace elements and found moderately high concentrations of lead, zinc, and copper. He did not know, however, whether the values were in the crystal lattice or in fluid inclusions. Table 8 is a comparison of Pb/K rations of his trace element analyses with the concentrations in fluid inclusions listed in Table 6. Although the analyses are on two different minerals, barite and fluorite, these minerals are approximately contemporaneous in time and, to a first approximation, the solutions are assumed to be similar. The Pb/K ratio in sample P-50 is from fluid inclusions; if the solutions in the two minerals are similar, then the Pb/K ratios should be similar. The slightly higher ratio from barite suggests that most Pb occurs in the inclusions but some must be present in the lattice. This is compatible with the openess of the barite crystal structure compared to fluorite. Although data are not available, it is assumed the distributions of copper and zinc are similar to that of lead. Regardless of where the metals are in the barite, the analyses indicate the presence of copper and zinc even though no such minerals were observed in the veins.

Several conclusions can be deduced about the veins from the data presented:

1. The veins are epithermal veins deposited by saline hydrothermal solutions.

Table 8. Comparison of Pb/K ratios from barite (after Walker, unpub, data, 1975) and fluorite (from Table 6, this paper). The barite ratio is the average of 18 analyses.

Sample	Pb/K	Mineral	Analytic Method	Material Analyzed
Average of Walker's samples	0.269	Barite	X-ray Fluorescence	Whole mineral
P-50	0.146	Fluorite	Atomic Absorption	Fluid inclusions

2. The solutions were probably dominated by heated meteoric ground water.

3. The heat was probably supplied by inferred and exposed stocks.

4. The high K/Na ratio and the lead isotope data from the Tres Montosas area suggests that the albitization of potassium feldspar may have been a possible source for the lead and barium. However, these data do not eliminate contributions from magmatic sources.

5. No similar data are available for copper, zinc, silver, and gold. The copper, zinc, and silver could have been derived from red-bed type deposits; or all four may have come from the intrusives; a combination of sources is also a possibility.

The ideas presented above are based on scanty geochemical data and are by no means conclusive. The data does not preclude the contribution of hydrothermal constituents from the intrusives but it does fit the model of heated ground water carrying mineral constituents derived from the surrounding sedimentary rocks. Further data from different parts of the vein system and for different elements may require a different interpretation.

Disseminated Mineralization

The Sixty prospect is interpreted as an epigenetic, supergene deposit with copper, lead, silver, and vanadium transported by ground water at low temperatures. The alteration in the tuff of Nipple Mountain is the result of hydrothermal processes and served as ground preparation for the solutions. The fracturing and argillic alteration provided sites for deposition and pyritization provided a slightly reducing environment for the deposition of chalcocite. The mineralization was localized probably by a combination of two things: 1.) the area being part of a major ground water channelway, and 2.) faulting.

The copper-bearing solutions came in contact with the pyrite and deposited chalcocite and chalcopyrite(?). The oxidation of chalcocite resulted in the remaining copper minerals: malachite, cuprite, tenorite, and chrysocolla. This mineral assemblage is similar to those observed in sedimentary copper deposits (red-bed deposits). The reported silver values may be in chalcocite (Lindgren, 1933), mottramite, or a separate, unrecognized phase.

The association of copper and silver suggests a supergene origin. Copper and silver are not closely associated ? in a typical hydrothermal system; copper occurs in mesothermal deposits and silver occurs in the lower temperature epithermal deposits. When they do occur together, it is generally in supergene deposits formed by oxidation, leaching, migration, and redeposition. The shape of the deposit (see Fig. 25) is also indicative of a supergene origin. It is an irregular blanket-shaped body with small dimensions. The bottom of the mineralized zone closely parallels the ground surface which suggests deposition above the water table.

The origin of the mineralization and its age are uncertain. No datable structures, veins, or dikes cut the deposit which suggests only that it is late Oligocene or younger. One possible source of the mineralization is leaching from nearby veins, although none of these contain significant amounts of copper at the present level of erosion. Copper-bearing veins are present in the Silver Hill area, about four miles to the east, and others might be present beneath the alluvial fill of the Mulligan Gulch graben. A similar mineralogy in the Silver Hill veins was reported by Simon (1973). If this is the source, then the age of the deposit must be Miocene or younger since the veins at Silver Hill cut the La Jara Peak Andesite (24 m.y., Chapin, 1971-a). Another possible origin is through lateral-migration of copper from supergene alteration of a mineralized intrusive now buried beneath the Mulligan Gulch graben.

The mineralization in the Banner drill hole is different and apparently unrelated to the Sixty prospect. A general zonal relationship has been observed with increasing depth; pyrite → pyrite plus quartz-calcite veinlets → pyrite plus quartz-calcite veinlets plus chalcopyrite-sphalerite-galena. Pyrite is relatively consistent throughout the hole, but chalcopyrite-galena-sphalerite occur only within the lower 100 feet. The quantities are small, but the economic implication may be significant. The zonal relationship suggests the proximity of the rocks in the drill hole to a stock at depth, perhaps the northern perimeter of the inferred Cat Mountain stock. If the sedimentary rocks beneath the Spears Formation are the Sandia Formation, then the Kelly Limestone may be in contact with the stock and replacement-type deposits similar to those in the Kelly district may be present. If so, possible mineralization in the Kelly Limestone would be within 2000 feet of the surface.

The Sixty prospect occurs at the intersection of three major structural trends: 1.) the northwest-trending Capitan lineament; 2.) the north-trending monoclinal flexure and fault zone; and 3.) the northeast-trending Morenci-Magdalena lineament which controlled major paleovalleys. This favorable structural setting has caused the rocks, especially the tuff of Nipple Mountain along Highway 60 (see Fig. 26),

Figure 26. Photograph showing the intense fracturing of the tuff of Nipple Mountain in a roadcut along Highway 60. The fracturing is the result of the location of the highly silicified tuff at the intersection of three major structural trends: 1.) the northwest-trending Capitan lineament; 2.) the north-trending monoclinal flexure and fault zone; and 3.) the northeast-trending Morenci-Magdalena lineament. Photograph was taken looking northeast.

to be intensely fractured. The location of the Sixty prospect and the mineralization in the Banner drill hole at this structural intersection is probably not coincidental and should be considered in any exploration plan.

Target Areas

Based upon the geological and geochemical evidence, three target possibilities are outlined:

1. Replacement deposits in the Kelly Limestone.

   a. The Kelly Limestone is probably present within 2000 feet of the surface at the Sixty prospect. Deepening the Banner drill hole would provide both a stratigraphic test and a test of possible mineralization.

   b. Beneath the Cat Mountain district, the Kelly Limestone is probably present within 2600 feet of the surface and near the top of the inferred stock.

   c. The Abo Formation is near the margin of the Tres Montosas stock and is affected by contact metasomatism. The Kelly should be present within 2600 feet of the surface and may be mineralized. However, if the Tres Montosas stock dips outward at a low angle, the sedimentary rocks underlying the Abo Formation may be stoped out.

2. Vein mineralization at depth.

A small possibility exists for increased mineralization in the tuff of Nipple Mountain at depth in the Cat Mountain district. If the overlying Spears andesites acted as a relatively impermeable capping, then the hydrothermal solutions may have spread outward into the more permeable tuffs. Also, the siliceous composition and relatively brittle character of the tuff of Nipple Mountain may be favorable to better vein development and higher gold values.

3. Extension of the Cat Mountain district to the south.

If the piedmont gravels south of the Cat Mountain district form a thin cover, then mineralization from the district may extend southward under the cover. The presence of the exposed Monica Canyon pluton suggests that stocks may exist close to the surface.

CONCLUSIONS

Several contributions to the geology of the Magdalena area have resulted from the investigation of the Tres Montosas-Cat Mountain area.

1.) The only exposures of Paleozoic sedimentary rocks outside the Magdalena and San Mateo Mountains crop out within the map area. The presence of these rocks and the extensive outcrops of the Spears Formation indicates that the Gallinas uplift is a relatively deeply eroded, structurally high block.

2.) A sequence of very fine-grained, calcareous sandstones to siltstones was penetrated by the Banner drill hole. Because no pre-Tertiary marker beds were encountered, the age of these rocks is unknown. The evidence presented suggests that they may be part of the Pennsylvanian Sandia Formation. Lithologically and petrographically these rocks are similar to the middle Sandia Formation in the Magdalena Mountains. They contrast with Mesozoic clastic rocks by being clean, quartz sands and silts which are almost entirely free of feldspar. Mesozoic clastic rocks are generally feldspathic, cherty sandstones. The location of the thesis area on the northern flank of a Laramide uplift which exposes progressively older rocks to the south places these sedimentary rocks in a reasonable structural setting to be part of the Sandia Formation. The exposures of the Abo Formation just to the north of the drill hole strengthens this interpretation. Paleontological and palynological data are not definitive, but they do not eliminate the possibility that these rocks may be part of the Sandia Formation.

3.) The rocks of the map area are composed dominately of volcaniclastic sedimentary rocks overlain by welded ash-flow tuffs with minor interbedded lava flows. The stratigraphic section of Cenozoic rocks is similar to that described by other workers in the Magdalena area (Brown, 1972; Simon, 1973; Chamberlin, 1974; Blakestad, 1976). A new stratigraphic unit, informally named the tuff of Gray Hill, has been mapped in the southwestern part of the study area. It is a crystal-poor, moderately-to densely-welded, multiple flow, compound cooling unit of ash-flow tuffs occurring between the andesite of Landavaso Reservoir and the Potato Canyon Tuff. The tuff of Gray Hill fills a paleovalley incised through the andesite of Landavaso Reservoir. Within the paleo-valley the tuff of Gray Hill rests directly on the A-L Peak Tuff. The tuff of Gray Hill is probably correlative with Simon's (1973) crystal-poor upper tuff unit.

4.) The A-L Peak Tuff fills a north-northeast-trending paleovalley on Gray Hill. Thicknesses of the tuff range from 300 to 1000 feet within the valley. This paleovalley was later reentrenched and filled by the tuff of Gray Hill. The paleovalley is probably a tributary of a larger paleovalley which trends northeastward from Tres Montosas to the Granite Mountain area. Simon (1973) described a paleovalley in the Silver Hill area which controlled distribution of the tuff of La Jencia Creek. Older paleovalleys would account for the unusual thickness of the tuff of Granite Mountain on Tres Montosas and of the tuff of Nipple Mountain near the Sixty prospect. These paleovalleys are probably fault controlled by the Morenci-Magdalena lineament.

5.) Chemical analyses of the basalt of Council Rock have led to its classification as an alkali-trachyte to trachy-andesite. The average of 4 analyses show it to be high in SiO_2 (54.30 percent) and alkalie (Na_2O - 5.49 percent and K_2O - 2.15 percent) with normative nepheline. Plagioclase compositions vary about An_{50} and are consistent with a classification of the basalt of Council Rock as an alkali-trachyte to trachy-andesite.

6.) The occurrence of limestone pebble conglomerates and quartzite breccias in the outcrops of the Abo Formation suggest that faulting may have been active during Permian time.

7.) The development of the Mt. Withington cauldron approximately 32 m.y. ago formed a complicated series of radial, concentric, and transverse faults along the cauldron margin. These faults were later utilized by gold-bearing quartz veins in the Cat Mountain district. Emplacement of a small pluton, the Monica Canyon stock, may have been controlled in part by the structural margin of the cauldron. A north-trending graben radiating from the cauldron margin forms a prominent structure east of Gray Hill. These structural and mineralogical observations suggest an analogy of the Cat Mountain district with the Creede mining district in Colorado.

8.) North-trending faults, which controlled the emplacement of numerous intrusives, broke the ignimbrite plateau approximately 30 m.y. ago. This same trend was utilized by basin and range faulting which began in the Magdalena area approximately 25 m.y. ago and resulted in a series of north-trending grabens and horsts. The Mulligan Gulch graben and Gallinas uplift were formed at this time. Although the dominant trend of basin and range faulting was to the north, a series of northeast-trending faults related to the bifurcation of the Rio Grande rift is also apparent.

9.) Three known and three inferred intrusives occur along a twenty mile interval from Gray Hill on the south to Abbey Springs on the north. They are probably related to an elongate batholith beneath the area which initiated the high-angle, Oligocene faulting and resulted in the formation of a monoclinal flexure along the western margin of the Mulligan Gulch graben. Stocks extending from this batholith rose to within 2000 feet of the Oligocene surface. Two stocks are exposed in the map area. A third stock, located in the Cat Mountain district, is inferred from felsic dike swarms, epithermal quartz veins, hydrothermal alteration, and a weak aeromagnetic low.

10.) Hydrothermal alteration is widespread in the map area. There is no apparent relationship of the hydrothermally altered areas to exposed stocks; concentration of alteration along faults suggests that the fluids were derived at depth and moved upward along the faults.

11.) Fluid inclusion analyses from samples of vein mineralization showed that the ore-forming solutions were 3-molal-NaCl-equivalent solutions at temperatures around 180°C. The solutions contained sufficient lead (6200 ppm) to precipate galena. Analyses of barite from the same veins by Walker (unpub. data) showed that the solutions also contained copper (443 ppm) and zinc (330 ppm).

12.) A small oxide copper deposit, the Sixty prospect, is located south of Highway 60. Mineralization consists of chrysocolla, malachite, and other oxides with minor chalcocite which occurs as fracture fillings and disseminated blebs. Based on the type of mineralization and its occurrence, the presence of silver with the copper, and the blanket shape of the deposit, the Sixty prospect is interpreted to be of supergene origin.

13.) A deep diamond drill hole at the Sixty prospect penetrated the volcanic rocks and bottomed in dark, carbonaceous siltstones. The core was propylitically altered with disseminated pyrite, plus pyrite and quartz-calcite veinlets to a depth of 1622 feet. Chalcopyrite, galena, and sphalerite were observed in veinlets in the last 100 feet of core. The consistent propylitic alteration and increasing intensity of mineralization with depth suggests that the drill hole is near a buried intrusive.

14.) The occurrence of the Sixty prospect at the intersection of three major structural trends, the possibility that the Kelly Limestone is within 2000 feet of the surface, and the exposed and inferred intrusives make the Tres Montosas-Cat Mountain area one of the most favorable parts of the Magdalena area for base metal exploration.

APPENDIX

Procedures for Obtaining Fluid Inclusions for Atomic Absorption Analysis

The following procedure was followed in order to obtain uncontaminated fluid inclusions from fluorite for atomic absorption analysis.

1.) Hand pick 10 to 50 grams of broken fluorite to assure that the sample is pure.

2.) Break up the sample in a teflon mortar (to prevent sodium contamination) to about 8 mesh (most breaks will occur along secondary planes of fluid inclusions; this exposes the secondary inclusions to the wash solutions).

3.) Rinse the sample thoroughly at least three or four times with deionized water.

4.) Wash the sample with hot (70° to $80^{\circ}C$), concentrated HNO_3 plus HCl in a teflon beaker and place beaker with sample in an ultrasonic cleaner for ten minutes.

5.) Repeat step 3.

6.) Crush the washed sample to $\pm$ 200 mesh in a teflon mortar in 25 to 30 ml. of an 0.1 N HCl plus deionized water solution. Avoid contamination of the sample with sodium and potassium by using plastic gloves.

7.) Filter the sample and save the solution for AA analysis. Keep the solution in a plastic bottle.

8.) Use an extra sample of plain wash water from step 6 as a blank.

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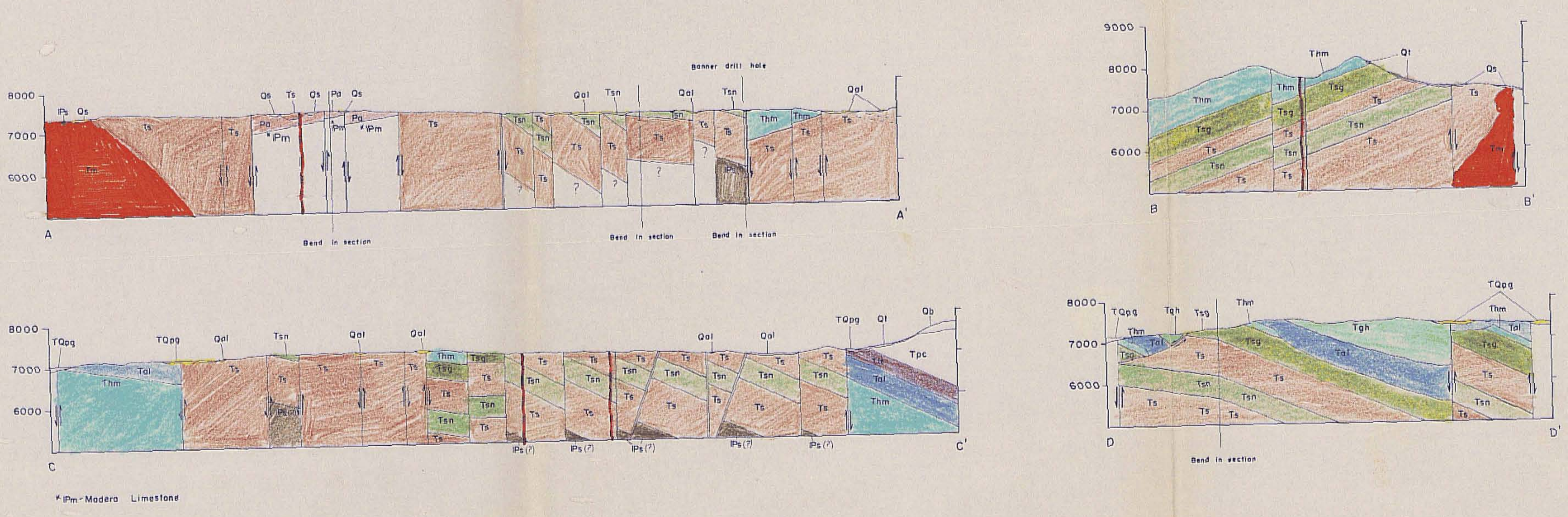
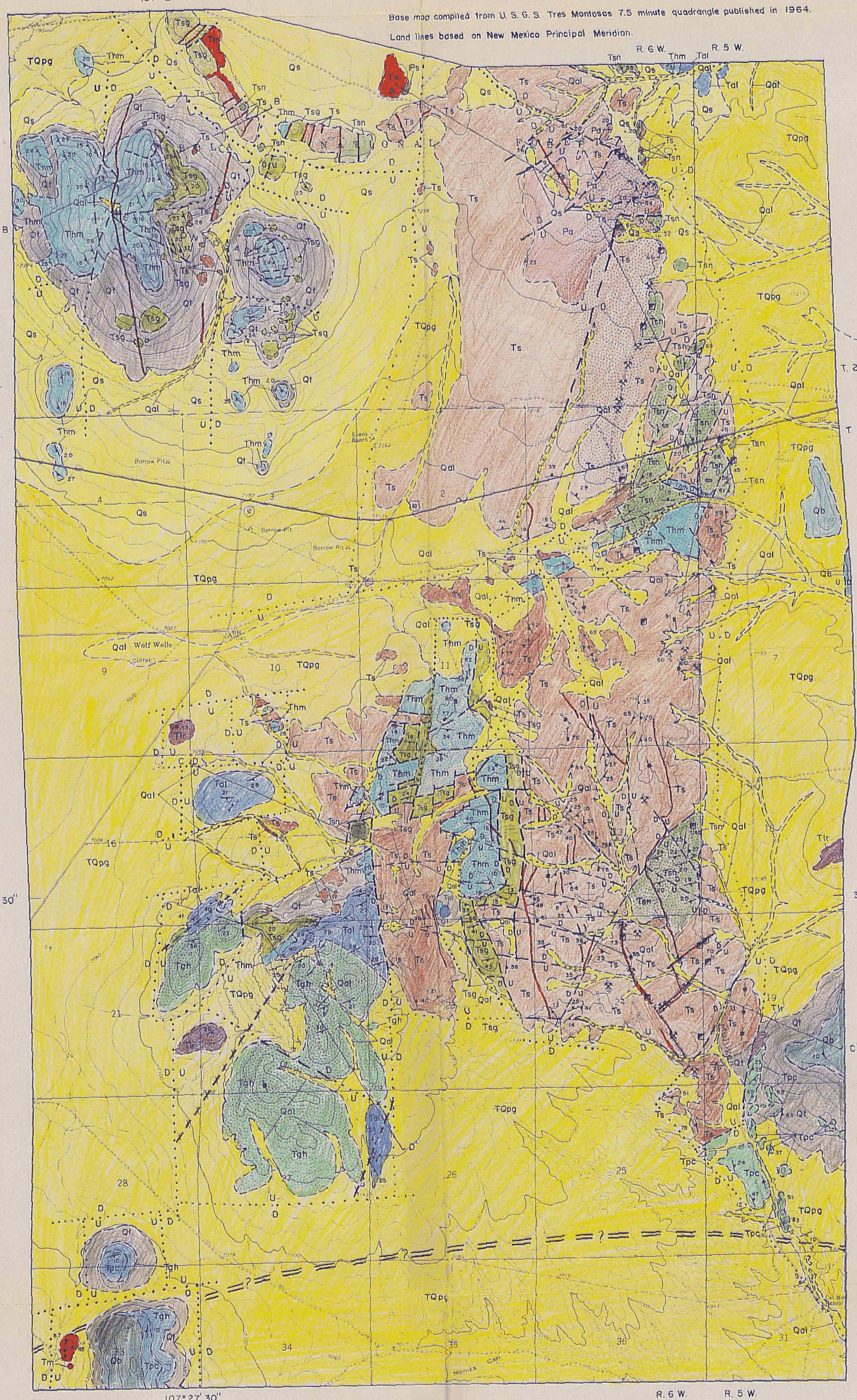
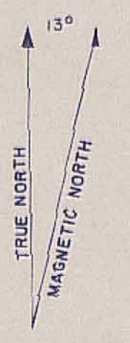
PLATE I







Approximate Mean Declination, 1964

EXPLANATION

QUATERNARY

- Qal — Alluvium
- Qs — Eolian Sand
- Qt — Talus
- Qb — Basalt of Council Rock
- TQpg — Piedmont Gravels

TERTIARY

- Tm — Monzonite-granite stock
- Latite dikes

DATIL GROUP

- Tpc — Potato Canyon Tuff
- Tgh — Tuff of Gray Hill
- Tlr — Andesite of Landavaso Reservoir
- Tal — A L Peak Formation
- Thm — Hells Mesa Formation
- Ts — Spears Formation; Tsg — Tuff of Granite Mt; Tsn — Tuff of Nipple Mt

PALEOZOIC

- Pa — Abo Formation
- IPs — Sandia Formation

Contact. *Dashed where approximately located, dotted where covered.*

High angle fault. U, upthrown side D, downthrown side. *Dashed where approximately located dotted where covered.*

Vein. *Dashed where inferred. Shows 75° and vertical dips.*

Paleovalley wall

Mineral prospect

Adit

Shaft over 10 feet deep

Drill hole

Open cut

Improved road

Unimproved road

Intermittent stream

Strike and dip of bedding

Strike and dip of foliation

Strike of vertical foliation

Strike and dip of joints

Strike of vertical joints

Trend of lineation

Altered rock usually containing oxidized pyrite.

Cauldron margin (AFTER DEAL AND RHODES, IN PRESS)

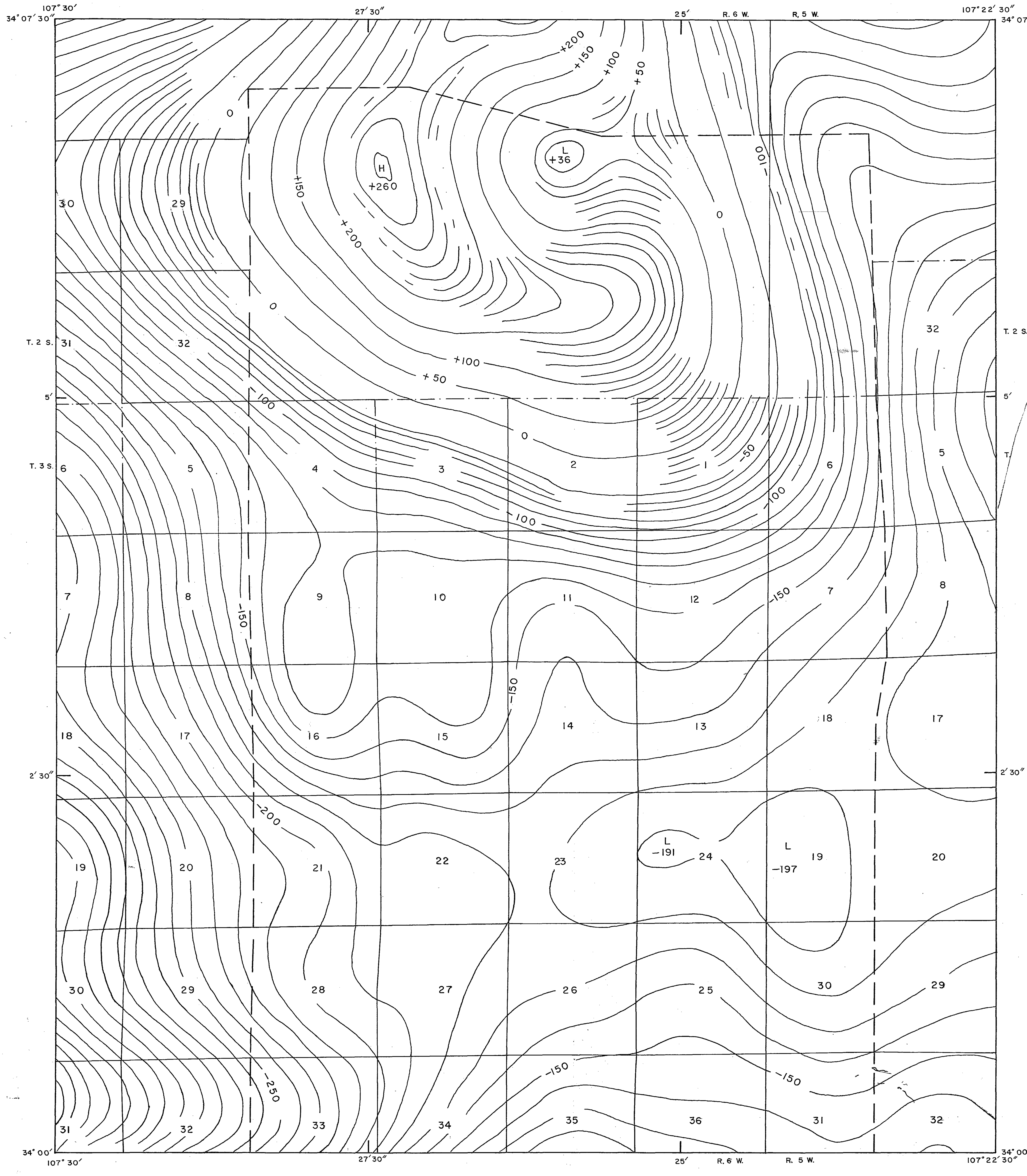
GEOLOGIC MAP AND SECTIONS OF THE TRES MONTOSAS-CAT MOUNTAIN AREA, SOCORRO COUNTY, NEW MEXICO

by

William H. Wilinson, 1975

Scale 1:4000

CONTOUR INTERAL 20 FEET
DATUM IS MEA SEA LEVEL



Contour Interval	10.0 Gammas
Datum	52,164.79 Gammas
Flight Line Spacing	1.0 Mile(s)
Flight Altitude	10000 Feet ASL
Flown and Compiled	1973
— — —	Outline of Thesis Area

PLATE II
TRES MONTOSAS QUADRANGLE
RESIDUAL MAGNETIC INTENSITY

SCALE 1:24000

N

COMPILED BY: GEOMETRICS

ENLARGED FROM
U. S. GEOLOGICAL SURVEY
OPEN FILE MAP

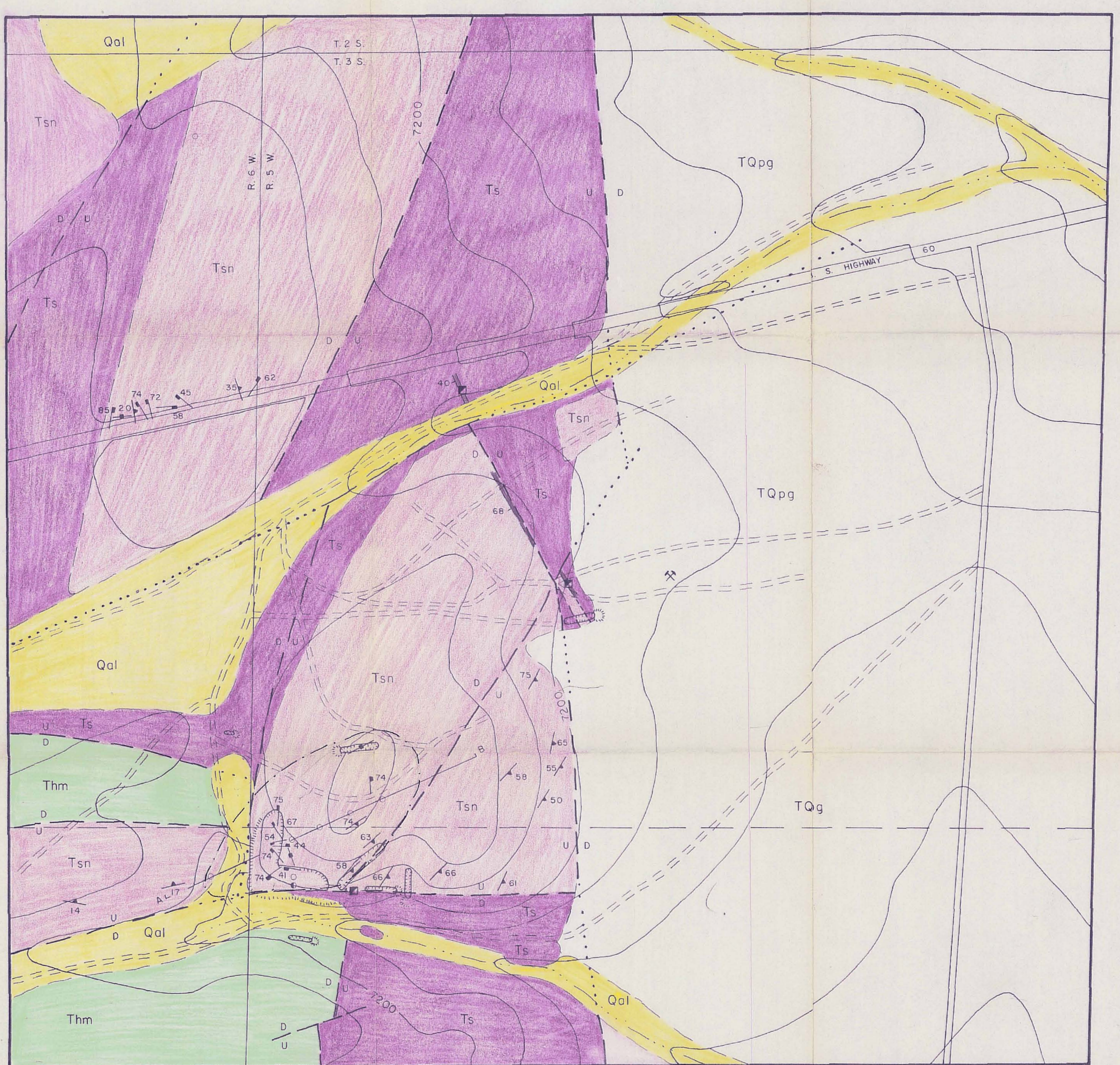
AREA 4 3 N

SW NEW MEXICO

Prepared in cooperation with the New Mexico Bureau of Mines and Mineral Resources.

2 of 3

OF 39



EXPLANATION

Qal
Alluvium

TQpg
Piedmont Gravels

Thm
Hells Mesa

Ts Spears
Tsn Tuff of Nipple Mountain

Contact
Dashed where approximately located.

High Angle Fault
Dashed where approximately located; dotted where covered.

Vein showing dip

Approximate outline of copper mineralization

Strike and dip of foliation

Strike and dip of joints

Strike of vertical joint

Mineral prospect

Shaft over 10 feet deep

Open cut

Banner drill hole

Other drill holes

Major highway

Improved dirt road

Trail

Intermittent stream

PLATE III
DETAILED GEOLOGIC MAP OF THE SIXTY COPPER PROSPECT

By: WILLIAM H. WILKINSON, JR., 1975

N

0 200 400
FEET

Base map compiled from S. G. S. Tres Montosas 7.5 minute quadrangle published in 1964.