40

GEOLOGY OF THE COUNCIL ROCK DISTRICT
SOCORRO COUNTY, NEW MEXICO

A Thesis
Presented To
the Faculty of the Department of Geoscience
New Mexico Institute of Mining and Technology

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Richard Martin Chamberlin
May, 1974

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

Charles E. Chapman

Kent C. Condie

Robert H Weber

A. J. Budding

Date 11/27/74

CONTENTS

ILLUSTRATIONS

PLATE PAGE

FIGURE

Appendix

TABLES

Appendix

ABSTRACT

Bedrock exposures in the Council Rock district are chiefly Oligocene ash-flow tuffs of the Datil volcanics. Andesite lava flows and volcaniclastic sediments occur in some cooling breaks in the tuffs. No significant differences in stratigraphic relationships or petrology were observed in comparison to an equivalent Oligocene section in the Southern Bear Mountains (Brown, 1972). A late Oligocene stock partially exposed in the south central portion of the area consists of a granite core with andesite to quartz monzonite around the border. Tertiary-Quaternary pediment gravels and basalt flows occur in grabens formed by basin and range block faulting. Observations outside the area confirm that Council Rock is on the buried flank of a Laramide uplift.

Major structural features of the Council Rock district are high angle faults (NNW and NE trends dominant) and a partially exposed north-trending monoclinal fold which forms the east flank of the Gallinas uplift. Both fault trends have been active episodically since mid-Oligocene time and it is proposed that they mirror preexisting fault zones in basement rocks. Formation of the monoclinal fold is attributed to intrusion of a 20-mile-long pluton at depth in late Oligocene time. Intersections of major Oligocene faults striking approximately N 10° W and N 45° E were important controls in the emplacement of several stocks which are inferred to be extensions of the elongate pluton.

Two unexposed stocks are inferred in the area on the basis of felsic dike swarms, hydrothermal alteration, veining and local structural features. Epithermal quartz-carbonate veins near Council Rock, once mined for their silver content, are an expression of one of these unexposed stocks. Stratigraphic and structural relationships in this area suggest the roof of the stock may be within 2000 feet of the surface. The area is recommended as a favorable target for further evaluation with regard to porphyry-type base metal sulfide mineralization. Extensive hydrothermal alteration coincident with the west side of the Mulligan Gulch graben is probably genetically tied to the deep pluton which produced the monoclinal fold.

A petrologic study of the Tres Montosas stock suggests that upward diffusion of alkali-rich water vapor was the most significant process in its differentiation. Narrow rims of orthoclase commonly mantle high-temperature plagioclase phenocrysts in the border facies rocks. This feature is interpreted as evidence of an alkali diffusion process which has been "frozen" into the rocks by rapid crystallization.

Compositional variation of feldspars in the Hells Mesa Formation indicate it is an "upside down" compositionally zoned ash flow sheet. A model proposed by Brown (1972, p. 74) concerning the petrogenesis of the Hells Mesa and A-L Peak ash-flow sheets is expanded upon. The expanded model advocates that incorporation of a large amount of meteoric water (Lipman and Friedman, 1974) into a batholithic sized volume of alkali-andesite magma followed dominantly by upward diffusion of an alkali-rich aqueous vapor phase is the critical process in the development of silicic magmas which are erupted to form ash-flow tuffs.

INTRODUCTION

Purpose of the Investigation

The objectives of this thesis are to determine the stratigraphic relationships, structural trends, patterns of hydrothermal alteration, and the distribution of intrusive rocks in the Council Rock district, Socorro County, New Mexico. These relationships are important for the following reasons:

1. Structural relationships that controlled the emplacement of an exposed, non-mineralized, hypabyssal Tertiary stock (here named the Tres Montosas stock) may be used to locate other intrusive centers as targets of possible "porphyry-type" or "replacement-type" base metal mineralization.
2. The inter-relationships of intrusions to hydrothermal alteration, epithermal veins, stratigraphic units, and structural features at Council Rock, provides a basis on which to evaluate the district's economic potential.
3. Descriptions of variations in the volcanic stratigraphy between the Southern Bear Mountains (Brown, 1972) and the Council Rock district may be of value in future geologic investigations to the west of Council Rock.

Location and Accessibility

The Council Rock district, as mapped, covers a nearly rectangular area of about thirty square miles within the

Cibola National Forest. The center of the district is about 14 miles due west of the town of Magdalena, Socorro County, New Mexico (Fig. 1). The map area is approximately bounded to the north by 34° 12' N latitude, to the south by 34° 7' N latitude, to the east by 107° 23' 7" W longitude and to the west by 107° 28' 30" W longitude.

The study area is located in the northeastern corner of the Datil-Mogollon volcanic field (Fig. 1). Council Rock is the name given to the prominent outcrop of a basalt dike in the northeast quarter of the district. The name is derived from the use of this landmark as a meeting place between Indians and settlers in the 1800's.

Physiographically, the Council Rock district is located on the eastern edge of a low north-south divide which connects the Gallinas Mountains with the San Mateo Mountains. Present topography is strongly controlled by block faulting typical of the Basin and Range province. Grabens occuring to the east and to the west of the Gallinas uplift are the Mulligan Gulch trough, also known as the Magdalena Plain, and the North Lake Basin, respectively. Figure 2 is a panoramic view of the study area and the surrounding landforms. Relief is less than 900 feet in the district and along most of the divide; however, a prominent landmark known as Tres Montosas just south of the study area, rises about 1300 feet above the surrounding terrain. Physiography changes rapidly toward the north because of the proximity of the Colorado Plateau province. Another significant tectonic feature of great importance, the north-south trending Rio Grande rift, is

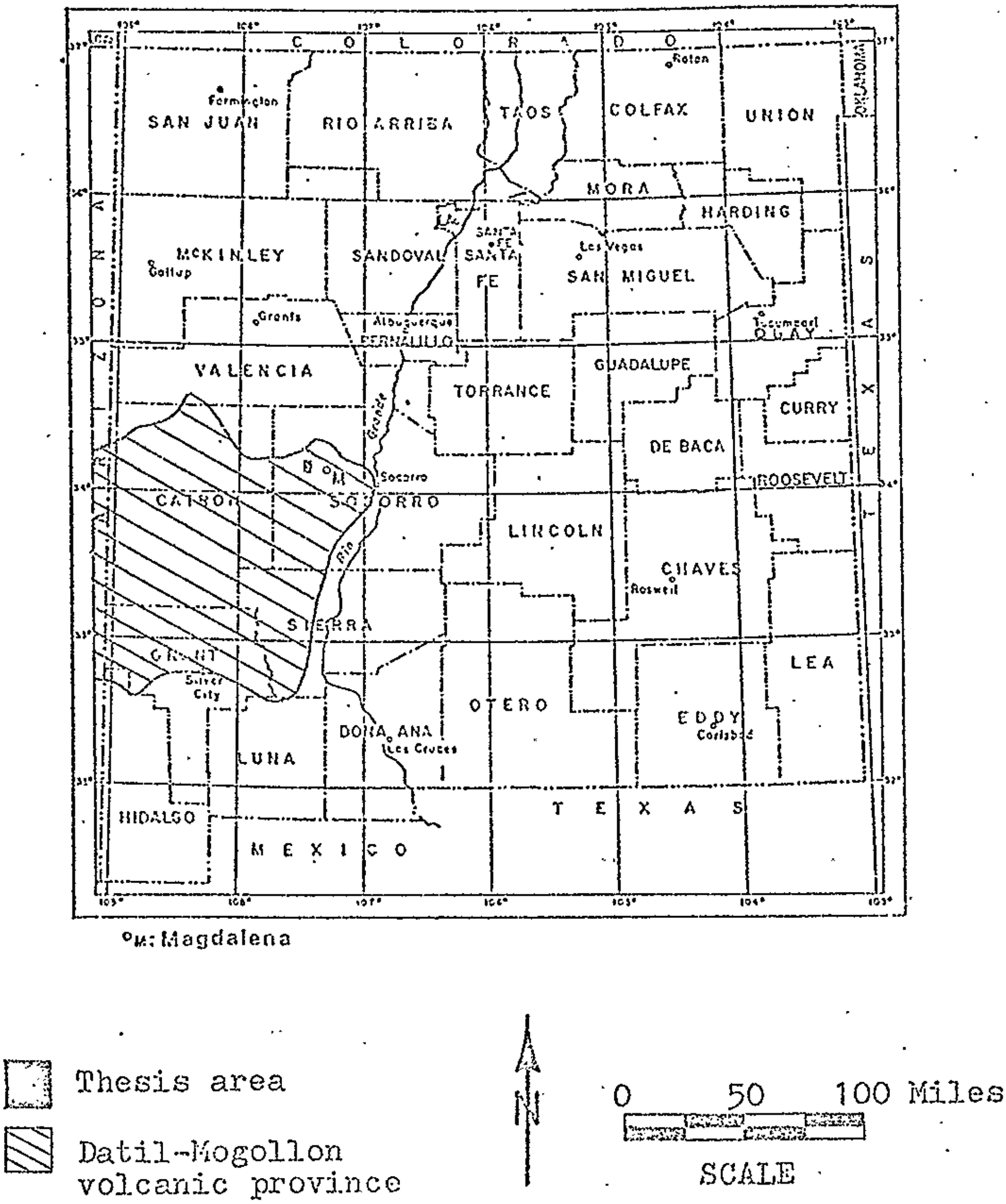


Figure 1. Index map of New Mexico, showing location of thesis area with respect to the county of Socorro and the Datil-Mogollon volcanic province.

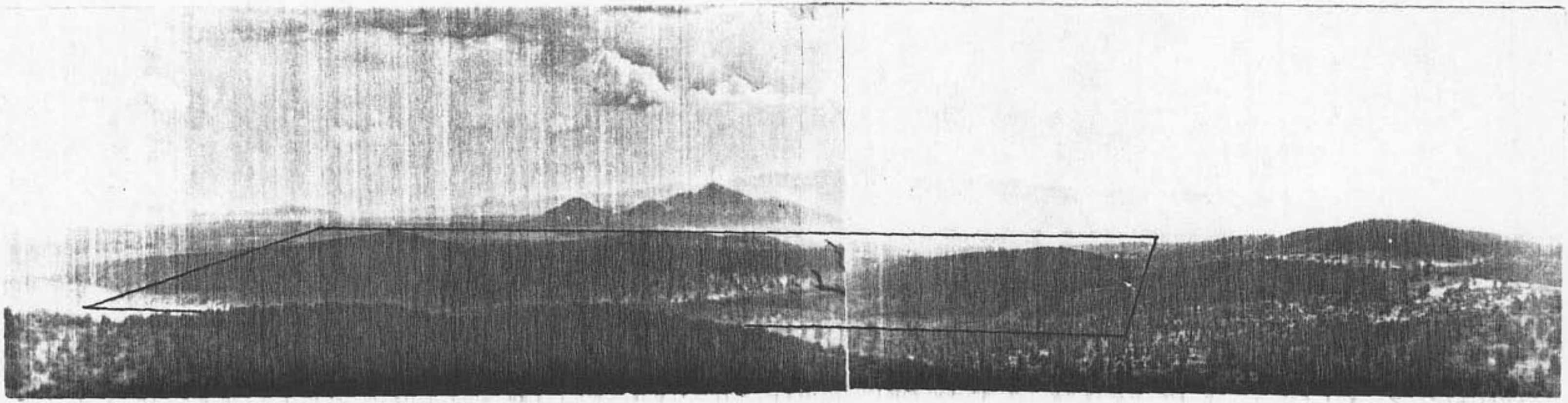


Figure 2. Panoramic view of the Council Rock district looking south from Gallinas Peak. Tres Montosas is the prominent cluster of hills at the center. The San Mateo Mountains form the highest point on the horizon. The basins of San Augustin and Mulligan Gulch are to the right and left of Tres Montosas. The approximate location of the boundaries of Plate 1 are shown by pen lines.

located about 35 miles east of Council Rock.

Easy access to the north half of the district is provided by an improved forest service road which trends westerly from State Road 52 to North Lake via the Council Rock Ranch. The southern portion of the thesis area is best reached from U.S. Highway 60 by ranch roads of the Montosas Cattle Company. Wood cutters trails are numerous throughout the area and allow four-wheel-drive vehicular travel to within a mile of any point in the district.

Methods of Investigation

During the summer and fall of 1971, surface geology was mapped on portions of the Tres Montosas and Gallinas Peak 7.5 minute quadrangles (1:24000) published by the United States Geological Survey. Aerial photographs from the Geological Survey (VARJ series, 3-20-63) at a scale of 1:31, 680 proved to be valuable in locating and outlining outcrops. Structural lineaments were often well displayed on these aerial photographs. A topographic base map on mylar was used for preparation of the final geologic map.

One hundred and seventeen thin sections were made from rock samples collected in the area for the purposes of correlating or characterizing rock units, studying hydrothermal alteration, and determining the paragenesis of vein minerals and petrogenesis of intrusive rocks. Modal analyses of eighteen thin sections of samples from the Tres Montosas stock were prepared by James Bruning using a Zeiss microscope equipped with a Swift automatic point counter. Ten of these samples were collected by W.H. Wilkinson, from the south border of the stock. Another eight thin sections of the Tres Montosas stock were later stained to aid in the identification of potassium feldspar by using the method of Chayes (1952).

Fabric description, preliminary mineral identification and estimates of modal mineralogy were completed on a Zeiss binocular petrographic microscope. Microscopic visual estimates of modal mineralogy were used to classify rocks according to Travis (1955). The composition of plagioclase was determined using the Fouqué method (Troger, 1959, p. 101) and by the Rittmann zone method (Emmons, 1943, p. 115-133) utilizing a five-axis universal stage. The universal stage was also used to measure optic axial angles of alkali feldspar, plagioclase and pyroxenes. Extinction angles of clinopyroxenes ($Z \wedge C$) were also measured utilizing the universal stage.

Optical data were used to determine the structural state and composition of feldspars and the composition of pyroxenes. The methods of these determinations are described in the appendix.

Previous Work

Previous geological investigations in the Council Rock area have been of a reconnaissance nature. The first recorded investigation in the vicinity was made by Herrick (1900) as part of a reconnaissance survey in portions of Socorro and Valencia Counties. His brief observations were that the Gallinas, Datil and Bear Mountains were composed of trachyte and rhyolite intrusives. Winchester

(1920) observed volcanic rocks overlying formations of Cretaceous age along the Alamosa Creek Valley (Rio Salado). He named these volcanic units the "Datil Formation" and described a type-locality at the north end of the Bear Mountains.

Loughlin and Koschmann (1942) began a detailed comprehensive geological investigation of the Magdalena mining district in 1915; their work was later published as U.S. Geological Survey Professional Paper 200. They stated that their banded rhyolite unit (equivalent to the lower A-L Peak Formation of this report) is an extensive formation west of Magdalena. Givens (1957) and Tonking (1957) made independent studies of the Tertiary volcanic rocks in the Dog Springs and Puertecito 15-minute quadrangles, respectively. Tonking subdivided the Datil Formation into three members which he named "Spears", "Hells Mesa" and "La Jara Peak" (from oldest to youngest). Givens subdivided the Hells Mesa Member into seven mappable subunits in the Gallinas Mountains. Equivalents of the La Jara Peak Member were not observed by Tonking, Givens or the writer in the Gallinas Mountains. Willard (1959) conditionally correlated the La Jara Peak Member with a post-Datil basalt sequence in the Datil Mountains. Later, Weber (1963) excluded the La Jara Peak Member from the Datil Formation. Weber (1971) then elevated the Datil Formation to group status. Park (1971) has conducted a detailed petrologic study of the Anchor Canyon stock located at the north end of the Magdalena range.

Brown (1972) and C.E. Chapin (oral commun., 1972) provided detailed descriptions and analyses of measured sections in the Spears and Hells Mesa Formations. Brown (1972) subdivided the Hells Mesa Formation into a lower crystal-rich member, informally termed the tuff of Goat Springs, and an upper crystal-poor member, termed the tuff of Bear Springs. Deal and Rhodes (1974, in press) subsequently renamed the tuff of Bear Springs as the A-L Peak Formation for a 2000-foot section exposed on A-L Peak in the northern San Mateo Mountains.

Deal and Rhodes (1974, in press) have delineated the boundaries of a cauldron (caldera) in the Mount Withington area of the San Mateo Mountains. They believe that this cauldron is the source for both A-L Peak Formation and a thick sequence of overlying tuffs which they named the Potato Canyon Rhyolite. Elston and others (1968, 1970, 1973) are now in the process of studying eruptive patterns and their tectonic relationships in the Datil-Mogollon volcanic province. Simon (1973) recently completed an investigation of the stratigraphy, structure and mineralization of the Silver Hill area. W.H. Wilkinson (in preparation) has completed detailed mapping of the Tres Montosas area contiguous to, and south of, the Council Rock district. D.A. Krewedl (in preparation) has mapped the central Magdalena Range and suggests the presence of another cauldron in the Sawmill Canyon area, which may also have been a vent area for the A-L Peak Formation.

Numerous radiometric (mostly K-Ar) dates on the Datil-

Mogollon volcanic units and intrusions have been provided by several authors. Weber and Bassett (1963) obtained ages for the Nitt and Anchor Canyon stocks located in the Kelly mining district and for the basal welded ash-flow 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 welded tuffs of the Hells Mesa Member. Kottlowski, Weber and Willard (1969) listed 49 radiometric dates of Cretaceous and Tertiary igneous rocks in the New Mexico region and summarized their relationships to mineralization episodes. Five previously unpublished age determinations were listed by Weber (1971) for Tertiary igneous rocks from central New Mexico. Recently, Chapin (1971) published a date for the La Jara Peak Formation and evaluated its significance in regard to mineral exploration. E.I. Smith and others (1974, in press) have dated the A-L Peak and Potato Canyon Formations in the San Mateo Mountains using the fission track method. Elston and others (1973) have summarized all K-Ar dates available for the Mogollon-Datil province. The rocks dated are interpreted to represent 3 separate volcanic cycles. A new date on the unit of Arroyo Montosa (Simon, 1973) provides a narrow bracketing for the onset of basin and range faulting in the Magdalena area.

Acknowledgements

I gratefully acknowledge the help of the many individuals who assisted me during the course of this project. W.E. Arnold

and M.J. Jaworski provided equipment and ideas used in the preparation of the geologic map. A.J. Budding, R.H. Weber, K.C. Condie and W.H. Wilkinson furnished the author with helpful ideas and information concerning the study during informal office discussions. My wife Louise was a great help in the preparation of the manuscript. Thanks also go to Pete Evans, a rancher in the thesis area, who graciously permitted access through his private lands and W.E. Walsh, of Santa Fe, New Mexico, who provided information on the magnetite mineralization at the Big John mine.

To Charles E. Chapin, my thesis advisor, I owe special gratitude for the original suggestion of the study area and for his valuable advice and keen observations in both field and office. Financial assistance for field work was provided through the New Mexico State Bureau of Mines and Mineral Resources.

STRATIGRAPHY AND PETROLOGY

Prevolcanic Rocks

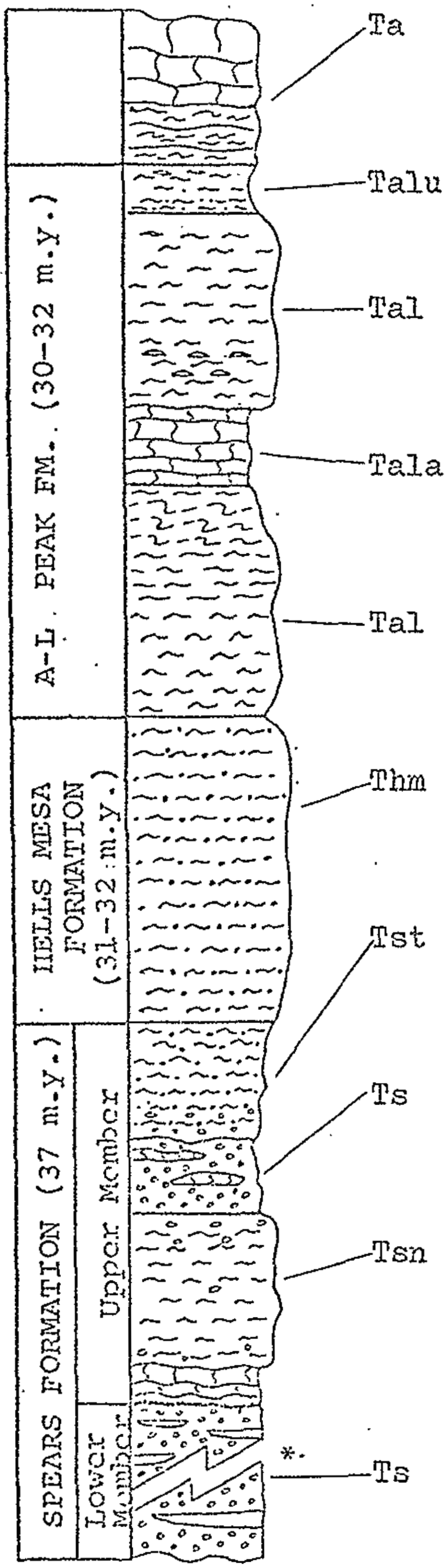
Prevolcanic sedimentary rocks crop out about 1½ miles to the north and 1 mile to the south of the thesis area. To the north, mapping by Tonking (1957) indicates that the base of the Spears Formation of Oligocene age rests conformably on the Baca Formation of Eocene age. Fluvial sandstones, mudstones and limestone-cobble conglomerates of the Baca Formation were observed just north of the study area at the head of Deep Well Canyon by the writer and C.E. Chapin. About one mile southeast of the Tres Montosas stock, W.H. Wilkinson (in preparation) has mapped a paleo-topographic high of the Abo Formation of Permian age surrounded by outcrops of the Spears Formation.

Similar north to south stratigraphic relationships from conformity to unconformity have been observed by Tonking (1957) and Brown (1972) in the Bear Mountains and in the northern Magdalena Mountains. These relationships suggest that both the Council Rock and the Bear Mountains are located on the north flank of a pre-Oligocene uplift. The age of the uplift is Laramide (late Cretaceous to middle Eocene). D.O. Snyder (1971), conducted a paleocurrent direction analysis on exposures of the Baca Formation in Socorro and Catron Counties and concluded that it was deposited in an east-trending basin. In addition, Snyder suggests that the major source of detritius was from positive areas to the south and west of the basin.

In the late Eocene, just prior to the onset of Oligocene volcanism, west-central New Mexico was eroded to a surface of moderately low relief (Chapin, 1971b; Epis and Chapin, 1973). Hence, the base of the Oligocene volcanic pile varies from a conformable relationship with the Eocene, Baca Formation in the east-trending Laramide basin to an angular unconformity which places the base of the Spears Formation in contact with progressively older rocks southward toward Tres Montosas. The transition from a conformable to unconformable relationship is not exposed within the study area and cannot be accurately determined from available data.

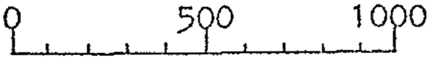
Tertiary Volcanic Rocks

Bedrock exposures in the thesis area are chiefly welded ash-flow tuffs of Tertiary age. Interbedded lava flows and volcaniclastic sedimentary rocks are minor in outcrop area. Oligocene volcanic rocks and volcaniclastic rocks are divided into three formations which are from oldest to youngest, the Spears, Hells Mesa and A-L Peak Formations. A maximum total thickness for these three formations in the Council Rock district is estimated to be 4425 feet (Fig. 3). About 400 feet of Oligocene basaltic-andesite flows cap the A-L Peak Formation in the study area and are tentatively correlated with the andesite of Landavaso Reservoir (Simon, 1973, p. 34). Brown (1972) has presented detailed descriptions and modal analyses of samples from measured sections for most of these same rock units in the southern Bear Mountains.



MAP DESIGNATION	DESCRIPTION
Ta	purplish-gray, aphanitic, platy, flow-folded, basaltic-andesite flows at base to reddish-brown, porphyritic, blocky, flows of andesite at top (andesite of Landavaso Reservoir)
Talu	light-gray to white, simple cooling unit of densely to moderately welded, moderately crystal-rich, rhyolite ash-flow tuff
Tal	reddish-brown and purplish-gray, compound cooling unit of densely welded, crystal-poor and flaggy (sometimes pumice-rich), lithic-poor, rhyolite ash-flow tuff
Tala	dark gray, porphyritic, (olivine) basaltic-andesite flows at base to reddish-brown, porphyritic, (pyroxene) partially amygdaloidal, basaltic-andesite flows at top
Tal	light-gray and massive to flaggy and purplish-brown, fluidal-banded, contorted, compound cooling unit of crystal-poor, densely welded, rhyolite ash-flow tuffs
Thm	pink to purplish-gray, multiple-flow, simple cooling unit of densely welded, massive, blocky, cliff-forming, crystal-rich, quartz-rich, quartz latite to rhyolite ash-flow tuffs
Tst	purplish-to reddish-gray, (greenish-gray where propylitized) compound cooling unit of poorly to densely welded, crudely bedded, crystal-rich (lithic-rich at base), latite ash-flow tuff
Ts	dark purple, andesitic mudflow breccias and conglomerates with minor reddish-brown, aphanitic and porphyritic, trachytic andesite flows (upper contact is gradational)
Tsn	light pink to grayish-white, compound cooling unit of poorly to moderately welded, massive, crystal-poor, sometimes lithic-rich, latite (?) ash-flow tuffs with medium-gray, coarsely porphyritic, amygdaloidal andesite flows at base (tuff of Nipple Mountain)
Ts	purple and reddish-brown (greenish-gray where propylitized) latitic and andesitic conglomerate and sandstones

Regional Unconformity



Scale (in feet)

* 800 foot interval not shown

Figure 3. Generalized stratigraphic column of Oligocene volcanic rocks in the Council Rock district. Thicknesses indicated are maxima, estimated from structure sections.

Spears Formation

Tonking (1957) named the thick basal section of latitic and andesitic epiclastic volcanic rocks and less voluminous interbedded ash-flow tuffs and lavas the Spears Member of the Datil Formation. Rocks of this type mark the beginning of volcanism in many Oligocene volcanic provinces of the Southern Rocky Mountain region (Lipman and others, 1970). Burke and others (1963) reported a date of 37.1 m.y. (K-Ar) for a latite tuff breccia collected from the upper part of the Spears in the Joyita Hills about forty miles northeast of Council Rock. Recently Weber (1971) raised the Datil Formation to group status and Chapin (1971a) in turn has raised the Spears to formational status. Brown (1972) has since subdivided the Spears Formation into a lower epiclastic member and an upper member of volcanic rocks and minor interbedded volcaniclastic sedimentary rocks.

Exposures of the upper member of the Spears Formation indicate that it is a continuous unit throughout the length of the study area. The lower member is only partially exposed in the area but drill hole data indicate that it is a thick, continuous unit in the subsurface of the Council Rock district. The maximum total thickness of the Spears Formation in the district is estimated at 2200 feet.

Lower Member. Within the study area a single small outcrop of the lower member of the Spears Formation is located just southeast of the Tres Montosas stock. It consists of dark purple, andesitic, pebble conglomerates and a few thin interbeds of purple medium-grained sandstones.

An estimate of the thickness and lithology of the lower member of the Spears Formation in the subsurface of the Council Rock district can be made from several sources which describe this unit in nearby areas. At Hells Mesa, Tonking (1957, p. 56) measured and described 1025 feet of section comprising the lower member and which consists of quartz latite tuffs, breccias and agglomerates interbedded with volcanic conglomerates, sandstones and numerous thin beds of siltstone and claystone. Brown (1972, p. 10) describes marked facies changes in the Spears Formation along the Bear Mountains and northern Magdalena Mountains. His observations may be summarized by two generalities:

1. Volcaniclastic sedimentary rocks of the lower member generally coarsen toward the south.
2. Lava flows and ash-flow tuffs of the upper member generally thicken toward the south.

Approximately 1200 feet of the lower Spears Formation was penetrated in the Banner drill hole at the Sixty Copper prospect. In this drill hole, the lower Spears consists predominantly of coarse conglomerates grading to finer conglomerates lower in the section. Interbedded sandstones and siltstones are more abundant near the base of the section. A few minor latite flows were also observed in the sequence. Cross sections presented by Givens (1957, plate I) suggest a thickness of about 4000 feet for the total Spears Formation at the northern base of Gallinas Mountains. This thickness is probably exaggerated by unrecognized transverse faults repeating the section. A thickness of 1200 feet for the lower member of the Spears Formation, as indicated from the Banner drill hole is probably the most reasonable estimate for the study area.

Upper Member. Volcanic and interbedded epiclastic-volcanic rocks of the upper portion of the Spears are found in three separate areas along the east boundary of the thesis area. The writer has subdivided these rocks into three map units. In the Bear Mountains, the resistant overlying Hells Mesa Formation has created cliffs or escarpments which have shed a mantle of talus over the upper Spears making a mappable subdivision of the upper member impossible. Gentle slopes common in the Council Rock area have not allowed the formation of major talus cones, and these units are well exposed. In ascending stratigraphic position, the units are designated as follows: (1) tuff of Nipple Mountain (Brown, 1972, p. 14), (2) upper Spears epiclastic rocks, and (3) crystal-rich latite tuffs of the upper Spears.

Tuff of Nipple Mountain. The tuff of Nipple Mountain as described by Brown (1972, p. 14) is here redefined to include the "turkey track" andesite flows (Brown, 1972, p. 13) commonly found at the base of the tuff of Nipple Mountain ash-flow sequence. Reasons for this change are the occurrence of andesite 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. Regional mapping in the Magdalena, Bear and Gallinas Mountains has shown the tuff of Nipple Mountain to be an excellent marker horizon between the upper and lower members of the Spears Formation.

Outcrops of the tuff of Nipple Mountain cover approximately three-quarters of a square mile in the following three separate localities: east of the Tres Montosas stock, south of Council Rock Arroyo and north of Gallinas Springs Canyon. Outcrops of the ash-flow portion weather to a buff-colored platy and sandy soil and the "turkey track" andesites form a dark gray soil with distinctive porphyritic clasts. The unit characteristically forms hogbacks where steeply inclined. The tuff of Nipple Mountain crops out discontinously along the east side of the Gallinas uplift over a distance of approximately 12 miles. East of Granite Mountain and in the Kelly mining district, the tuff of Nipple Mountain fills channels cut in the lower member of the Spears. A similar relationship may be responsible for the discontinous nature of this unit along the Gallinas uplift. Alternatively this discontinuity may be structurally derived.

The "turkey track" andesite ranges from a thickness of zero feet at Gallinas Springs Canyon to approximately 100 feet south of Montosa Arroyo. In the vicinity of the Tres Montosas stock, it contains amygdules outlined by pistachio-green epidote and filled with euhedral brown andradite-garnet. Metamorphism of this rock unit will be discussed later in a section concerning the Tres Montosas stock.

East of the Tres Montosas stock, the "turkey track" andesite varies from a blue-gray color, mottled with white plagioclase phenocrysts, to a dense black rock with fresh, clear plagioclase visible only as reflections along cleavage planes. The latter variation occurs adjacent to the contact with the stock. One other small triangular-shaped outcrop of the "turkey track" andesite is found about one half mile west-northwest of the Council Rock Ranch. Here again, it is a blue-gray color, but the amygdules consist of white calcite grading outward to pink hematitic calcite. In thin section, this rock contains from 15 to 20 percent phenocrysts of plagioclase, An_{53} (Fouqué method, one grain), averaging approximately 4 mm in length in a groundmass of calcic andesine (Michel-Levy method, 20 measurements). Both phenocrysts and groundmass plagioclase are often partially altered to low-birefringent clay minerals.

Cooling breaks occupied by andesite flows were observed near the middle of the tuff of Nipple Mountain in the Banner drill hole at the "Sixty Copper prospect" and in a hole on the northeast side of the Tres Montosas stock drilled by Bear Creek Mining Company. These breaks, together with variations in abundance of lithic fragments and pumice indicate that the ash-flow sequence of tuff of Nipple Mountain is a multiple-flow compound cooling unit. The ash-flow portion of the tuff of Nipple Mountain is estimated to have a thickness of 400 feet.

Purple and brown andesitic lithic fragments containing white argillized plagioclase phenocrysts are fairly abundant at the top and base of the tuffs (Fig. 4). In thin section, a devitrified matrix of poorly welded glass shards averaging 0.2 to 0.3 mm in length, with a few unbroken oval-shaped

Figure 4. Outcrop of the tuff of Nipple Mountain. Note the presence of typical Spears lithic fragments of purple porphyritic andesite. The flaggy fracture and light gray color are common to this unit in the Council Rock area.

glass bubbles, comprises about 85 percent of the rocks. In most sections, very fine-grained cherty quartz fills the remaining pore space and a high-birefringent clay mineral, probably illite, commonly fills cavities in uncollapsed pumice. This cherty cement is probably the controlling factor in the resistant, massive weathering character of this unit. Disseminated opaque dust within the axiolitic-devitrified glass shards makes them readily discernible from the clear siliceous cement. This ash-flow sequence appears to have been a preferential channelway for hydrothermal solutions and (or) meteoric waters, because of its high initial permeability.

Crystals normally make up less than two to three percent of the tuff of Nipple Mountain. Small microperthic sanidine crystals containing exsolved strings and patches of polysynthetically twinned albite(?) appear to be approximately equal in volume to that of altered plagioclase. The composition of a single plagioclase phenocryst was An_{37} (Fouqué method). In many thin sections, however, both feldspars are completely altered to a gray opaque clay.

Thin sections from dense gray blocky-jointed outcrops of the tuff of Nipple Mountain where it abuts the Tres Montosas stock are composed of a felsic, allotriomorphic-granular, very-fine grained (0.03 to 0.05 mm in diameter) matrix with a few small grains of magnetite with haloes of biotite and a few completely argillized phenocrysts of feldspar. The vitro-clastic nature of this rock has been completely erased by hornfelsic recrystallization.

Upper Spears Epiclastic Rocks. Outcrops of these rocks consist primarily of crudely bedded well-indurated mud-flow breccias with no recognizable internal stratification or imbrication of lithic fragments. A few thin reddish-brown aphanitic, and sometimes porphyritic, andesite flows are interbeded with the laharic breccias at Montosa and Council Rock Arroyos. At Gallinas Springs Canyon, andesite flows cap the epiclastic breccias and are nearly equal to them in volume. Lithic fragments in the mud-flow breccias are well-rounded to sub-angular and vary from pebbles to boulders of andesite and latite (Fig. 5).

These mudflows and andesite flows crop out rather poorly compared to the tuff of Nipple Mountain, or the densely welded crystal-rich latite tuffs immediately above them. The epiclastic rocks normally form a dark reddish-brown to purple soil containing abundant well-rounded cobbles and pebbles of latites and andesites. The only exception to this weathering habit is found in the baked periphery of the Tres Montosas stock where rounded clasts do not weather into the soil. In this area, Spears rocks may be distinguished from the mafic border facies of the stock only where vague outlines of lithic fragments can be observed.

Although the upper Spears epiclastic rocks could vary significantly in thickness by nature of their origin, it appears that the relatively smooth erosion surface developed on the tuff of Nipple Mountain resulted in a relatively uniform thickness which varies from 130 to 200 feet. A thickness of 369 feet for this unit in the Bear Creek drill

Figure 5. Outcrop of massive mudflow breccias of the upper member of the Spears Formation in Gallinas Springs Canyon. A greenish-black propylitized mafic dike, about five feet thick, cuts the Spears epiclastic rocks on the left side of the print.

hole may be exaggerated by a high-angle reverse fault (Cross section B-B', Pl. 1). The upper contact of these rocks with the overlying crystal-rich lithic-rich latite ash flows often consists of a gradational change marked by an increasing abundance of white feldspar phenocrysts in the matrix of a lithic-rich flow of mud and ash.

Upper Spears Crystal-rich Latite Tuffs. Variations in composition, grain size and degree of welding indicate that these ash-flow tuffs are a multiple-flow compound cooling unit. Lateral thickness variations in this uppermost portion of the Spears are normally minor. One notable exception occurs in the vicinity of Gallinas Springs Canyon where approximately half of the section appears to be missing, apparently due to non-deposition of the lower lithic-rich ash flows in the vicinity of a paleo-topographic high. Estimates of the thickness of these tuffs range from a minimum of 100 feet to a maximum of 300 feet.

Outcrops of the basal poorly welded lithic-rich ash flow of this unit at Council Rock arroyo are commonly pale greenish-gray due to pervasive propylitic alteration. Elsewhere, fresh hand specimens are characterized by purplish-gray colors speckled with abundant chalky-white phenocrysts of sanidine and plagioclase in approximately equal proportions. Quartz is generally absent except in the transition to the ash flow tuffs of the overlying Hells Mesa Formation. Copper-colored biotite is common in deuterically altered zones near the top of the crystal-rich latite tuffs.

Crystals generally comprise 40 to 50 percent of these rocks.

The upper contact of these tuffs with the Hells Mesa Formation is quite subtle. A thin hematite-stained conglomerate (Brown, 1972, p. 17) separates the Spears from the Hells Mesa in the Bear Mountains; unfortunately, the conglomerate is missing in the Council Rock district. Consequently, the formation boundary is placed at the first appearance of abundant quartz phenocrysts, which approximately concides with a consistent morphological change related to welding characteristics. The moderately to densely welded latite ash flows of the Spears often have a crudely bedded appearance, weather to rounded outcrops, and form an equigranular soil. On the other hand, outcrops of the densely welded Hells Mesa tuffs have a massive blocky-jointed appearance and form large angular blocks of talus.

Outcrops differ greatly in their appearance in the hornfels zone around the Tres Montosas stock from their equivalents outside this zone. Lithic-poor crystal-rich latite tuffs of the upper part of the Spears are found in contact with the east border of the stock near Pine Well. In this area hornfelsed crystal-rich latite tuffs are dark-gray massive blocky-jointed rocks which strongly resemble monzonite border facies rocks found along the west and south boundary of the stock. Hand specimens of these hornfelsed tuffs have a waxy-gray matrix containing fine-grained clear plagioclase, white potash feldspar and abundant clots of metallic black magnetite. The observation of andesitic lithic fragments outlined by potash (?) feldspar reaction rims in some outcrops was the only field indications that these outcrops belonged to the Spears Formation rather than to the stock. In thin section, a hornfelsed latite tuff sample consisted of about 20 percent broken phenocrysts of potash feldspar and nearly equal amounts of plagioclase feldspar (An_{32}, Fouqué method, average of three measurements) in a matrix of equigranular, very fine-grained potash feldspar and clinopyroxene. Broken crystals and a seriate texture are primary textures remaining to reveal its pyroclastic origin.

Petrographically, samples of crystal-rich latite tuffs from the vicinity of Council Rock arroyo vary widely in their degree of alteration, which is generally inversely proportional to the degree of welding. Tuffs at the base of the section are poorly welded and argillic alteration of both plagioclase and sanidine to a gray opaque clay is nearly complete. Tuffs higher in the section usually exhibit varying degrees of propylitic replacement of sanidine by calcite and replacement of biotite by chlorite. Copper-colored biotites near the top of the sequence apparently formed by oxidation processes related to welding.

Compositional variations in these tuffs appear to be minor. Plagioclase ranges in composition from An_{28} to An_{33} (Fouqué method) for six phenocrysts in 3 different thin sections. Sanidine is slightly more abundant than plagioclase, and together these crystals make up about 40 percent of the rock. Feldspar phenocrysts vary in length from about 1 to 3 mm. Mafic minerals normally make up less than 10 percent of the rock and, in order of decreasing abundance, include magnetite, biotite and minor clinopyroxene. The groundmass of densely welded tuffs in this series consists of reddish-brown, partially to completely devitrified homogenous glass. Quartz phenocrysts are not entirely absent from the upper tuffs near their gradational contact with the Hells Mesa, but they are much smaller in size and sparse in abundance.

Hells Mesa Formation

By agreement among geologists presently working in the northeast Datil-Mogollon volcanic field, the Hells Mesa Formation has been restricted to the basal unit of Tonking's measured section (1957, p. 56) of what he called the Hells Mesa Member of the Datil Formation. In its new restricted sense, the Hells Mesa is a quartz-rich densely-welded multiple-flow simple cooling unit of quartz latite to rhyolite ash-flow tuffs. Older terminology applied to equivalents of this formation are: rhyolite porphyry sill (Loughlin and Koschmann, 1942, p. 33), and tuff of Goat Spring (Brown, 1972, p. 19). Biotite from outcrops near the base of this formation at Hells Mesa has been dated by the K-Ar method as 30.6 ± 2.8 m.y. (Weber and Bassett, 1963). 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 are in better agreement with other dated units. Geologic mapping in the Gallinas, Bear, Magdalena, San Mateo and Lemitar Mountains, has shown the Hells Mesa Formation to be a mappable unit of regional importance.

The Hells Mesa Formation typically forms steep cliffs in the block-faulted and tilted Bear Mountains. The Hells Mesa also forms most of the steep slopes of Tres Montosas, where it is estimated to be about 600 feet thick. However, talus masks much of the lower slopes of Tres Montosas making this estimate tenative. At Gallinas Springs a maximum thickness of 1200 feet was originally estimated for the Hells Mesa. Further observation indicated that at least two transverse faults may repeat portions of the section. A second calculation indicated a minimum thickness here of 800 feet which is considered by the writer to be a reasonable estimate of its true thickness at this locality. In the study area, the Hells Mesa Formation crops out as low rounded hills with a few steep slopes formed only where cut by major drainages. This unusual geomorphic expression for the Hells Mesa may be related to structural complexities or possibly to abrupt changes in thickness from West to East in the Council Rock area. The latter conclusion is preferred by the writer since a maximum thickness of 500 feet is indicated for the Hells Mesa in a vertical section just east of the Tres Montosas stock. This topic will be discussed in greater detail in the structural section of this report.

The Hells Mesa Formation crops out in a semi-continuous manner over approximately six square miles in the area of investigation. The best exposures occur in steep-walled canyons of the Council Rock and Gallinas Springs drainages where the massive homogeneous resistant nature of the formation is best revealed. Pumice often weathers differentially from some outcrops leaving behind "crescent-like" cavities, convex-upward at the top and flat on the bottom. However, pumice is often absent from these densely welded outcrops and attitudes of compaction foliation are often difficult to determine.

Broad, gently sloping surfaces developed on this unit in the Council Rock area are generally mantled by large angular blocks averaging from six inches to one foot in length. Interstices between blocks are commonly filled by buff colored sand.

Fresh hand specimens of the Hells Mesa tuffs exhibit varying hues of medium to light-purplish-gray lithoidal matrix comprising about 50 to 60 percent of the volume of the rock. Weathered surfaces are normally shades of brown or gray. Plagioclase often has a greenish-gray cast and sanidine is nearly always milky and white. Fragments of feldspar crystals show a continuum of sizes from about 3 mm to 0.1 mm; smaller grains tend to be crowded together as clots in the matrix. Clear sub-equant quartz crystals, as much as 4 mm in diameter, commonly comprise about 5 to 10 percent of the rock. Outcrops near the top of the formation, however, contain as much as 15 percent quartz. Black to copper-colored biotite is the only other commonly recognized phenocryst.

The upper contact zone of the Hells Mesa Formation is often bleached by hydrothermal solutions or possibly by groundwaters. The contact of the Hells Mesa Formation with the overlying A-L Peak Formation is not exposed anywhere in the study area. Usually the contact is along small alluviated drainage channels. A friable bentonite layer about two feet thick is exposed in a road cut at this contact on Gray Hill, four miles to the south of the thesis area (Wilkinson, in preparation). Outcrops of Hells Mesa are uniformly and densely welded. Pumice and aphanitic purple lithic fragments become abundant locally but are generally absent. Some outcrops near the base of the Hells Mesa contain 10 percent or more lithic fragments. These observations indicate that the Hells Mesa Formation is a multiple-flow simple cooling unit.

Thin sections show that rocks in the Hells Mesa Formation all have a porphyritic and seriate texture. Explosive pulverization and (or) intra-flow abrasion resulted in comminution of the phenocrysts. Both sanidine and plagioclase exhibit minor degrees of deuteric alteration to low-birefringent clay minerals; sanidine is generally the least altered of the pair. Sanidine is often microperthitic, containing patchy exsolutions of albite-twinned plagioclase. Some sanidines have undergone patchy replacement by calcite which may be replacing exsolved plagioclase; however, intermediate stages of plagioclase replacement confirming this were not observed. In most thin sections, sanidine is about twice as abundant as plagioclase and normally comprises over 20 percent of the total rock volume. Subhedral quartz crystals often have inwardly mushrooming embayments filled with brown glass. A few percent of biotite is common in rocks of the Hells Mesa. The biotite may vary from a pale green slightly pleochroic variety to a type strongly pleochroic in reds and browns. Traces of clinopyroxene and hornblende may be accidental xenocrysts incorporated from vent rocks or from the underlying erosion surface.

Densely welded glass in the groundmass of the Hells Mesa is reddish-brown to light brown in color. The glass is normally devitrified, and small spherulites of radially disposed cristobalite and potash feldspar are common. Dust-like inclusions of iron oxide which are abundant in the matrix, commonly outline fused glass shards. Glass shards are strongly wrapped around phenocrysts due to differential compaction. Only one type of lithic fragment is common in the Hells Mesa Formation. These granule to pebble sized, reddish-brown lithic fragments are porphyritic aphanitic andesites composed of argillized feldspar and disintegrated mafic minerals in a brown groundmass. The lithic fragments are very likely derived from the Spears Formation.

Field and labratory observations suggest a consistent, vertical compositional-variation in the Hells Mesa Formation. Data presented by Brown (1972, p. 26-28, Table 1, Figures 7 and 8) indicate an upward overall increase in the quartz/feldspar ratio. Chemical analyses by Deal and Rhodes (1972, oral commun.) of two samples: M-24-23 and M-24-33 from the measured section of Brown (1972, p. 27) indicate an upward decrease in CaO from 0.53% to 0.27% and, unexpectedly, a slight decrease in Na_2O in the same direction. The writer has measured the anorthite content of 20 plagioclase crystals

(Rittmann zone method) within two thin sections from the Hells Mesa Formation in the study area. Sample 1-16 was collected approximately 30 feet above the basal contact of the Hells Mesa. The range of anorthite content for ten plagioclase crystals in this sample is An_{25} to An_{32} with an average value of An_{28}. In Sample 1-17, collected approximately 40 feet below the top of the Hells Mesa, ten plagioclase crystals ranged in composition from An_{22} to An_{25} and averaged An_{23}. In addition, the average axial angle of sanidine (measured on the universal stage) decreased upwards from a $2V_x=46^\circ$ (average of 4) to a $2V_x=41^\circ$ (average of 5). In general the 2V of low sanidine becomes smaller with decreasing Na content (Tröger, 1956, p. 96). However, the degree of ordering of Al cations is another important factor which controls the 2V of sanidine.

These observations suggest a trend opposite of that typically cited in the literature (Lipman and others, 1966; Ratte′ and Steven, 1964; Smith and Bailey, 1966). Lipman (op. cit. p. 18) states that the typical compositional trend in thick ash-flow sheets is from a crystal-poor rhyolite at the base to a more crystal-rich quartz latite at the top. The Hells Mesa appears to have a trend from latite to quartz latite to rhyolite. Brown (1972, p. 74) has postulated that fissures initially tapped a zoned magma chamber at a low level, which allowed more mafic magma to be erupted first followed by increasingly siliceous magma. This process would require more siliceous magma to move down to the level of the venting fissures as the magma chamber was drained.

The result would be compositionally zoned ash-flow sheet whose zonation is the reverse of that commonly observed.

A-L Peak Formation

The A-L Peak Formation is the formal name proposed by Deal and Rhodes (1974) for a 2000-foot-thick section of homogenous, densely-welded, crystal-poor, rhyolite ash-flow tuffs exposed on the northeast flank of A-L Peak in the northern San Mateo Mountains. Deal and Rhodes (1974) have also delineated the boundaries of a major resurgent cauldron (20-25 miles in diameter) centered about Mt. Withington, which is located about 20 miles south of Council Rock. They believe the Mt. Withington cauldron is the source area for the A-L Peak Formation and a younger sequence newly named the Potato Canyon Rhyolite.

Stratigraphic and petrologic equivalents of the A-L Peak Formation have been previously described and informally named in earlier investigations. The formation correlates with the "banded rhyolite" of Loughlin and Koschmann (1942), middle 65 feet of the type section of Tonking's Hells Mesa Member (Tonking, 1957), and the tuff of Bear Springs (Brown, 1972, p. 31). E.I. Smith, and others (1974) have dated the A-L Peak Rhyolite at 31.8 ± 1.7 m.y. using the fission track method.

Outside the Mt. Withington cauldron, the A-L Peak Rhyolite grades laterally into a composite sheet (R.L. Smith, 1960, p. 158) in which rhyolite crystal-poor ash-flow tuffs are interbedded with thin crystal-rich, quartz latite ash-flow tuffs and basaltic-andesite lava flows (Chapin and others, in preparation). For this reason it is referred to here as the A-L Peak Formation rather than A-L Peak Rhyolite as named by Deal and Rhodes. The A-L Peak Formation has been subdivided into four mappable units in the Council Rock area. Three ash-flow cooling units are recognized, of which the lower and middle cooling unit are quite similar petrologically but are separated by intervening basaltic-andesite flows. The upper cooling unit is a simple cooling unit of moderately crystal-rich rhyolite.

Lower Cooling Unit. The lowest subdivision of the A-L Peak Formation crops out over about three and one half square miles of the thesis area. It is exposed semicontinously along a north-trending zone, about one mile wide, from Arroyo Montosa to Gallinas Canyon. It is, however, noticeably absent in an area near Council Rock. Coincident with its northerly outcrop trend is a zone of concentrated faulting and hydrothermal alteration. For this reason, the lower A-L Peak crops out as low rounded hills which weather readily to a soil of reddish-brown and white platy fragments of small size.

A second area of wide exposure of these lower A-L Peak tuffs is found along an east-west trend in the northwest corner of the thesis area. At this locality, their character is remarkably similar to that described by Brown (1972, p. 31) in the Bear Mountains.

The lower cooling unit of the A-L Peak Rhyolite is a multiple-flow compound-cooling unit comprised of two recognizable members in the study area. The basal member consists of approximately 350 feet of light-purplish-gray, massive, crystal-poor rhyolite (Fig. 6). Its massive nature appears to be related to a scarcity of pumice and a moderate to low degree of welding.

Welded to the lower member is the purplish-brown densely welded, fluidal-banded, contorted member (Brown, 1972, p. 38). Its thickness is estimated at 250 feet. In the upper third of the contorted member, the compaction foliation has been warped to form flow-folds. The flow-folds often occur as flat-bottomed synclines and tight V-shaped anticlines with amplitudes of about two feet and wavelengths of about 10 feet (Fig. 7). Axial planes of these asymmetric folds dip to the north and range in strike from N 85° W to S 83° W (8 measurements). However, when the regional dip is removed by rotation to the horizontal the axial planes of these folds all dip to the south at angles averaging about 80 degrees. Schmincke and Swanson (1967, p. 656) have described similar structures in welded ash-flow tuffs of the Gran Canaria Island. They observed that the more gentle limb of the folds consistently dipped sourceward. Brown's data (1972, p. 78) and the writers observations in regard to the orientation of these structures are consistent with the proposed source of the A-L Peak Formation in the San Mateo Mountains. The orientation and repeated occurrence of these widespread structures argues for a primary origin. Because the compaction foliation itself is deformed, development of the flow folds must

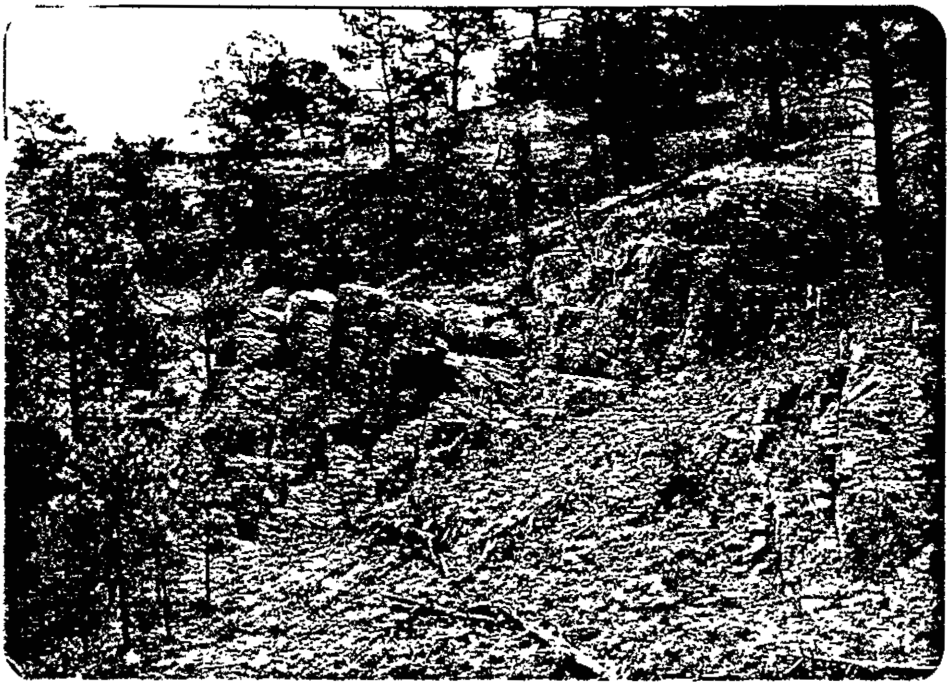


Figure 6. Outcrop of the basal gray-massive member of the A-L Peak Formation near Gallinas Springs. Columnar jointing is readily apparent and approximately at right angles to the compaction foliation.

Figure 7. Outcrop of the contorted member in the lower cooling unit of the A-L Peak Formation located about one-half mile west-northwest of Gallinas Springs. Note the tight V-shaped anticlinal fold interpreted to have formed during primary laminar flow.

have occurred after the flow had largely compacted and began to weld, but while the material was still moving in a laminar manner (Lowell and Chapin, 1972).

Elongated pumice also forms a primary lineation in the lower part of the contorted member. Trends from four outcrops varied from N 8° W to N 3° E, approximately at right angles to the axial planes of nearby flow folds. The pumice lineation probably formed by differential movement within the tuff at the same time the flow folds formed.

Megascopically, colors range from light gray and purplish gray in moderately welded portions of the sequence to dark chocolate brown where densely welded. Phenocrysts average about 1.0 mm in length and comprise generally less than about five percent of the rock. This is notably less than the average of approximately 10 percent phenocrysts observed in the southern Bear Mountains (Brown, 1972, p. 35). Chalky white sanidine (0.5-2.0 mm) is the dominant mineral phase, followed by smoky quartz (less than 1.0 mm) and traces of plagioclase and biotite. In many specimens subhedral sanidine crystals appear to have been leached to form cellular "honey-comb" like crystals. Pumice and lithic fragments are characteristically scarce in the gray massive member. However, the contorted unit may contain up to 15 percent pumice and about 3 percent aphanitic, brown andesite lithic fragments.

Petrographically, there is little difference in the mineralogy of these ash flows. Eutaxitic structure is evident from sub-parallel elongate glass shards and from flattened pumice which is often differentially compacted around crystals and lithic fragments. Pumice, near the top of the contorted unit has been completely replaced by bladed crystals of potash feldspar around the rim with equigranular, anhedral quartz crystals (0.05 to 0.3 mm) filling the center. The groundmass of these tuffs is consistently devitrified to very fine-grained quartz and alkali feldspar as axiolites and unoriented masses. Two to three percent of the groundmass in the massive member is hairlike hematite crystals (less than 0.1 mm long). A much greater concentration of very fine disseminated hematite (15 percent) in the matrix of the contorted unit is apparently the major reason for its darker color. The greater degree of welding in the contorted member is also probably important in this color change.

Sanidine is the most abundant phenocryst throughout the lower cooling unit. It is estimated to be about 4 to 5 times as abundant as quartz and range from 4 to 7 percent by volume. Nearly all sanidine appears to have been perthitic, but alteration of the exsolved potassic phase to sericite and illite (?) masks the true relationship. Secondary potash feldspar produced during devitrification and from vapor phase processes has in some instances also been altered to clay. This fact suggests that hydrothermal fluids, or ground waters, are the cause of argillization. Removal of these clays from the sanidine crystals is the probable origin for the "honey-comb" texture described earlier.

Quartz crystals are usually anhedral and are slightly more abundant in the gray massive member than in the contorted member. However, quartz never exceeds one percent by volume in either. Plagioclase was not observed in any specimens from the lower cooling unit.

Interbedded Andesites. In most of the study area thin flows of dark reddish-brown aphanitic basaltic andesite separate the lower and middle cooling units of the A-L Peak Formation. Thin beds of tuffaceous sandstone and granulestone occur locally where these lavas thin over a structurally controlled topographic high. The thickness is highly variable ranging from 0 to 200 feet.

Outcrops generally weather to a dark-brown clayey soil found along gentle slopes at the base of ridges or as small hollows between outcrops of welded tuff. The best exposures are found in small tributary drainages along the south side of Gallinas Canyon (Fig. 8). The andesites are generally massive although some are autobrecciated. Vesicular horizons are rarely exposed, but where found the vesicles are nearly all filled with cherty quartz and may contain some blue-green celadonite.

Hand specimens are usually aphanitic-porphyritic although, at first glance, the fine grain size (approximately 0.5 mm) and dark color of most phenocrysts may cause them to be overlooked. Flows near the base of the series tend to be darker and more abundant in ferromagnesian minerals. Fine-grained reddish-brown iddingsite (after olivine) and black pyroxene may comprise as much as 25 percent by volume of these lavas. Phenocrysts of plagioclase (0.5-2.0 mm long) became abundant near the top of this lava flow sequence.

Determination of extinction angles for plagioclase

Figure 8. Exposure of a basaltic-andesite lava flow interbedded within the A-L Peak Formation. Dark-gray, vesicular blocks of older basaltic andesite are enclosed in reddish-brown autoclastic breccias. The outcrop is located approximately one half mile southwest of Gallinas Springs.

phenocrysts and groundmass microlites suggested that these lavas are basaltic andesites. A sample taken from the base of this unit contained 15 percent olivine and 10 percent augite ($2V_x$= 53° ± 4° , Z∧C= 44° ± 2°) as fine grained phenocrysts (0.5-1.5 mm). Olivine occurs as subhedral and euhedral hexagonal forms rimmed by reddish-brown iddingsite. Angitorite sometimes occurs along fractures. Augite is present as fresh, neutral-gray crystals (in thin section) that are smaller than the olivine phenocrysts and commonly glomeroporphyritic. Calcic labradorite microlites (An_{64}, average of 5 determinations by Rittmann zone method) are the dominant phase in the groundmass and comprise about 40 percent of the rocks volume. Approximately equal volumes of augite and magnetite form the remaining groundmass.

Less mafic lavas, which form the major volume of the sequence, have plagioclase as the dominant phase in both phenocrysts and matrix. Plagioclase crystals are normally zoned; one phenocryst ranged from An_{51} to An_{46} (Fouqué method). In general plagioclase phenocrysts are sodic labradorite while groundmass plagioclase microlites are calcic andesine. Augite phenocrysts and traces of olivine are also present making as much as 15 percent of the rocks volume.

Small outcrops of tuffaceous sandstone and granulestone occur adjacent to a north-trending fault which truncates the basaltic andesites about one-half mile south of Gallinas Springs. Clasts in the granulestone are predominantly derived from the gray massive member of the lower cooli unit. Densely welded clasts derived from the contorted member are also present in small amounts (less than 3 percent). Fragments are sub-angular to sub-rounded and vary from three to five millimeters in length. Sub-rounded "honey-combed" sanidine crystals and microcrystalline cherty cement comprise the remainder of the rock. A tuffaceous fine-to medium-grained sandstone which overlies the granulestone is chalky-white and thinly laminated. In decreasing order of abundance sand-sized tuff clasts, angular quartz grains and perthitic sanidine are cemented by cherty quartz to form this rock.

Thinning of the basaltic-andesites accompanied by the occurrence of these locally derived sediments approaching the north-trending fault suggests the minimum age of the fault to be late Oligocene (slightly younger than the lower A-L Peak Formation). This conclusion is confirmed by the occurrence of a welded fault contact between the gray massive member and the contorted member about two hundred yards along the strike of the fault to the north of the tuffaceous sandstone outcrop (Fig. 17, this report). The term "welded" fault contact implies that the fault formed while the contorted unit was still hot enough to reweld itself to the lower member after being emplaced in contact with it across the fault.

Middle Cooling Unit. The middle cooling unit of the A-L Peak Formation is a uniform multiple-flow sequence of crystal-poor welded rhyolite ash-flow tuffs. Its estimated maximum thickness is five hundred feet. Exposures are mostly restricted to a four-square-mile area of rolling hills in the northwest quadrant of the study area. The lack of distinct zones of welding and a low dip to these tuffs are major controls in its topographic expression. The lower contact normally follows a topographic break, which may be attributed to the relatively soft nature of the underlying andesites or possibly an unwelded basal zone in the ash-flows. The characteristic occurrence of a spherulitic densely welded zone within ten feet of the base would necessitate a very thin unwelded zone, if present. A similar spherulite zone has been noted in the Bear Mountains (Brown, 1972, p. 42).

Hand specimens of the middle cooling unit from densely welded zones are usually light purplish-gray on fresh surfaces and weather to a light brown. A few reddish-brown zones are associated with moderately to poorly welded portions of the sequence. Phenocrysts of subhedral, chalky white sanidine (0.5-3.0 mm) appear to be slightly more abundant than in the lower cooling unit. The sanidine-quartz ratio progressively increases upwards in the unit as also does the total crystal content. Estimates of phenocryst content range from five percent crystals at the base to about eight percent at the top. Pumice is most abundant near the middle of the section where it is estimated to be five to ten percent by volume. Lithic fragments are rare and where found they are consistently small (less than 2.0 mm). They consist of aphanitic andesite and make up less than one percent of the rock.

In thin section the groundmass consists of moderately to densely welded glass shards and pumice. All vitric material has crystallized to fine grained quartz and alkali feldspar (0.1-0.5 mm). Ghosts of glass shards are visible under high magnification only because of very fine hematite dust (less than .005 mm) which outlines them. Devitrification usually has produced a random orientation of the quartzo-feldspathic intergrowth, although axiolites and spherulites were also observed.

Fresh sanidine phenocrysts were rarely observed in thin section. Most are chalky white and altered to a low-birefringent clay which is probably a product of deuteric alteration. This conclusion is substantiated by the persistent, widespread occurrence of the alteration.

Sanidine is the most abundant phenocryst, comprising as much as 5 percent by volume. Measurements of axial angles for six sanidine phenocrysts, in a single section from the middle of the unit, varied from $2V_x = 26° \pm 2°$ to $30° \pm 2°$. Small albite-twinned plagioclase crystals are often enveloped within large euhedral sanidines. The plagioclase is anomalously fresh compared to the sanidine, even when present as individual crystals. Extinction angles and 2V measurements for the plagioclase indicate that it is high temperature albite to sodic oligoclase. Anorthite values for three measurements ranged from seven to eleven percent. The 2V of one crystal was measured as $2V_x = 48° \pm 2°$ to eliminate ambiguities involved for extinction angles ($X' \wedge (010)$) of less than 14° on the Rittmann zone curves. The anorthite content determined by 2V and that determined by extinction angle differed by one percent anorthite. Plagioclase was present in all of seven thin sections from the middle cooling unit; however, estimates did not exceed one percent by volume. Traces of reddish-brown biotite were noted in a few sections. Subhedral and angular broken quartz crystals comprise from one to three percent of rocks from the middle unit. Quartz becomes slightly more abundant toward the top of the middle cooling unit.

Upper Cooling Unit. The youngest of the A-L Peak ash-flow tuffs is a simple cooling unit of poorly to densely welded, moderately crystal-rich rhyolite ash-flow tuff. It is exposed at two small outcrops in the northwest quadrant of the thesis area. The larger and better exposure occurs as a narrow north-trending strip about one mile in length in the vicinity of South Well. A variable estimated thickness of 75 to 125 feet is attributed to erosion of the upper poorly welded zone prior to extrusion of the overlying lava flows. At South Well, where all but the poorly welded basal zone is exposed, the upper tuff crops out as a series of rounded blocky ledges from which compacted pumice easily weathers to form platelike vugs. The stratigraphic position and petrology of this unit suggests that it may be equivalent to the lower Potato Canyon Rhyolite (Deal and Rhodes, 1974).

Hand specimens of the upper cooling unit are light gray to light pinkish gray on a fresh surface. Weathered surfaces are commonly light tan or may be stained dark reddish brown by iron oxide leached from the overlying andesites. The tuff contains 10 to 20 percent phenocrysts with quartz slightly more abundant than sanidine which is sometimes chatoyant. Lithic fragments (0.3 to 1.0 cm) of aphanitic reddish-brown andesite and light-pink welded tuff are common throughout the unit and may comprise 3 percent of the rocks volume. Pumice is most abundant in the upper half of the unit where it ranges from about 2 to 3 cm in length and makes up 10 to 15 percent of the rocks volume.

Petrographic analysis of sanidine and plagioclase utilizing a universal stage suggests a slightly more mafic composition for the upper cooling unit in comparison to the middle cooling unit. Sanidine has an average $2V_x = 36^\circ$ (five crystals) and ranged from 32° to 39°. The average composition of plagioclase is An_{12} (three crystals, Rittmann zone method). The modal mineralogy of a densely welded sample was estimated to be 11 percent quartz, 7 percent sanidine, 1 percent plagioclase, a trace of biotite, 3 percent lithic fragments and 10 percent pumice in a finely devitrified groundmass. Crystals range in size from 0.2 mm to 4.0 mm with an average of about 1.0 mm. On the average, sanidine is only slightly larger than quartz but both are significantly larger than plagioclase, which averages 0.4 mm in length.

Andesite of Landavaso Reservoir

The youngest of the Oligocene volcanic rocks exposed in the study area is a series of thin purplish-gray to reddish-brown basaltic-andesite flows (map designation: Ta). These lava flows are equivalent in stratigraphic position and of similar petrology to the andesite of Landavaso Reservoir mapped by Simon (1973) along the east side of the Mulligan Gulch graben. Reconnissance traverses to the west of the thesis area, in the vicinity of Lion Mountain, indicate that these basaltic andesites are overlain by a thick sequence of "moonstone" (chatoyant sanidine) moderately crystal-rich welded rhyolite ash-flow tuffs. These tuffs are most likely equivalent, in part, to the Potato Canyon Formation which also overlies the andesite of Landavaso Reservoir at Landavaso Reservoir. The Potato Canyon Rhyolite has been dated by Smith and others (1974), using the fission track method, at 30.3 ± 1.6 m.y..

Exposures of the andesite of Landavaso Reservoir consist of platy to massive lavas which cover an area of approximately one square mile in the northwest quadrant of the thesis area. The estimated maximum thickness of these flows is 400 feet. The largest continous exposure is centered around a topographic high, hill "7914" which is interpreted as the source vent for these lavas. This vent area is here named the Gallinas Springs intrusive center. Nearly vertical flow foliation observed on this hilltop and a concentric arrangement of flow fold axes about the high are the basis of this interpretation (Fig. 9). The basal lavas of this unit characteristically weather to large plate-like fragments from six inches to one foot in length and averaging about one-half inch in thickness. The platy fracture of these rocks is attributed to the accumulation of volatiles along closely spaced shear planes developed during flowage. Lavas become massive with increasing distance from the vent as well as upward in the section. The upper half of the andesite of Landavaso Reservoir tends to be reddish brown in color and blocky in outcrop character.

Handspecimens of the platy lavas are phenocryst poor and contain less than three percent of pinkish-white

Figure 9. Exposure of a large plunging synclinal flow-fold in the basal platy basaltic-andesite flows of the andesite of Landavaso Reservoir. For scale, the dog stands about one foot in height. Note the abundance of large platy fragments which are typical of the basal flows. The outcrop is located approximately two miles southwest of Gallinas Springs.

plagioclase laths ranging from 2.0 to 4.0 mm in length. A few greenish-black stubby pyroxene phenocrysts (average length approximately 1.0 mm) may also be present in specimens of the platy flows. In comparison, the blocky flows are distinctly porphyritic and may contain from 10 to 20 percent plagioclase laths (as much as 7.0 mm long) and a few percent of pyroxene. Drusy quartz and blue-green celadonite may occur as a cavity filling in vesicular zones.

Petrographic analysis of the platy lavas showed them to be basaltic andesites. The larger phenocrysts of plagioclase are commonly zoned in a normal and oscillatiory manner. The composition of one strongly zoned phenocryst ranged from An_{70} in the core to An_{46} in its narrow, sharply defined rim. Microlites of plagioclase in the same rock varied in composition from An_{45} to An_{54} and averaged An_{51} (five determinations by Rittmann zone method). The groundmass of this sample from the platy flows consists of approximately 70 percent trachytic plagioclase, 15 percent intersertal magnetite cubes and 15 percent stubby neutral-brown clinopyroxene. This same clinopyroxene also occurs as glomeroporphyritic phenocrysts and was determined to be diopsidic augite ($2V_z = 55^\circ \pm 2^\circ$, $Z \wedge C = 39^\circ$).

Similar analyses of the blocky lavas indicated that they are predominantly andesites. Five plagioclase phenocrysts in a sample of the blocky lavas ranged from An_{42} to An_{48} and averaged An_{45} (Rittmann zone method). A zoned plagioclase in this same sample was determined to have a core of An_{52} and a rim of An_{36} (Fouqué method). Clinopyroxene phenocrysts in the blocky flows were determined to be augite ($2V_z = 49° \pm 2°$, $Z \wedge C = 43°$). These relationships suggest that the blocky andesites are differentiates of the basaltic-andesite magma. The groundmass of the blocky andesites varies from dark-brown glass to subtrachytic and felty plagioclase microlites with minor magnetite and clinopyroxene.

Tertiary Intrusive Rocks

Mafic Dikes

Two distinct groups of mafic dikes are recognized in the study area on the basis of petrology and relative age. Dikes of similar occurrence and petrology in the Bear Mountains are described by Brown (1972, p. 55) and Loughlin and Koschmann (1942, p. 43). Basaltic andesite (or andesite) and lamprophyre dikes comprise the older group designated on the geologic map as Tmd. The younger group consists of olivine basalt dikes which cut pediment gravels and are the source of flows capping these gravels. This group will be discussed in a later section under the heading, basalt of Council Rock.

Five individual mafic dikes belonging to the older group were mapped. Three of these are andesites or basaltic andesites of quite similar composition and textures to lava flows interbedded within the A-L Peak Formation and to the andesite of Landavaso Reservoir. There is compelling evidence for a late Oligocene age for the longest of these dikes. This dike, cropping out about 1½ miles southwest of Gallinas Springs, is remarkably similar in texture and composition to blocky andesites from the andesite of Landavaso Reservoir. It is less than one-half mile from the proposed volcanic vent. Moreover it is significantly vesicular (about 5 percent) suggesting that the present level of erosion is very near to that of the ground surface when the dike was emplaced. The two other mafic dikes observed in the area are best described as lamprophyres in that they are dark aphanitic rocks containing sparse phenocrysts of a ferromagnesian mineral (Fig. 5, p. 22 of this report). The outcrops of both lamprophyres are about two-thirds of a mile east of Gallinas Springs on the north side of the arroyo. Recurring movement along the fault zone into which they were injected has intensely fractured the dikes and permitted strong propylitic alteration by hydrothermal solutions.

The lamprophyres are grouped with the andesite dikes on the basis of similar composition. The groundmass of the lamprophyres consists of 70 percent sub-trachytic plagioclase, partially replaced by calcite and quartz. The remainder is comprised of an interstitial granular ferromagnasian mineral, probably pyroxene, which is completely replaced by chlorite. A semi-fresh plagioclase microlite of the lamprophyres was determined to have a composition of An_{42} (Rittmann zone method). In the andesites, plagioclase phenocrysts are sodic labradorite and groundmass microlites are calcic andesine. Hence the andesites and lamprophyres appear to have similar compositions.

The andesites and basaltic andesites are distinctly porphyritic and differ from the lamprophyres mainly in texture. The modal mineralogy of a typical andesite is: 24 percent plagioclase (An_{51-59}), 3 percent iddingsite after olivine, and 3 percent augite ($2V_z = 53° \pm 2°$, $Z \wedge C = 41°$) (all as phenocrysts) in an intergranular groundmass of plagioclase ($\sim An_{46}$), clinopyroxene and minor olivine.

Latite Intrusives

The major concentration of latite intrusives in the study area occurs within one mile of the perimeter of the Tres Montosas stock. Brown (1972, p. 64) has found a similar relationship of latite dikes associated with the La Jencia (monzonite) stock in the Bear Mountains. The distribution of latite dikes in radial and concentric faults about the Tres Montosas stock along with subtle similarities in petrologic character to the monzonite facies of the stock suggest a genetic tie. The dikes range from 1 foot to 20 feet in thickness and 50 to 1500 feet in length of outcrop.

An oval-shaped plug of latite porphyry 1200 by 1400 feet forms a topographic high 3/4 of a mile east of Pine Well. The outcrop is blocky and massive in appearance. Talus derived from this resistant rock unit surrounds much of the outcrop and obscures most of the intrusive contact.

Fresh hand specimens of latite are generally light brownish-gray to light-buff in color. Greenish-gray varieties exhibit features of propylitic alteration in thin section. The latite dikes around the Tres Montosas stock are quite similar in texture and composition to a sample from the plug. Phenocrysts of normally zoned plagioclase form about 25 percent of the latites and occur as small laths and larger equant crystals from 1.0 to 7.0 mm in length. The most strongly zoned phenocryst observed had a core of An_{33} and rim material of An_{17} (Fouqué method). Many of the plagioclase crystals are mantled by narrow rims of untwinned cloudy alkali feldspar. This feature is also quite common in samples from the monzonite porphyry facies of the Tres Montosas stock. Brown to dark-reddish-brown pleochroic biotite is the only other common phenocryst and may comprise about 3 to 7 percent by volume of the latitic rocks. The groundmass feldspars of these latite dikes are commonly altered to low-birefringent clay minerals. The repeated occurrence of this feature in what appear to be unaltered latites suggests some type of a selective reaction (alteration?) process. In the sample from the latite plug, about 95 percent of the groundmass is stubby carlsbad twins of alkali feldspar, probably orthoclase, (0.02 to 0.3 mm long) with the remainder consisting of magnetite. Traces of apatite were observed in several latite samples.

Other latite dikes in the northwest part of the map area crop out within 1¼ mile of the Gallinas Springs intrusive center. In hand specimen, they appear quite similar to latite dikes near the Tres Montosas stock except that some have a pinkish groundmass. In thin section however, it is apparent that their composition is markedly different. Very-fine-grained (0.05 to 0.2 mm) quartz anhedra in the groundmass make up about 10 percent of the rock. Plagioclase microlites are also present in the groundmass (~15 percent). These samples are more correctly described as quartz latites. This compositional difference, along with the geographic location of these dikes, suggests that they are related to the Gallinas Springs intrusive center rather than to the Tres Montosas stock.

Phenocrysts of calcic to sodic oligoclase and biotite are common to the quartz latites and in approximately the same proportions as in the latites. Because of the very small size of the quartz crystals, this important difference in composition was not recognized in the field. Therefore the latites and quartz latites are not differentiated on the geologic map.

Rhyolite Intrusives

Felsic quartz-porphyry dikes of quartz latite to rhyolite composition are probably the youngest of the Oligocene intrusive rocks. These silicic intrusives are anomalous in that their two major outcrop trends, N 80° W and N 70° E, are clearly discordant with the major structural fabric in the study area. Outcrops range in width from 30 to 200 feet and in length from 400 to 4000 feet. Most are semicontinous and linear in nature, however, southwest of Gallinas Springs a change to an en echelon pattern occurs.

The relative age of these felsic dikes is fairly well bracketed. They cut the andesite of Landavaso Reservoir southwest of Gallinas Springs and are cut and altered by quartz veins near Council Rock. They are also apparently truncated by major basin and range faults at Council Rock.

As stated above the composition of these dikes varies from quartz latite to rhyolite. The longest sub-linear trend (N 80° W) extends about 3 miles from the northwest fork of Council Rock Arroyo almost to the west edge of the map area. Field observations and petrographic examination suggests a progressive compositional change from quartz latite to rhyolite moving from east to west along this trend.

From east to west the following changes are noted: quartz phenocrysts progressively increase in abundance from 6 percent to 13 percent; the matrix changes from white to glassy black; the plagioclase/alkali feldspar ratio decreases from slightly greater than 1.0 to about 0.25; plagioclase composition varies from An_{37} at the east end, to An_{27} near the middle to An_{13} at the west end; and a decrease in sanidine $2V_x \approx 42^\circ$ to 30° suggests an increase in potassium content toward the west. Since the felsic dikes cut progressively higher stratigraphic units toward the west it is difficult to determine if these changes represent lateral compositional variations in a magma chamber at depth or vertical variations in a laterally uniform dike. Additional evidence favors the latter situation. The optical properties of plagioclase in sample 1-64 from the east end indicate a low-temperature, plutonic, structural state ($2V_z = 90^\circ \pm 2^\circ$, $X' \wedge 010 = 20.5^\circ$). This is an enigmatic situation since the same specimen also contains sanidine phenocrysts as opposed to orthoclase. This data suggests a cooling rate intermediate to that of the plutonic and volcanic environments. Sample 1-67 from the west end of the dike trend is a black rhyolitic vitrophyre. This sample contains high-temperature sodic oligoclase ($2V_x = 52^\circ \pm 2^\circ$, $X' \wedge 010 = 8^\circ$). The highly alkaline character of this vitrophyre is revealed by a trace of spodumene phenocrysts ($2V_z = 54^\circ \pm 3^\circ$, $Z \wedge C = 27^\circ$). Thus the changes in composition described above are probably related to vertical variations in the transition from the hypabyssal to the volcanic environment.

A small triangular felsic plug, about 300 feet on a side, which crops out 1½ miles southwest of Gallinas Springs, consists of multiple intrusion of a coarsely porphyritic, medium-gray dacite, or quartz latite, and a light-gray rhyolite. An extension of this intrusive to the south is the only rhyolite dike in the area with a northerly trend.

Loughlin and Koschmann (1942, p. 43) and Brown (1972, p. 65) describe felsic dikes of similar composition and age relationships. The geologic map of Loughlin and Koschmann (1942, Pl. 2) indicates that white rhyolite dikes cut the granite and monzonite of the Anchor Canyon and Nitt stocks, respectively. Chapin and others (in preparation) have recognized that the extent of these white rhyolite dikes correlates very well with the lateral extent of the Magdalena composite pluton. A similar correlation of felsic dikes with a gravity-delineated granitic pluton has been observed in the Little Belt Mountains of Montana (Witkind and others, 1970, p. B64). Thus it seems valid to use the presence of felsic dike swarms to delineate unexposed plutons. The geologic map (Pl. 1, this report) shows the distribution of the rhyolite dikes. Their close association with hydrothermal alteration, quartz veins, other intrusives and a volcanic vent all support the presence of unexposed stocks below the Council Rock area and below the intrusive center about one mile southwest of Gallinas Springs.

Tres Montosas Stock

In the southwest corner of the study area a roughly circular pluton of intermediate to silicic intrusive rocks crops out discontinously from under pediment gravel and blow sand. Approximately 90 percent of the stock is veneered by surficial deposits; however, the distribution of outcrops along with topographic and structural expression of the stock suggest that it is a continuous cupola-like body beneath the surface. Because of the intrusive's proximity to the peaks of Tres Montosas, one mile to the southwest, it is here referred to as the Tres Montosas stock. The Tres Montosas stock is the only exposed pluton known in the Gallinas Mountains.

The Tres Montosas stock is quite similar in composition, level of emplacement and cross-cutting relationships with country rocks to stocks described in the vicinity of Magdalena. Best known of these are the monzonitic to granitic stocks of the Kelly district described by Loughlin and Koschmann (1942, p. 36-40). The Nitt and Anchor Canyon stocks of the Kelly district have been dated by K-Ar methods at 28.0 ± 1.4 m.y. and 28.3 ± 1.4 m.y., respectively (Weber and Bassett, 1963, p. 220). These ages are in good agreement with those of the A-L Peak Rhyolite (31.8 m.y., Smith and others, 1974) which is the youngest rock unit known to be cut by the Magdalena pluton, and the La Jara Peak Andesite (23.8 m.y., Chapin, 1971-a) which is younger than the pluton. By association, a late Oligocene age was originally inferred by the writer for the Tres Montosas stock.

A sample of metasomatic hedenbergite syenite was collected by the writer from the margin of the Tres Montosas stock at the Big John mine for K-Ar dating. The sample was selected on the basis of it's fresh appearance (though closely associated with apparent hydrothermal magnetite-vein mineralization at the mine). A whole rock K-Ar analysis, by Geochron Laboratories, Inc. yielded a date of 33.9 m.y. which is older than the A-L Peak Formation which the stock intrudes. This apparently high age may be explained by the following observation. Petrographic examination of the dated sample reveals as much as 10 percent pyroxene by volume. According to Damon (1968, p. 14) pyroxenes from intrusive environments commonly yield high ages due to excess argon. A positive conclusion that may be drawn from the date is that the stock is definitely Oligocene in age.

Most outcrops of the Tres Montosas stock are comprised by its mafic border facies which discontinuously outlines the stock by a series of low arcuate ridges. Border exposures range from massive, blocky cliffs to low hills mantled by dark brown soil with abundant mafic, aphanitic float. The central core rocks crop out as small ledges projecting from beneath pediment gravels and as very low flat hills dotted with a few rounded boulders.

Most of the contact between the stock and country rock is approximately located because of colluvium and soil cover. An exception is found along the west margin where quartz monzonite porphyry is clearly visible in contact with crystal-rich Hells Mesa tuffs. Although the contact is an irregular surface, it is estimated to dip at about 30 degrees to the west at this location. This suggests that the apex of the roof of the stock was approximately 1500 feet above the present erosion level. However, the dip of the contact has not been observed elsewhere making this conclusion tenative. Marked doming and faulting of wall rocks around the periphery of the stock, along with the widespread distribution of latite dikes, suggest that the Tres Montosas stock was forcefully intruded to a high level in the volcanic pile. Probably less than 2000 feet of Oligocene volcanic strata separated the present level of erosion and the ground surface at the time of emplacement. Therefore, it seems reasonable to assume that some type of volcanic eruption occurred in association with intrusion of the stock.

Facies. Three principal facies are present in the Tres Montosas stock: andesite to granodiorite, pyroxene latite and monzonite to quartz monzonite, and granite. Granite occurs in the core of the pluton with intermediate composition rocks occurring at the border. Ferro-pyroxene syenites also occur locally in border facies rocks as a product of contact metasomatism. Spatial relationships of outcrops suggest that most of the syenites were originally granodiorites. The inferred distribution of the three principal facies and sample locations discussed later in the text are shown by Figure 10. The simple relationships between facies as portrayed on this map are highly simplified because of poor exposures.

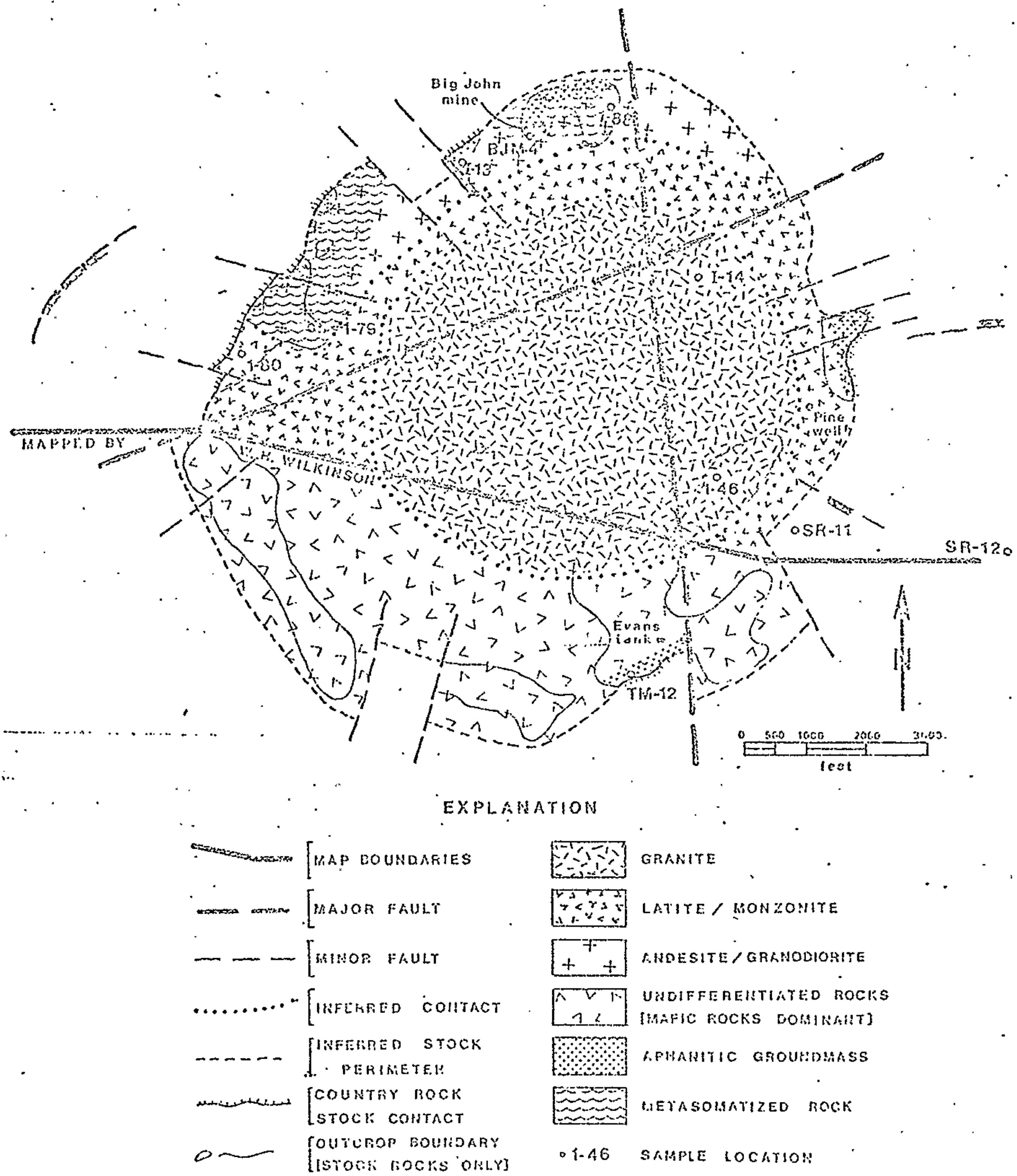


Figure 10. Inferred distribution of principal rock types in the Tres Montosas stock. Sample locations referred to in the text are shown. Metasomatized rocks are chiefly hedenbergite syenites.

Andesite and granodiorite are the oldest in the intrusive sequence. Andesites form a chilled sheath about the outer surface of the stock at the northwest, southwest and south margins. Near the Big John mine, andesite porphyry is apparently gradational into fine- to medium-grained granodiorite. Andesite hand specimens are black to dark-gray dense porphyritic rocks with small phenocrysts of clear plagioclase and greenish-black pyroxene.

Under the microscope the andesite porphyry is seen to consist of phenocrysts of sodic labradorite to calcic andesine, endiopside (Fig. 3 appendix), and sparse magnetite, in a trachytic to felty groundmass of calcic andesine with minor amounts of magnetite and pyroxene. Plagioclase phenocrysts are euhedral, exhibit oscillatory and normal zoning and, in one case, possess a narrow reverse-zoned rim. The average composition of 13 plagioclase phenocrysts in sample TM-12 is $An_{43.8}$. Modal analyses of TM-12 and other representative samples for the Tres Montosas stock are listed in Table 1.

Porphyritic granodiorite hand specimens range from black to gray-brown with phenocrysts of lath-shaped plagioclase, 2.0 mm to 1.0 cm in length and medium grained pyroxene. A fine-grained groundmass of alkali feldspar and quartz, comprises about 20 to 30 percent of the rock. Thin section examination of sample number 1-88 shows it to consist of 65 percent calcic andesine (high-temperature) and 15 percent diopsidic augite as phenocrysts. Groundmass minerals consist of a granophyric intergrowth of alkali feldspar and quartz in a ratio of about 4 to 1.

Table 1.

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

Rock type	Andesite	Quartz Monzonite	Granite
Sample no.	TM-12⊡	1-80	1-46
plagioclase	24.44*	27.69*	3.85☆
K-feldspar	1.65*	48.65☆	59.08☆
quartz	--------	14.67	35.19
pyroxene	8.40	0.35	--------
hornblende	--------	3.67	--------
biotite	--------	2.62	--------
opaques	1.65	2.36	1.88
groundmass	63.87	--------	--------
totals	100.01	100.01	100.00

* volcanic (high-temperature)

☆ plutonic (low temperature)

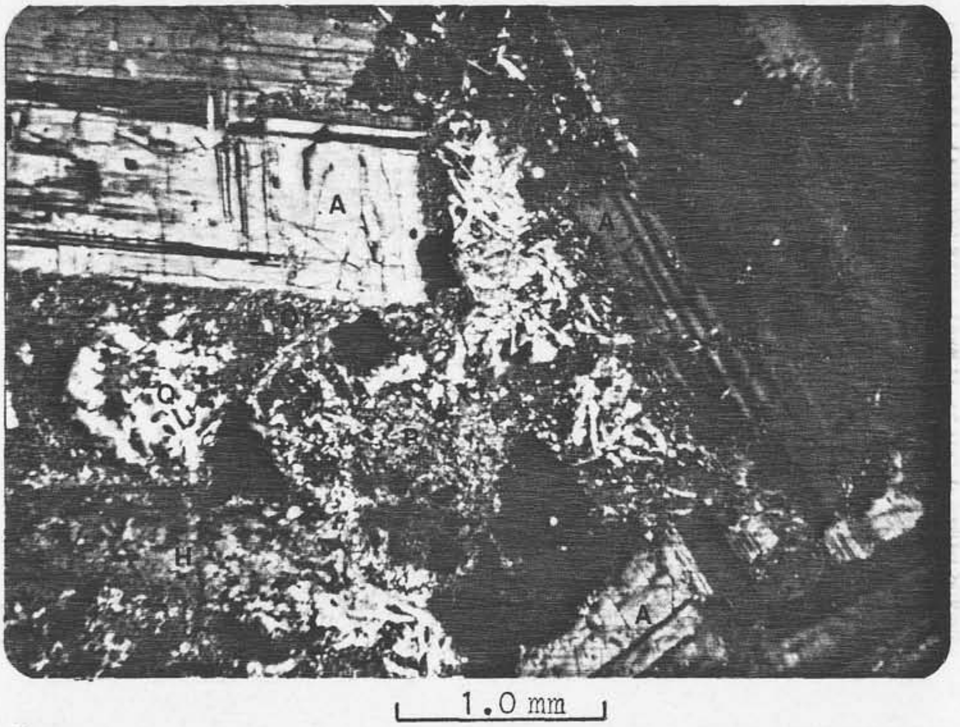
⊡ collected by W.H. Wilkinson

Granophyric groundmass is a feature common to all the principal facies in the stock. Barker (1970, p. 3342) indicates granophyres only occur in epizonal intrusions and extrusive igneous rocks and suggests that rapid crystallization is a critical factor in their formation. Another feature common to rocks of the border facies is the mantling of high-temperature (volcanic) plagioclase by rims of alkali feldspar. Alkali feldspar rims occurring in sample number I-13 have a $2V_x \approx 47°$ and groundmass feldspar has a $2V_x \approx 53°$. The same thin section was stained for potassium feldspar (Chayes, 1952). This eliminated the possibility that the rims could be untwinned high oligoclase. The measured 2V's are compatible with anorthoclase and orthoclase. The white clouded appearance of the rim material favors the latter but this is not diagnostic. Photomicrographs of thin sections 1-88 and I-13 which illustrate textures and other features described above are shown in Figure 11.

Latites and monzonites with a wide variation in composition and textures are intimately associated with the andesites and granodiorites of the border facies. Even though latite intrudes granodiorite near the Big John mine, contacts between andesite and pyroxene monzonite are probably mostly gradational. A notable exception occurs along the west margin of the stock where quartz monzonite is in sharp contact with pyroxene syenite suggesting the quartz monzonite is related to a later intrusive event.

Viewed in thin section, the groundmass textures of latites vary from seriate, allotriomorphic granular in

11A.



11B.

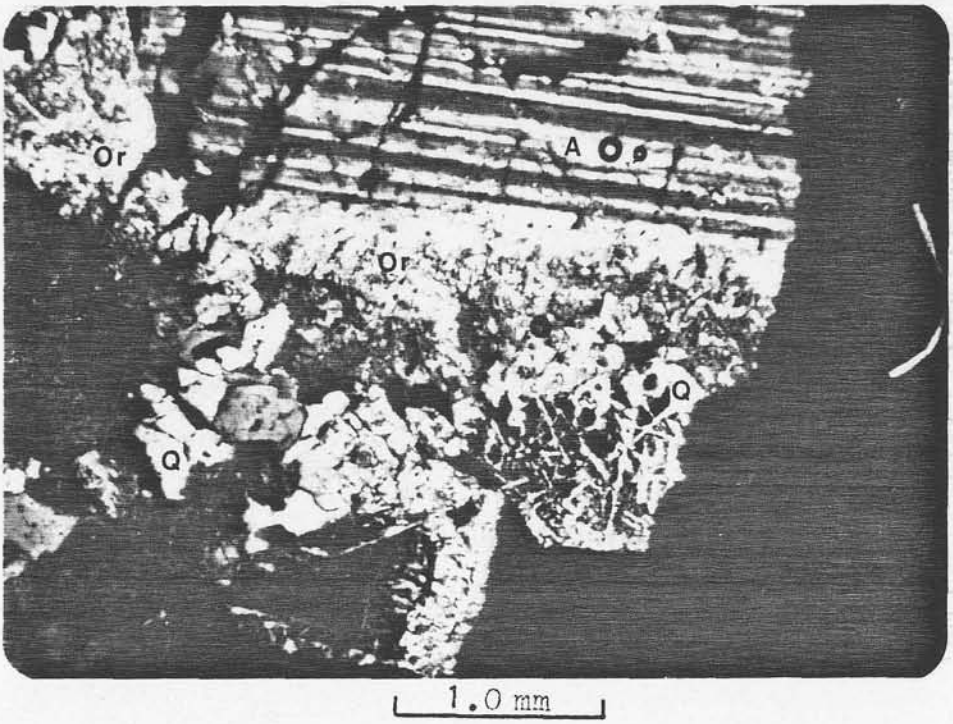


Figure 11. A. Granodiorite porphyry (1-88) with high-temperature plagioclase phenocrysts. Note the granophyric quartz and alkali feldspar in the groundmass. Crossed nicols.

B. Granodiorite porphyry (I-13) with rim of alkali feldspar mantling a high-andesine phenocryst. Section stained for K-feldspar. Mineral phases: A, andesine; P, pyroxene; H, hornblende; Q, quartz; Or, alkali feldspar. Crossed nicols.

specimens taken near the outer contact to hypidiomorphic granular in rocks closer to the core of the pluton. The allotriomophic granular textures may be related to protoclasis, or contamination of the melt by wall rocks. Although no xenoliths of wall rock were observed there seems to be a correlation of poorly welded latite ash-flow tuffs of the Spears Formation as wall rocks and the microgranular textures. Some phenocrysts (?) of oligoclase have sharp narrow rims of normally zoned andesine to oligoclase suggesting the cores are actually xenocrysts.

Two distinct types of monzonites are recognized: augite monzonites and quartz monzonites. It could not be definitely established whether the quartz monzonites represent a normal differentiation product of the pyroxene monzonites or whether they represent separate intrusions from a differentiating magma body at depth. As indicated earlier, quartz monzonite does have a sharp contact with pyroxene syenite, but this is not sufficiently definitive to resolve the above question. It is clear from several modal analyses that an antipathetic relationship exists between pyroxene and quartz, thus suggesting a common parent.

Modes of three pyroxene monzonites from the south and east border facies range between the following limits: plagioclase, 20-29 percent; alkali-feldspar, 42-45 percent; pyroxene, 22-31 percent; quartz 0.5-5 percent; opaques (mostly magnetite) 1-6 percent; and biotite 0-0.1 percent. Plagioclase is found as subhedral laths from 1-5 mm in length with oscillatory and normal zoning common. The compositional range of plagioclase is from An_{24} to An_{45} with an average of about An_{32}. Alkali feldspar occurs as stubby carlsbad twins in the groundmass and sometimes as a narrow rim around plagioclase phenocrysts or as a micrographic intergrowth with quartz. Subhedral neutral-gray augite grains range in size from 0.05 mm to 2 mm in diameter and average about 0.3 mm. Biotite and apatite sometimes occur in trace amounts.

The modal analysis of sample 1-80 shown in Table 1 appears to be representative of quartz monzonites which occur mainly along the west and southwest margin of the stock. Pyroxene ranges from about 0.5 to 5 percent with the presence or absence of uralitic hornblende (formed at the expense of pyroxene) as the primary cause of this variation. The quartz monzonite is distinctly porphyritic in comparison to the pyroxene monzonite. Plagioclase phenocrysts as much as 2 cm in length comprise about 10 to 25 percent by volume; anorthite values measured for 8 grains averaged An_{37}. Rims of alkali-feldspar around plagioclase are more abundant than in the pyroxene monzonites. The $2V_x$ of one groundmass crystal of alkali-feldspar in sample 1-80 was measured to be 80 degrees, eliminating anorthoclase. Quartz occurs as grains in the interstices of the groundmass orthoclase. Traces of rutile and sphene appear as late-stage crystals in association with quartz.

A histogram illustrating the distribution of plagioclase compositions in border facies rocks (excluding syenites) is shown in Figure 12. The distribution appears to be bimodal

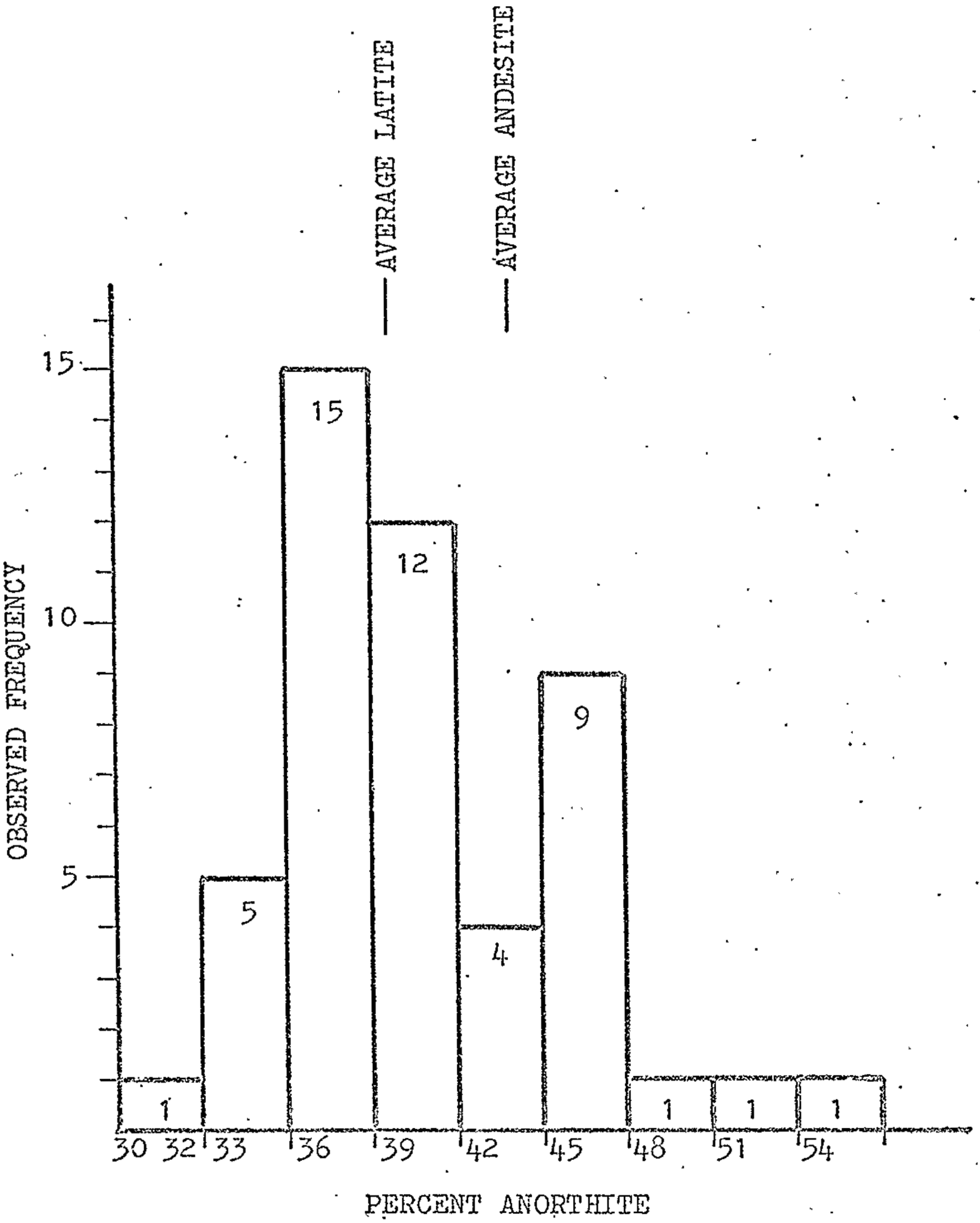


Figure 12. Frequency diagram of anorthite content for 50 plagioclase phenocrysts in 9 samples of border facies rocks of the Tres Montosas stock. The distribution is suggestive of a bimodal population.

but more measurements are needed to be sure. A bimodal distribution would suggest a multiple intrusion origin. As might be expected, plagioclase in border rocks with an aphanitic matrix have high-temperature optics. However, granodiorites (1-88 and I-13) and monzonites (1-80 and TM-27), also contain high-temperature plagioclase phenocrysts (10 checked) some of which are in association with orthoclase. It is assumed here that most border facies rocks in the Tres Montosas Stock contain high-plagioclase. Reference to the occurrence of high-temperature plagioclase in the chilled borders of epizonal stocks and batholiths has been made by several authors (Tuttle and Bowen, 1958, p. 116; and Cater, 1964, p. 45).

The seemingly enigmatic association described above of high-temperature andesine and low-temperature orthoclase may be explained by late-stage deuteric alteration of plagioclase to orthoclase. The catalytic effect of water is probably the critical factor in allowing the formation of orthoclase as opposed to sanidine. Experimental data (Donnay, 1960, p. 173) indicates that the rate of cooling and catalytic effects of water are the dominant factors controlling the transformation from high-temperature to low-temperature feldspar. The temperature of crystal growth does not appear to be a critical factor. Cater (1969, p. 42) has also observed similar late stage potassic metasomatism in labradorite granodiorites and quartz monzonites of the Cloudy Pass epizonal batholith in the Northern Cascade Mountains. He cites Kennedy (1955) to explain the phenomenon by the "upward migration of alkali-rich solutions...should concentrate alkalis in the upper parts of intrusions where they could crystallize as orthoclase and other alkali-rich minerals." In support of this conclusion, the hedenbergite-orthoclase syenite (samples BJM-4 and 1-79), which is clearly of metasomatic origin, also contains relict cores of high-temperature andesine. Boone (1962) has observed similar relationships in a composite pluton in Maine. However he suggests that "potassic enrichment" may also occur by volatile diffusion in the magma itself prior to complete crystallization.

Leucocratic granite and granite porphyry form the central core of the Tres Montosas Stock. Granite has been observed cutting monzonite near Evans Tank (Wilkinson, in preparation). In addition, float of fine-grained aplitic granite was found on the poor exposure of latite east of Pine Well suggesting an intrusive relationship for granite exists there also. The largest outcrop of medium- to coarse-grained granite occurs just south of Pine Well. Textures vary from hypidiomorphic to allotriomorphic granular and from equigranular to coarsely porphyritic. Chalky pink orthoclase phenocrysts as much as 3 cm in length comprise about 15 to 25 percent of porphyritic specimens. A fine-grained porphyritic granite, found as abundant float north of Pine Well (sample I-14), is unusual in that the large phenocrysts of alkali-feldspar are sanidine instead of orthoclase. Minerals identifiable megascopically in the granites are: pink orthoclase, smoky quartz, some chalky white plagioclase, and sparse hematite, limonite and hornblende. Most of the limonite is pseudomorphic after pyrite.

Modal analysis of sample 1-46 (Table 1) is fairly representative of granites of the central core. It is a medium-grained equigranular rock. The proportion of orthoclase in porphyritic granites increases by as much as 10 percent over equigranular rocks but the sum of orthoclase and quartz in all specimens remains approximately constant at 95 percent. In thin section, plagioclase is difficult to recognize because it exhibits a very fine albite twinning. Even in grains oriented with the (010) nearly perpendicular to the section the albite twinning may be overlooked. The combined Rittmann zone – $2V_z$ method indicates that plagioclase of the granites is low-temperature oligoclase ($2V_x = 85° \pm 2°$, $X' \wedge 010 = 17°$). The composition of 6 measured grains ranged from An_{28} to An_{36}. Orthoclase is consistently clouded and occurs as anhedral to subhedral grains. Late stage granophyric masses of orthoclase and euhedral quartz are common. Optic axial angles of orthoclase ranged from $2V_x = 65°$ to 75°. The 2V's of sanidine phenocrysts in sample I-14 have a wide variation; $2V_x = 22$, 33 and 38 degrees suggesting a range in Or content of 45 to 85 percent (Fig. 2 appendix). This wide range in apparent composition is probably invalid and suggests that other factors are playing a part in controlling the axial angles of these alkali feldspars. Varying degrees of triclinity and unmixing are two such factors. Another important aspect of this rock is the presence of orthoclase in the groundmass and as irregular mantles about the sanidine. This observation shown in Figure 13 suggests that the catalytic effect of

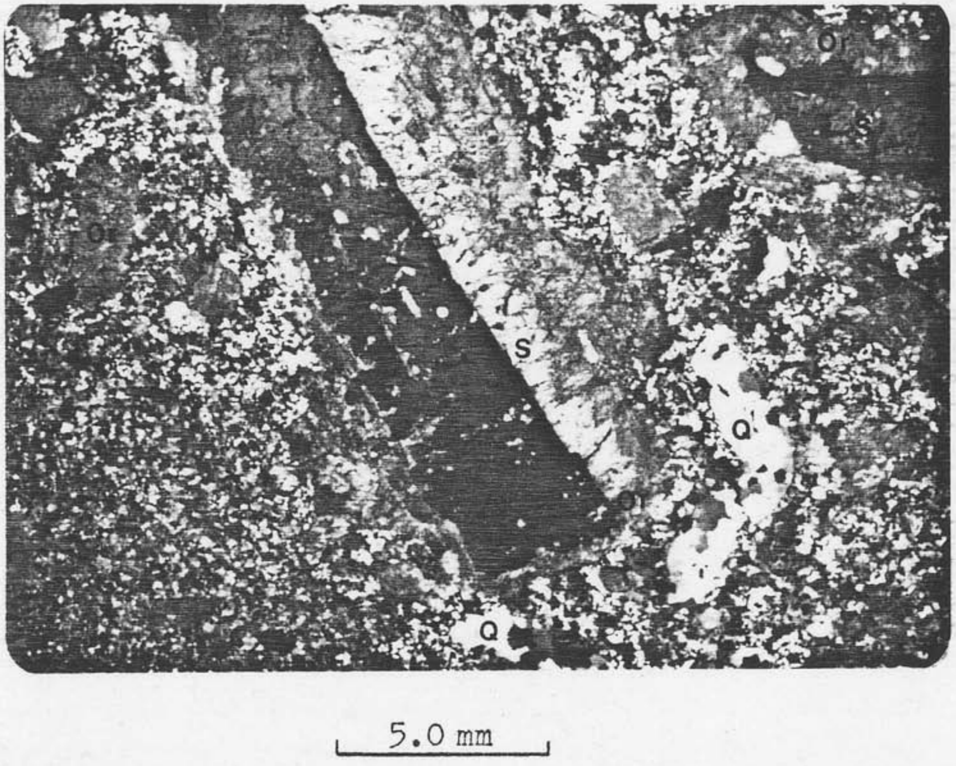


Figure 13. Sanidine granite porphyry (I-14) of the central core in the Tres Montosas stock. Orthoclase is 'replacing' sanidine as irregular rims around the larger phenocrysts. Note the elongate xenolith of quartzite warped around the large sanidine phenocryst. S, sanidine; Or, orthoclase; Q, quartz. Crossed nicols.

water vapor is of critical importance in the inversion of sanidine to orthoclase.

Quartz occurs in several forms in the granites. Single grains from 0.05 to 2.0 mm are common in anhedral forms. Granophyric quartz is well developed in the more porphyritic varieties. Quartz may also occur as quartzite xenoliths which are clearly being resorbed by the melt (Fig. 13).

Rutile microlites, mostly associated with late stage quartz, are common to all the granite samples. Ilmenite and leucoxene are found in samples from the west center of the pluton. Traces of biotite, hornblende and limonite were also noted.

Strong argillic (?) alteration of orthoclase and plagioclase is widespread in the granitic rocks. The relationship of minor amounts of pyrite to this process is not clear. The intensity and distribution of this alteration suggest a deuteric origin.

Hedenbergite syenite at the Big John mine and along the west margin of the stock display several lines of evidence for ferro-potassic metasomatism. Magnetite in veinlets as much as 5 cm thick and in disseminated grains comprises 5 to 25 percent of rocks by volume on the Big John dump. Dark green hedenbergite occurs as a peripheral mineral around magnetite veins and randomly in the host rock as anhedral grains averaging about 0.3 mm across. In thin section, the texture of the rock is a "classic" allotriomophic granular. As illustrated in Figure 14 minor amounts of high-temperature andesine are found as cores of

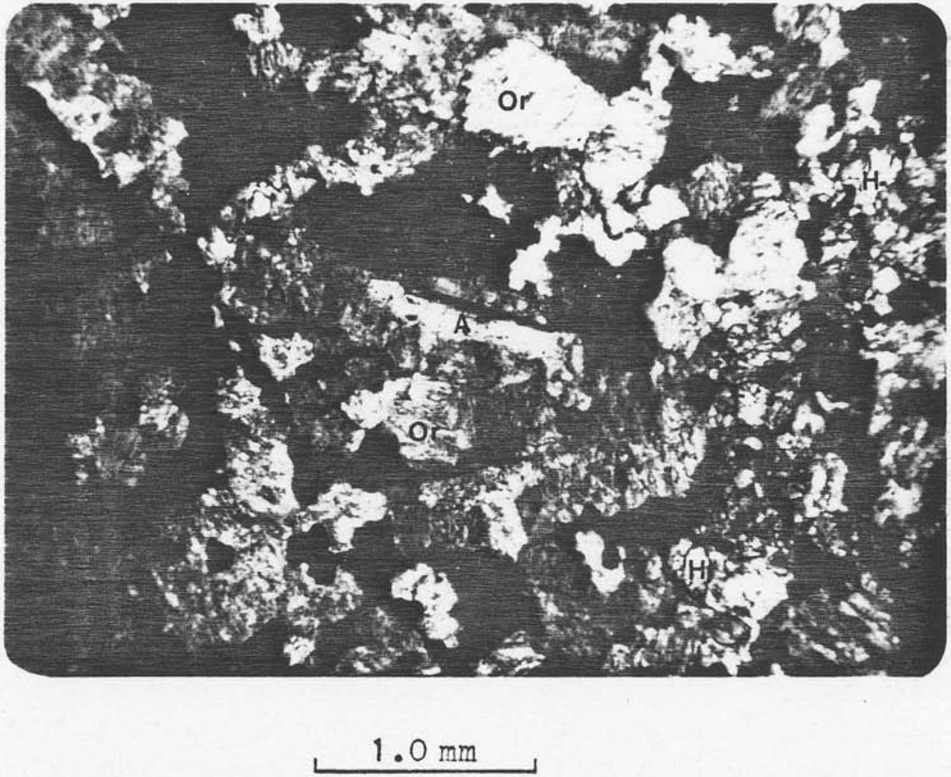


Figure 14. Allotriomorphic-granular hedenbergite syenite (BJM-4) from the Big John mine--Tres Montosas stock. Note the large anhedral orthoclase crystal at the center which has a core of high-temperature andesine. Or, orthoclase; A, andesine; H, hedenbergite. Black grains are magnetite. Crossed nicols.

some of the larger orthoclase crystals. In some cases carlsbad twin planes remain common to the plagioclase and the secondary orthoclase.

Contact metamorphism and metasomatism is evident as a wide aureole of hornfelsed wall rocks about the Tres Montosas stock. Vitroclastic textures in ash-flow units have been recrystallized to a very-fine-grained granoblastic (granular) mixture of alkali feldspar and quartz recognizable in hand specimen as a dull to waxy gray appearing groundmass. Ubiquitous very-fine-grained biotite formed at the expense of magnetite is common to wall rock samples taken from within 500 feet of the contact.

An amygdaloidal "turkey track" andesite, (sample SR-11) has recrystallized to a spotted hornfels and is especially revealing as to the conditions of metamorphism. Fine-grained biotite which permeates the groundmass of this rock is indicative of potassic metasomatism since it is unlikely that there was sufficient potassium in the original rock to form this much biotite. Two types of crystallization centers are recognized by different mineral assemblages in concentric zones about the centers. From the center outward the assemblage:andradite, wollastonite, ferrosalite (Fig. 3B appendix), diopside, magnetite, biotite is inferred to have originated from recrystallization of hematitic calcite amygdules common in this unit at other localities. The assemblage diopside, idocrase and rutile, oligoclase, magnetite, biotite has probably crystallized from titaniferous ferromagnesian phenocrysts. Zone relationships and the different assemblages are shown in Figure 15. The mineral assemblages listed above are indicative of upper hornblende-hornfels to pyroxene-hornfels facies (Winkler, 1965, p. 59) equivalent to a minimum temperature of about 550° ± 20 °C at 250 bars (1 km depth). Another sample of the "turkey track" andesite (SR-12) was collected approximately 3500 feet from the eastern contact of the stock. Resinous brown garnet and calcite are visible in hand specimen filling round vesicles. Seen in thin section, epidote occurs as a concentration of bladed crystals about the perimeter of the amygdules. Pyroxene phenocrysts (?) are replaced by epidote and chlorite. This assemblage is indicative of the albite-epidote hornfels facies which begins at 380° ± 10 °C at 250 bars.

Petrogenesis. The close association of high-temperature and low-temperature feldspars in the same rocks, along with other petrographic data and field relationships can now be interpreted in terms of the magmatic history of the Tres Montosas stock. There are several magmatic and closely associated processes by which an intrusion may achieve its final make up. Processes such as: differentiation, progressive contamination and (or) assimilation, deuteric alteration, metasomatism and single intrusion versus multiple intrusion are evaluated here in regard to their importance in the formation of the Tres Montosas stock. Differentiation is here subdivided into two processes: crystal settling and (or) zoning, and diffusion of an alkali-rich vapor phase.

The Tres Montosas stock is probably a rare specimen of

5.0 mm

Figure 15. Spotted hornfels (SR-12) after amygdaloidal "turkey track" andesite of the Spears Formation. Two types of crystallization centers are recognized: (A) after calcite amygdules, and (B) after ferromagnesian phenocrysts. The light brown tint of much of the groundmass is created by very-fine-grained biotite. Nicols inclined at 70 degrees.

a magmatic product in which traces of the original reactants are found. The writer does not pretend that the interpretation which follows is completely documented nor applicable to all magmatic environments. However, I believe that the Tres Montosas stock is a critical exposure of a rapidly crystallizing pluton in which hypabyssal magmatic processes are evident because they were "frozen" before the processes could be completed.

A model of the magmatic history of the Tres Montosas stock which summarizes conclusions reached earlier in this section, and in other sections of this report, is as follows:

1. The parent magma, alkali (?) andesite, (p. 82) was intruded to a shallow level, probably less than 500 feet from the top of the volcanic pile (p. 58).
2. Volcanic plagioclase and granophyre in the border facies (p. 62,67) indicate crystallization of these rocks must have been extremely rapid.
3. Even though crystallization was rapid, components of alkali feldspar were also being rapidly introduced by an aqueous vapor phase (p. 67). This process began prior to complete crystallization as indicated by rims of orthoclase mantling phenocrysts of high andesine in monzonites (and latite dikes) sometimes in association with euhedral orthoclase microlites in the groundmass (p. 65).
4. Enrichment of the magma with potash continued past the time of complete crystallization. Both wall rocks (p. 73) and border facies rocks (p. 75) were

metasomatized by a potash-rich aqueous phase.

5. Contacts within border facies rocks (p. 59), cross-cutting relationships (p. 62, 68), and the distribution of plagioclase compositions (p. 66) all suggest multiple intrusion. However, the range in plagioclase composition (p. 60, 65, 69) for border facies rocks also suggests that fractional crystallization played a less important role in the development of the major rock types than did aqueous diffusion.
6. Contamination of the melt occurred adjacent to some less indurated wall rocks but the presence of andesine rims around xenocrysts of oligoclase (p. 64) indicates there was little chance for assimilation.
7. Crystallization began at the border and moved towards the core. The granitic core crystallized last with relatively high water pressures being the dominan factor in the inversion of high-temperature feldspars to low-temperature plagioclase and orthoclase (p. 69). That these minerals crystallized initially as high-temperature phases is indicated by the presence of sanidine in some granites (p. 69).
8. The granite core either formed in situ by the action of the aforementioned process of alkali enrichment or by later intrusion. Evidence for fractional crystallization is lacking. Plagioclase is unzoned and similar in composition to monzonites of the border facies rocks (p. 69). Thus formation in situ by "aqueo-alkali" enrichment appears to be

a likely process. Floating of quartz xenoliths derived from quartz-rich wall rocks at depth may be a major source of quartz in the granite (Chapin and others, in preparation).

The role of water in the differentiation of magmas has been discussed by several investigators. Kennedy (1955) presented a detailed theoretical discussion of its importance and Orville (1963) added some experimental data in the system: alkali feldspars, alkali chlorides, and water. Orville (1963, p. 201) concludes that "alkali metasomatism will take place in the presence of an alkali-bearing vapor phase as a natural consequence of temperature, pressure and compositional gradients in the Earth's crust". Several authors have reported evidence of this process in the field (Cater, 1969; Boone, 1962; Anderson, 1948). Boone (1962, p. 1474) stresses the point that the source of potassium in this processes is the magma itself. Boone (p. 1452) also points out that one of the major unknowns is the rate of this diffusion process. Qualitatively, the Tres Montosas stock indicates that the upward diffusion of an "aqueo-alkali" phase towards the top of a magma chamber is relatively much faster than liquid-solid fractionation processes.

Post-Oligocene Rocks

Tertiary-Quaternary Gravels

Two types of volcanic-rich fluvial sedimentary rocks and gravels are recognized in the study area although undifferentiated on the geologic map. The older type is found in fault contact with Oligocene volcanic rocks at Council Rock and east of the Tres Montosas stock. It consists of moderately-well-cemented, pink-to-tan, sandstones and conglomerates. The conglomerates contain abundant sub-rounded clasts recognizable as derived from the A-L Peak and Hells Mesa Formations. Many clasts are hydrothermally altered. Andesitic rocks form a very minor volume of the clasts.

Excellent outcrops of this series are found in the southernmost tributary of the Council Rock Arroyo. Bedding in these rocks dips to the west at about 10 to 15 degrees. This dip must be related to rotational movement of basin and range fault blocks since pebble imbrications indicate that the direction of sediment transport was to the east-southeast. An angular unconformity between these rocks and younger pediment gravels is assumed.

Outcrops of block-faulted pediment gravels occur in a narrow graben trending northeastward from the Tres Montosas stock. This structure is one of the few indications of northeast-striking basin and range faults in the study area. Outcrops of pediment gravels also occur on the down-faulted side of transverse faults about 1½ miles south of Gallinas Springs. For this reason a Miocene or younger age is inferred for these faults.

Large cobbles of magnetite are abundant in gravels at the east end of the narrow graben described above. Their source is inferred to be in contact metasomatic iron deposits of the Tres Montosas stock such as found at the Big John mine. A few boulders of granitic rocks associated with the magnetite help confirm this source. It is assumed that these gravels represent alluvial fan deposits at the mouth of a steep, structurally controlled northeast-flowing drainage.

The younger gravels have low primary (?) dips of about 5 degrees which are generally to the east in agreement with sedimentary transport directions. Younger gravels are recognizable by their onlapping relationship to outcrops of Oligocene units and by abundant rinds of white caliche on cobbles weathered out as float. The dominant lithology of clasts is generally the same as that of nearby outcrops of bedrock.

Tertiary-Quaternary Basalt

Olivine basalt occurs as dikes and flows cutting and capping pediment gravels in the thesis area. Council Rock is the northern extension of the longest dike in the area which trends north-northwest over a length of about 1½ miles. The basalt dikes have two major trends: north to north-northwest and northeast. The greater portion of the only northeast-trending dike in this vicinity crops out just east of the study area. It is exposed from its west end (northeast of Iron Mountain) northeastward for a distance of about 3000 feet. Another series of basalt dikes occur in en echelon pattern along a northerly direction in an area southwest of Iron Mountain.

The basalts have not been dated but are assumed here to be Pliocene. Several outcrops of nearly horizontal basalt flows of similar composition and occurrence have been mapped by Chapin (oral commun., 1972) on the Magdalena Plain southeast of Tres Montosas. Olivine basalt flows of this type have been informally termed the basalt of Council Rock by C.E. Chapin for their only known source area.

Hand specimens range from dark gray to black in color and are dense to vesicular. Fine grains of reddish-brown iddingsite, pseudomorphs after olivine, are the only phenocrysts readily visible and comprise 2 to 3 percent of the rock. Vesicular specimens may contain amygdaloidal calcite. Viewed under the microscope, labradorite is evident as the major phenocrystic phase (~10 percent). Plagioclase phenocrysts 2 to 5 mm in length, are normally zoned; one measured An_{61} in the core to An_{48} at the rim. Olivine also exhibits zoning which appears to be oscillatory. Olivine phenocrysts, mostly altered to iddingsite, range from 0.3 to 1.5 mm across and appear to be magnesium rich (Fo_{90}, $2V = 90° \pm 2°$). Sparse neutral-gray clinopyroxene also occurs as phenocrysts. Optical data ($2V_z = 50° \pm 2°$, $Z \wedge C = 38°$) indicates this is endiopside. Groundmass textures are predominantly trachytic to intersertal with andesine (An_{46}) the dominant phase. Granular minerals, iddingsite, clinopyroxene and magnetite, comprise about 25 percent of the matrix.

Kuno (1959, p. 45) has observed that strongly zoned Mg-olivine, titaniferous-augite, diopsidic-augite and the absence of reaction coronas around olivine are characteristic of alkali-olivine basalts. Basaltic andesites and andesites of the Spears Formation, A-L Peak Formation, andesite of Landavaso Reservoir and the Tres Montosas stock and the basalt of Council Rock all possess one or more of these ferromagnesian minerals characteristic of an alkalic parent magma. Ferromagnesian minerals characteristic of tholeiitic basalts (Kuno, 1959, p. 42) were not observed in any rocks of the study area. Therefore the writer tenatively proposes an alkalic parent magma for the "Datil" volcanic rocks. Lipman and others (1970, p. 2347) indicate an alkalic parent magma for volcanic rocks of the San Juan Mountains based on numerous chemical analyses. Proof of a similar magma genesis for the Datil volcanic field awaits sufficient chemical analyses.

Quaternary Deposits

Talus and Colluvium. A few small deposits of coarse angular debris derived from mass wasting were mapped in the study area. Such deposits occur at the base of cliff-forming units such as the Hells Mesa Formation, tuff of Nipple Mountain and a latite porphyry plug. The rarity of these deposits is attributed to the low relief in the area. The two larger deposits occur where resistant units, underlain by weak units, are cut by major drainages. Soil and vegetation help stabilize the upper portions of these deposits. A Pleistocene to Holocene age is inferred.

Eolian Sand. A thin veneer of wind-blown sand blankets most of the southwest quadrant of the thesis area. Prevailing winds and the distribution of these sands indicates their source is in the dry bed of a Pleistocene lake, now known as the Plains of San Augustin. The eolian sands are clearly discernable on aerial photos as light gray areas dotted by large trees (Ponderosa pines). Shallow ground water available in these sands is evidently capable of supporting thick stands of Ponderosa. A Pleistocene to Recent age is inferred for the eolian sands.

Alluvium. Recent stream gravels filling major drainages are here grouped under the title of alluvium. Weathered, dark-gray soils of probable Pleistocene age, also found as valley fill, are grouped with the coarser materials found in stream beds. Their age is contemporaneous in part with that of the eolian sand.

Petrogenesis of Oligocene Igneous Rocks

Brown (1972, p. 74) has presented a genetic model with regard to the crystallization history and mode of eruption for two major ash-flow sheets in the Magdalena area: Hells Mesa Formation (tuff of Goat Spring) and A-L Peak Formation (tuff of Bear Springs). The writer proposes that compositional data for feldspars in volcanic rocks of the study area and conclusions of a petrogenetic nature reached in earlier sections of this report can be used to make additions to Brown's model.

The use of coexisting plagioclase and alkali feldspar pairs in igneous rocks as a geothermometer to estimate the temperature of crystallization has been suggested by Barth (1951, 1962, 1968). In his 1968 publication, Barth provides a graph (p. 306, Fig. 1) by which the equilibrium crystallization temperature of feldspar pairs may be calculated to ± 50°C on the basis of chemical analyses of the feldspars. This writer has used this graph and an extrapolation along with optically determined compositons of feldspar pairs in the Hells Mesa and A-L Peak ash-flow tuffs to indicate a trend of crystallization temperatures for these volcanic units. Accurate estimates of these temperatures are not possible from the available data because of the significant error involved in estimating the composition of alkali feldspar and plagioclase from optical data. As discussed in the appendix (p.125) the probable error for optically determined alkali feldspar compositions in volcanic rock is ± 20 percent Or, and ± 3 percent An for plagioclase. This increases the possible error range for crystallization temperature estimates to as much as ± 225°C.

Crystallization temperatures calculated under the restrictions described above do however suggest a trend in agreement with the commonly accepted relationship, namely that the more siliceous a magma the lower its crystallization temperature. Compositional data and the calculated equilibrium crystallization temperatures of four samples from the Hells Mesa and A-L Peak Formations are listed in Table 2. Because of the large errors involved, the calculated crystallization temperatures should only be interpreted with respect to the trend they indicate and not with respect to their absolute values.

In the discussion of the Tres Montosas stock it was suggested that differentiation of alkali (?) andesite into granite by upward diffusion of a potassium-rich aqueous vapor phase is a very rapid and efficient process. Recently Lipman and Friedman (1974) have concluded from oxygen isotope data

Table 2

Approximate equilibrium crystallization temperature (Tc) for selected ash-flow tuffs in the study area indicated by the two feldspar geothermometer (Barth, 1968) using optically determined compositions of plagioclase and alkali feldspar.

Sample No.	Rock unit	Plagioclase Composition (± 3%)	Alkali feldspar Composition (± 20%)	Tc
	A-L Peak			
1-69	top	An_{12}	Or_{51}	630° ± 150°C
1-30	middle	An_9	Or_{71}	520° ± 150°C
	Hells Mesa			
1-17	top	An_{23}	Or_{37}	850° ± 200°C
1-16	base	An_{28}	Or_{25}	1050° ± 225°C

that compositionally zoned ash-flow sheets in Nevada represent a "major interaction of meteoric ground water and batholith-sized bodies of silicic magma prior to eruption". This important observation, plus conclusions reached in earlier sections of this report and the trend of crystallization temperatures (Table 2) are now combined into the following petrogenetic model for Oligocene igneous rocks in the Magdalena area:

1. Initial magmatic activity began in the mantle with the formation of large volumes of alkali olivine basalt (?) or alkali (?) andesite (Kuno, 1959; Aoki and Oji, 1966).
2. Diapiric rise of this body into the lower crust then followed. Some fractionation occurred before or during the ascent to produce intermediate-composition magmas which were emplaced as batholithic bodies. The surface expression of intrusion was the extrusion of voluminous alkali (?) andesites and derivative latites to form the Spears Formation.
3. At some later time, the rising upper surface of this batholith reached a level of abundant meteoric water (Lipman, 1974) and large volumes of water were incorporated throughout the melt by diffusion. As this occurred, the upper surface probably mushroomed (Thom, 1955) to form a wide, shallow magma chamber which increased the rate of incorporation of water into the relatively dry alkalic magma.
4. As water diffused into the chamber, SiO_2, alkalies,

trace metals, and volatile elements (initially part of the melt) were preferentially partioned into the vapor phase (Kennedy, 1955).

5. In response to a normal pressure gradient the vapor phase moved towards the top of the magma chamber (Kennedy, 1955; Boone, 1962; Orville, 1963). Thus potassium and, to a lesser extent, silica are concentrated near the top of the magma along with the vapor to form vapor-rich alkali rhyolite magma. The magma then started to cool at the top of the chamber in response to the normal geothermal gradient but crystallization was slow to begin because the increasing water content depressed the liquidus temperature (Kennedy, 1955). Thus a marked thermal gradient developed vertically in the magma as a result of the compositional gradient.
6. Crystallization began almost immediately near the base of the chamber because the diffusion of volatiles was removing K_2O and SiO_2 thereby raising the liquidus temperature. Crystal-liquid fractionation then became an important differentiation process in the lower portion of the chamber. However, since crystallization did not begin until much later at the top of the chamber it was not a significant process there.
7. At this point, the latter part of Brown's model (1972, p. 74, part 2, 3 and 4) concerning the mechanisms of eruption of crystal-rich quartz latite and crystal-poor rhyolite is pertinent: In summary they are:

a. Fissures tapped the lower level of the magma chamber resulting in eruption of a relatively hot, (cf. Table 2) crystal-rich, quartz-latite ash-flow sheet (Hells Mesa Formation). Draining of the magma chamber, from this level upwards, produced a compositionally zoned ash-flow that is "upside down" in comparison to most compositionally zoned ash-flows (Lipman and others, 1966; Ratté and Steven, 1964).

b. Later, another set of fissures intersected the upper portion of the magma chamber which permitted the eruption of a relatively cool crystal-poor rhyolite ash-flow sheet (A-L Peak Formation).

c. From time to time the first set of fissures were reopened to permit almost simultaneous eruption of crystal-rich and crystal-poor ash flows.

8. After eruption of the ash-flow sheets, alkali-andesite magmas continued to move upwards into the volcanic pile to form hypabyssal intrusions. In the study area, the Tres Montosas stock, andesitic, latitic and an east-trending rhyolite dike formed at this time. Erosion of the rhyolite dike to different vertical levels has revealed compositional variations indicating strong compositional gradients were renewed in the younger shallow intrusions. It is assumed that events similar to those as stated in steps 1 to 6 of this model were repeated to produce this relationship. The Tres Montosas stock was intruded to such a high level that evidence of the process of alkali-enrichment was "frozen" into the rocks.

STRUCTURE

Regional Structure

A detailed analysis of regional structural patterns in southwestern New Mexico has not yet been reported in the literature. Episodes of at least 2, and probably 3, stages of middle and late Cenozoic faulting are apparent in the study area. Mapping outside the study area indicates additional deformational periods during the Late Cretaceous-early Eocene (Laramide) and in the early Oligocene. Unraveling this complex structural pattern is made even more difficult by the presence of two regional unconformities and a large proportion of surficial cover (Chapin, and others, in preparation). In chronological order, major tectonic events which have taken place in the region (post-Cretaceous) are: Laramide folding and uplift, early Oligocene transverse (WNW) faulting, late Oligocene longitudinal (NNW) faulting, basin and range transverse (NE) faults, basin and range longitudinal (N) faults. The last two overlap in time and space.

According to Hunt (1967, p. 311), the Magdalena region is part of the Mexican Highlands section of the Basin and Range province. The structural framework of this province has long been a topic of contention among geologists. Stewart (1971) summarizes recently available geophysical and geological data. He interprets the basin and range structure as a series of horsts and grabens formed over a plastically extending substratum. Mackin (1960, p. 108) postulates another commonly accepted origin related to tilted fault blocks formed in a tensional environment. Both origins appear compatible with the structure of the Magdalena region. A late Oligocene age (~29 m.y.) for the onset of basin and range faulting in New Mexico is reported by Christiansen and Lipman (1972) and Chapin (oral commun., 1974).

In the Magdalena region, later periods of faulting are overprinted on a Laramide uplift(s?). Erosion in late-Eocene time beveled this uplift to a surface of subdued relief (Chapin, 1971 b, p. 194). The Baca Formation was deposited in an east-trending basin to the north of the study area as a result of this erosion (Snyder, 1971). The Council Rock district is located on the transition between uplift and basin. Locally, an east-northeast trend appears likely for this portion of the uplift; however, this observation is not meant to imply an east-west trend for the uplift. The interpretation that the region is on the broad nose of a wide north-plunging uplift is equally justifiable.

Laramide structures visible to the north on the Colorado Plateau are described as broad, open folds and thrust belts (Kelley and Wood, 1946; Tonking, 1957; Kelley and Clinton, 1960). Most early investigators have attributed these features to regional compression during late Cretaceous and early Tertiary time. Others (Eardley, 1962, p. 402; Mackin, 1960, p. 118; Thom, 1955, p. 369) suggest that the buoyant force of a rising body of magma is also a reasonable mechanism to form broad uplifts. The importance of gravity sliding on the flanks of steep uplifts to produce thrust faults is demonstrated by Pierce (1957).

A major west-northwest-trending fault crosses the Magdalena Mountains at North Baldy and crosses the Gallinas uplift in the vicinity of Highway 60 (Chapin and others, in preparation). Its location on the Gallinas uplift is inferred largely from aeromagnetic and subsurface data. North of the fault, a paleo-topographic high composed of the Abo Formation crops out from beneath the Spears Formation (W.H. Wilkinson, oral commun., 1972). South of the fault, carbonaceous siltstones of Mesozoic or Paleozoic age were intersected in a drill hole (Banner Mining Company) at about 1300 feet (Chapin, oral commun., 1972). Since the Spears rests on pre-volcanic rocks at both localities, an abrupt change in thickness of the lower Spears Formation may be inferred. Continuity in the tuff of Nipple Mountain across the fault implies that most movement had ceased by that time.

The importance of ancient structural trends in crystalline basement rocks should not be underestimated in any structural analysis. Reactivation of zones of weakness in basement rocks by younger tectonism is a commonly accepted concept. Elston (1970) has observed evidence for frequent reactivation of Late Createaceous or older fault zones with a north trend. He notes that volcanic rocks of the Mogollon Mountains are distinctly different from those of the western Black Range and interprets the cause of this difference as a north-trending structural-topographic barrier approximately continous with the Santa Rita/Hanover axis (op. cit., p. A-VI-2). Elston (1973, p. 2260) describes the Mogollon volcanic province as the surface expression of a major mid-Tertiary batholith.

It seems reasonable to the writer that adjustments in the thin crust between the top of such a batholith and the surface would be necessary in response to changes in magma pressure and the additional weight of newly erupted material. Pre-existing basement faults are the most likely places for compensating adjustments to occur. Evidence for faulting contemporaneous with eruption of major ash-flow sheets in the Magdalena area will be discussed under the heading: Oligocene Tectonics.

Local Structure

The relationship of structural trends in the study area to major structures of the Magdalena region is illustrated by Figure 16. Two dominant fault trends are recognized in the study area: longitudinal faults generally trend north (north-northwest to north-northeast) and most transverse faults trend northeast to east-northeast. A minor west-northwest trend is also apparent. Recurrent movement of these fault blocks at different times has produced a complex fault pattern. Strong deformation of wall rocks around the Tres Montosas stock have greatly increased the structural complexity in this area.

Several geologic and topographic features of the Council Rock district, and the Gallinas uplift in general, appear anomalous in comparison to other block uplifts in the Magdalena region. First and most notable of these features is a narrow zone of "grabenward" dipping volcanic strata which follows the east edge of the Gallinas uplift from Abbey Springs to

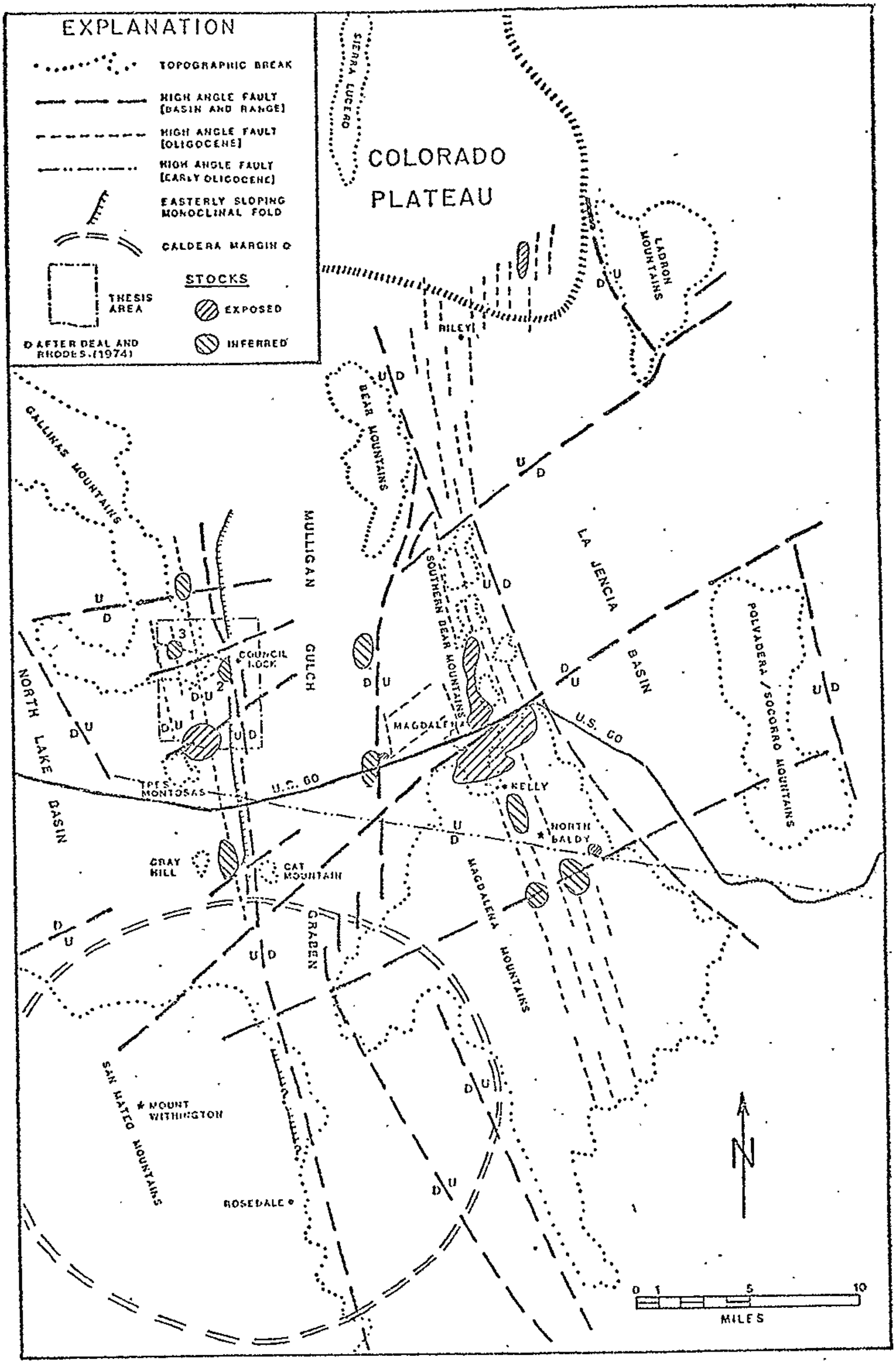


Figure 16. Major structural features in the Magdalena region with respect to thesis area. Exposed or inferred stocks within thesis area: 1, Tres Montosas; 2, Council Rock; 3, Gallinas Springs.

Cat Mountain. Dips range from 30 to 80 degrees in an easterly direction with most dips near 60 degrees. The second of these features is a pronounced structural asymmetry to the Gallinas horst with the structurally highest portion immediately adjacent to the east boundary of the uplift (see structure section D-D' Pl. 1). A third feature is the strong doming of wall rocks around the Tres Montosas stock accompanied by concentric faults downthrown toward the stock and numerous radial faults. Also, vertical to overturned dips occur locally in the area east of the Tres Montosas stock. Fourth, progressively older strata are encountered along a north to south traverse in spite of a regional southerly dip to the units. And finally, topographic relief over most of the uplift is quite small in comparison to its structural relief.

These features suggest a complex deformational history for the area involving many periods of tectonism. However the writer believes they can be interpreted logically as the result of two distinctly different tectonic events. The older may be summarily described as magmatic uplift and intrusion which took place during the middle to late Oligocene. The younger is attributed to block faulting of the basin and range style. Detailed discussion of these events follows.

Oligocene Tectonics

Faulting. Deformation in the form of down-to-the-west, north-trending, high-angle faults began in mid-Oligocene time. Some of this deformation occurred prior to, and (or) concurrent with, extrusion of the Hells Mesa and lower

A-L Peak ash-flow sheets. Evidence for near contemporaneity with eruption of the lower A-L Peak Formation is found in an excellent exposure about one-half mile southwest of Gallinas Springs. As shown by Figure 17, the exposure reveals a vertical fault contact between the gray-massive-member on the east and the chocolate-brown contorted member downfaulted on the west. The age of the fault must be nearly contemporaneous with that of the contorted member since the contorted member is welded to the gray massive-member across the fault. This same fault formed a topographic barrier to easterly flowing basaltic-andesite lavas interbedded in the A-L Peak Formation. Evidence for earlier faulting is found in thickness variations of the Hells Mesa Formation. There are only two localities in the thesis area where depositional upper and lower contacts of the Hells Mesa are exposed to permit an estimate of the thickness. In a vertical-dipping outcrop about two-thirds of a mile northeast of Pine Well the thickness is estimated at 500 feet. From a south-dipping exposure of Hells Mesa at Gallinas Springs the thickness was first estimated at 1200 feet. This value seemed anomalously high and up-to-the-south transverse faults were inferred to be present along topographic breaks. However, even with this assumption the minimum possible thickness is 800 feet. This rapid thickening to the north and west is interpreted here to be caused by down-to-the-west displacement on the Gallinas Springs fault prior to, or during, eruption of the Hells Mesa Formation. Structure sections A-A', C-C' and D-D' illustrate this increase in thickness from east to west. It can not be reasonably assumed

Figure 17. Looking north and down on a vertical fault contact between the gray-massive member (right) and the contorted member (left) of the A-L Peak Formation. The downfaulted contorted member is welded to the gray-massive member indicating the fault formed shortly after, or during extrusion of the contorted member.

that the entire 300-foot decrease in thickness took place across a single structural and topographic high. The abrupt change in thickness across the Gallinas Springs fault, as shown, is probably an over simplification. The Hells Mesa Formation is extremely resistant to weathering and is an excellent cliff former in the Bear Mountains and Northern Gallinas Mountains. The Hells Mesa forms high peaks at Tres Montosas and Gallinas Peak both to the west of the Gallinas Springs Fault. To the east, the Hells Mesa forms low, rolling hills in the vicinity of Council Rock. An abrupt thinning across the Gallinas Springs fault may contribute to this change in topographic expression.

An Oligocene age is also inferred for faults intruded by mafic to rhyolitic dikes. These dikes are related to unexposed stocks inferred to be similar in composition and age to the Oligocene Tres Montosas stock. Two dike trends are recognized: N 10° W to N 20° W, and N 75° W to S 70° W. All but one of the north-trending dikes occur in down-to-the-west faults. Dips on these dikes are all nearly vertical and whether they represent normal or reverse faults is a moot question. Evidence for later movement along these faults was observed in only one case. Reconnaissance traverses to the west of the study area indicate that high-angle faults downthrown on the west are a consistent pattern across the Gallinas uplift. Some of these may be related to basin and range faulting associated with the North Lake graben.

Transverse rhyolite dikes are probably related to local stresses developed over the back of a large felsic intrusion extending along a similar trend from Council Rock to one mile southwest of Gallinas Springs. Up-to-the-south northeast-trending transverse faulting of Oligocene age at the latitude of the Tres Montosas stock also seems necessary. This conclusion is based on the fact that the stock intrudes the Spears Formation around the south margin but intrudes the A-L Peak Formation on the northwest at approximately the same elevation. Simon (1973, p. 67) cites several localities in the Magdalena area where northeast-striking mid-Oligocene faults have controlled the distribution of the tuff of La Jencia Creek which is interbedded in the A-L Peak Formation.

Brown (1972, p. 84) reports a 25-mile-long Oligocene zone of longitudinal normal faults which was a major factor in the emplacement of the stocks near Magdalena. The Gallinas Springs fault was the most important controlling factor in the emplacement of the Tres Montosas stock and at least three other inferred stocks along its strike (Fig. 16). Intersections of this fault zone with northeast-trending faults of Oligocene age are probably of secondary importance in the location of these stocks. Assuming dip-slip movement on the Gallinas Springs fault, its estimated throw based on strike separation of contacts is 1200 feet. The trend of Oligocene longitudinal faults (average N 10° W) is generally paralled by older (Laramide) and younger (basin and range) structures. Deformation even older than Laramide along this trend is suggested by the presence of bedded sedimentary breccias in an outcrop of the Abo Formation located along the east flank of the uplift (W.H. Wilkinson, oral commun., 1972). From these observations the writer suggests that the N 10°W trend may be a major structural trend in crystalline basement rocks in the Magdalena region. Wertz (1968, p. 279) has used linear trends of intrusions to define the orientation of primary zones of weakness in basement rocks of southeastern Arizona.

Folding. Oligocene volcanic strata consistently dip to the east in a relatively narrow zone along the east flank of the Gallinas uplift from Abbey Springs to Cat Mountain, a distance of about 20 miles. A similar occurrence of east-dipping volcanic rocks in the Big Rosa Canyon area and along the east flank of the San Mateo Mountains (E.G. Deal, oral commun., 1972) may be a continuation of this structure. Volcanic units to the west of this zone have variable dips in a south to southwesterly direction generally within 10 degrees of the horizontal. Oligocene strata are not exposed immediately east of this zone and their attitude must be inferred. A small exposure of approximately horizontal strata of the A-L Peak Formation has been observed by Chapin (oral commun., 1972) about 2 miles southeast of Council Rock. Thus this zone may be interpreted as the crest of an easterly sloping monoclinal fold (Fig. 16). The term hinge line will be used herein as a synonym for monocline.

By a process of elimination, a late-Oligocene age is inferred for the hinge line. The flexure clearly postdates the mid-Oligocene since it deforms rocks of this age. A mid-Miocene, or younger, age for the hinge line is eliminated by the following observations. Basin and range faults, such as the Council Rock fault, closely parallel the hinge line and a genetic tie would seem reasonable by association. Drag along these down-to-the-east normal faults is a possible mechanism to create easterly dips in the strata. However, rapid changes of dip observed in the study area and attributable to drag do not extend more than 500 feet from faults. The hinge line zone averages about one mile in width. Pediment gravels just east of Council Rock have been rotated to a westerly dip of 10 to 15 degrees. This style of rotation of the upper surface of fault blocks away from grabens is recognized by many investigators as a common trait of basin and range faulting. Hence the formation of this flexure is eliminated from basin and range deformation on the basis of tectonic style and the lack of a reasonable mechanism for its formation under conditions of normal faulting.

According to DeSitter (1964, p. 196) "it is probable that all monoclines are related to upthrusts as opposed to normal faults "since in a tensional field it would be very improbable for the surface layers not to be broken by normal faults". He definer upthrust (op. cit., p. 137) as "a high-angle reverse fault" and notes that they are frequent in crystalline basement rocks bordering major uplifts. The presence of this monocline then implies the existence of north-trending basement fractures. Compression or vertical uplift are the only plausible mechanisms by which upthrusts are formed. Mackin (1960, p. 118) stresses the importance of magmatic intrusions as "structure makers" in the Great Basin. As stated earlier, widespread intrusion of felsic magma took place in the study area during late Oligocene. Hence, by association, a late Oligocene age is assumed for the monoclinal fold. Assuming this conclusion to be correct several other observations fit into this pattern:

1. A decrease in the average easterly dip from about 60 degrees to 30 degrees in the area north of Council Rock may be attributed to westerly rotation of the hinge line by the basin and range faults to the west.
2. The greatest intensity of hydrothermal alteration in the study area closely follows the monocline.
3. The absence of La Jara Peak andesite (23.8 m.y., Chapin, 1971 a) on the Gallinas uplift may be attributed to the monocline forming a topographic barrier to westerly flowing lavas.
4. Deep erosion of the Gallinas uplift compared to the Bear Mountains and Southern Magdalena Mountains may be attributed to a relatively long and unbroken erosional history since late-Oligocene time. The inferred origin of this monoclinal fold by magmatic intrusion is shown in Figure 18. If this model is correct, then this fold is the surface expression of a twenty-mile-long, deep-seated pluton with cupola-like extensions that are now recognized as exposed or inferred stocks.

Most other variations of structural dips are minor in comparison to the monocline. As shown in structure section E-E', flat bottomed synclines may be formed where doming by

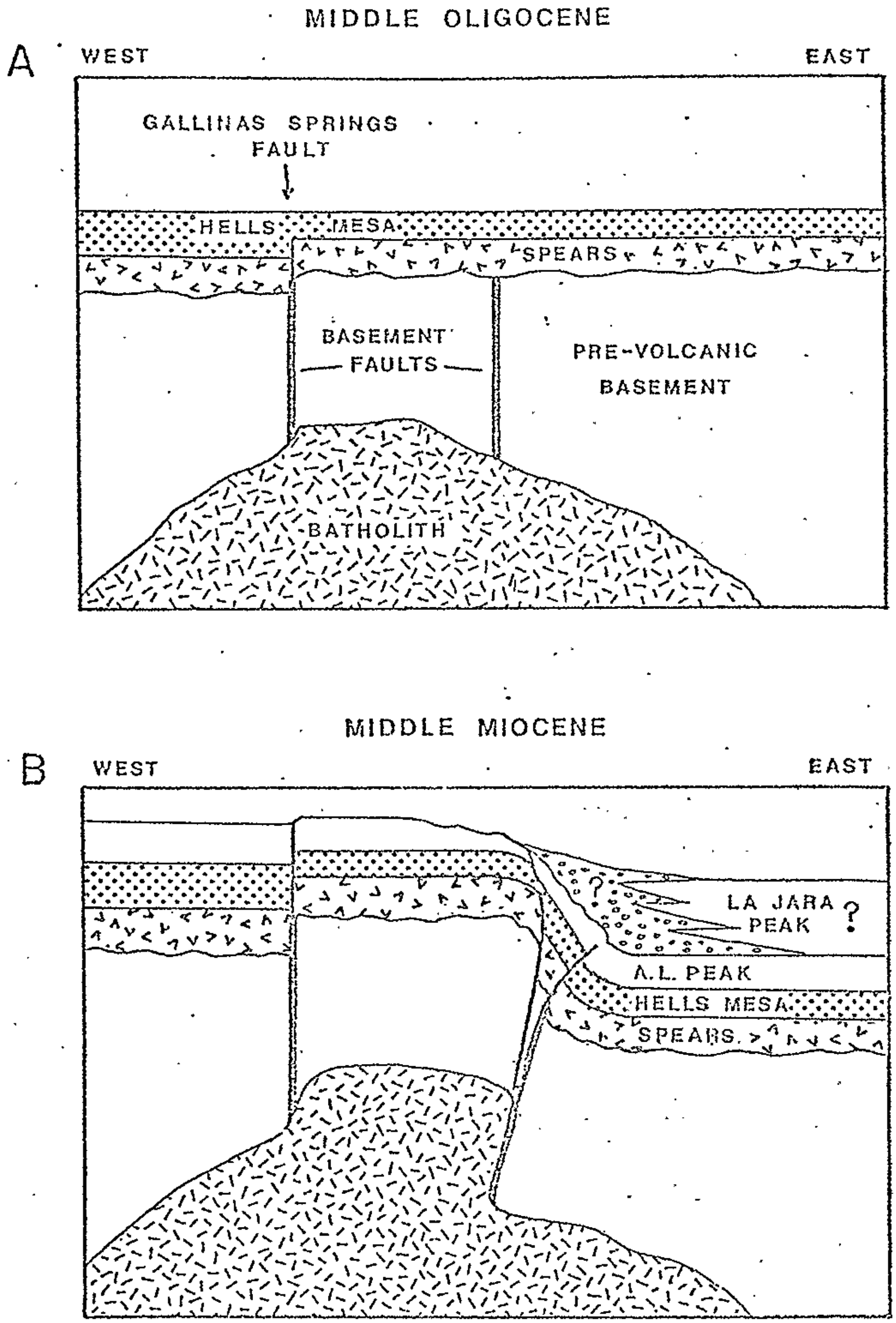


Figure 18. Diagrammatic east-west cross sections at the approximate latitude of Gallinas Canyon illustrating the development of the Gallinas Springs Fault and a monocline produced by magmatic intrusion.

stocks has reversed the regional southerly dip.

Structural Patterns around Stocks. Doming of wall rocks accompanied by radial and concentric faults, is an important characteristic of the Tres Montosas stock and the inferred Council Rock stock. Wall rocks surrounding the Tres Montosas stock are moderately domed with quaquaversal dips ranging from 20 to 40 degrees in a half-mile concentric zone about the perimeter. Vertical to overturned dips in a two square mile area east of the outcrop of the stock are partially attributed to foundering of the roof of the stock (see structure section A-A', Pl. 1) and to exaggeration of easterly dips in strata created by the previously discussed monoclinal fold.

Foundering of roof blocks is common in intrusions which come very close to the surface (Noble, 1952, p. 40). The satellitic latite porphyry plug to the east of the stock is inferred to have filled the void created by a foundered block west of the plug. Evidence for collapse of these roof rocks is circumstantial but convincing. If the outcrop distribution and attitude of units around the porphyry plug were to be explained entirely on the basis of block faulting, then over 5000 feet of down-to-the-west displacement would be required on the north-trending fault located along the east side of the plug. Further north, along the strike of this fault, a displacement of more than a few hundred feet can not be justified. Therefore, foundering accompanied by rotation of the foundered block about a hinge at its west edge is here proposed to explain the outcrop pattern.

Overturned strata at some distance to the north and south of the porphyry plug are probably related to reverse faults associated with magmatic uplift. In most cases the attitude of faults associated with the stock is not revealed in outcrop. Thus, the type of fault can not be inferred even though stratigraphic offsets are known. However reverse faulting is required to justify an anomalously thick interval of upper Spears epiclastic rocks in a drill hole located about one-half mile northeast of the stock (see structure section B-B' Pl. 1). Minor faults filled by quartz veins in the Council Rock area have determinable dips. The stratigraphic offset unmistakably indicates that some are reverse faults.

Arcuate concentric faults, generally downthrown towards the apex of the Tres Montosas stock, have broken the wall rocks into numerous small blocks. The dip of most of these faults and their classification is not known. Flow foliation in a concentrically oriented latite dike, west of the stock, dips 75 degrees toward the stock. Anderson (1937, p. 36) would describe this fracture as a cone sheet formed during doming of the wall rocks. However a cone sheet orientation is not physically compatible for all of the faults downthrown toward the apex of the stock. Most of the concentric faults are assumed to be vertical. This down-to-the-stock pattern of concentric faults is most likely related to the subsidence of magma pressure.

The structural pattern of doming, veins, dikes and faults for the inferred Council Rock stock indicates that the apex of the stock is east of the Council Rock fault. This basin and range fault presumably truncates the stock at depth. Structure section C-C' illustrates the relationship of veins and dikes to the inferred Council Rock stock.

Basin and Range Tectonics

Longitudinal Faults. Normal faulting along a north to north-northwest trend related to the formation of the Mulligan Gulch graben (and the Rio Grande rift) began in late Oligocene or earliest Miocene time (Christiansen and Lipman, p. 259; Chapin, oral commun., 1974). Longitudinal block faulting since the Miocene has been the dominant mechanism in the formation of the several horsts and grabens in the Magdalena area. Longitudinal basin and range faults are well expressed as prominent fault scarps in the Magdalena and Bear Mountains. Figure 16 shows the relationship of these faults to the major structural blocks in the Magdalena region.

In the study area, a narrow zone of down-to-the-east normal faults forms the east boundary of the Gallinas horst. A westward rotation of the older pediment gravels away from the Mulligan Gulch graben is typical of the basin and range style of deformation. Contrary to other localities mentioned above, this fault zone is topographically expressed only by a minor escarpment. The Council Rock fault, longest of this type, extends continously in a north-northwest direction along the entire length of the study area (about 6 miles). South of Arroyo Montosas this fault disappears under pediment gravels and north of Council Rock Arroyo it apparently bifurcates into a conjugate set of faults with a general north trend. The fault probably dies out somewhere between the study area and the Puertecito quadrangle (geologic map of Tonking, 1957, pl. 1). A throw of 800 to 1500 feet for the Council Rock fault is estimated from stratigraphic relationships. Displacement on the fault probably increases toward the south. Short, arcuate down-to-the-east faults which place Hells Mesa tuffs in juxtaposition with the tuff of Nipple Mountain in the area south of Council Rock are interpreted as landslide blocks secondary in origin to the Council Rock fault. North to northwest-trending basin and range normal faults located to the east of the Council Rock fault are recognized only because they are intruded by olivine basalt. A few down-to-the-east north-trending faults which occur near the Gallinas Springs intrusive center are probably Oligocene in age. A basin and range age for down-to-the-west longitudinal faults cannot be proved or disproved. Some movement related to formation of the North Lake graben is assumed, however, most of this movement may have taken place in the North Lake fault zone described by Givens (1957, p. 22). Quaternary movement along north-trending basin and range faults are indicated by fault scarps displacing alluvial sediments along Mulligan Gulch and east of Magdalena.

Transverse Faults. Very little physiographic or geologic expression of late-Cenozoic transverse faulting is evident in the study area. Therefore, the interpretation of these structures made here relies heavily on the observations of other investigators in the Magdalena area. Important characteristics of these faults as described by Brown (1972, p. 86-90) are:

1. A general northeast trend and a left-lateral sense of oblique-slip as determined by offset of dikes in the area east of Magdalena.
2. A structural and topographic low between the Bear Mountains and the Magdalena Mountains attributed to a northeast-trending graben formed by bifurcation of the Rio Grande Rift (Chapin, 1971b).
3. Complex mutually cross-cutting relationships between the longitudinal and transverse basin and range fault systems.
4. Cessation of movement on northeast-trending transverse faults but continued activity along longitudinal faults.

Chapin and others (in preparation) have inferred a maximum age of late Miocene for development of the San Augustin graben. This conclusion is based on field relationships of rhyolite lava flows extruded from a vent on Magdalena Peak which are dated at 14 m.y. (Weber, 1971). These rhyolite lavas must be older than the graben since they do not flow north into its structural topographic low.

Some northeast- to east-northeast-trending faults in the study area have features generally similar to those described above. A late Cenozoic age is implied by the consistent association of pediment gravels deposited on or preserved on the downthrown blocks. Nearly all of the transverse faults are downthrown to the north. This relationship has caused progressively older strata to be exposed at the surface from north to south in spite of a regional southerly dip. A strike separation of the Gallinas Spring fault where cut by a transverse fault northwest of the center of the study area is in agreement with oblique-slip movement but not in a left-lateral sense. Since the true attitude of the Gallinas Springs fault is not known, the suggested strike-slip component may not be real. Alternatively, the apparent horizontal separation could be the expression of up-to-the-south dip-slip movement on the transverse fault if the dip of the Gallinas Springs Fault is eastward.

A major zone of transverse faulting expressed by faulted pediment gravels and a northeast-trending basalt dike passes through the northern half of the Tres Montosas stock. As suggested in Figure 16, this zone may be an extension of the Bear Springs—Deer Springs fault zone described by Brown (1972, p. 88). Evidence for this correlation is based on the repeated occurrence of narrow, northeast-trending-grabens in both fault zones and the fact that a straight-line projection from the Bear Mountains intersects the Gallinas uplift at about the proper latitude. Contrary to this interpretation, however, Brown suggests that these faults change trend to a more south-southwest direction to intersect the Gallinas uplift south of U.S. Highway 60. It is suggested here that either interpretation is reasonable and a solution to this problem must await further data.

ECONOMIC GEOLOGY

The study area is centered about the Council Rock mining district where veins of lead carbonate were mined in the 1880's for their silver content (Lasky, 1932, p. 55). The history of the district is short lived and obscure. The district, originally known as Iron Mountain, is discussed briefly by F.A. Jones (1904, p. 123-125). He states that ore pipes of "hard-carbonate lead-silver ore" were mined as deep as 300 feet. Ore from the Old Boss mine is reported to have averaged $250 per ton. Jones also mentions an iron-bearing vein which was prospected to a depth of 80 feet. The original name of the district was derived by its association with abundant magnetite float in pediment gravels to the southeast of the vein workings. The name of the district was later changed to Council Rock for a townsite erected in the 1880's to the north of the mine workings near Council Rock.

The district is defined here as a ½ mile by 2 mile north-northwest-trending zone of abundant quartz-carbonate epithermal veins (Pl. 1). Some veins are associated with noticeable displacement of stratigraphic contacts and appear to be related to both normal faults and reverse faults. Many appear to have minor displacements as they commonly die out along strike in silicified shear zones. The greatest density of veining and old workings are concentrated in the south part of the district. Two vein trends are apparent, N 10° W to N 45° W and N 30° E to N 60° E. Most of the old working are situated at intersections of these two trends, hence the historical description of "pipe veins" appears accurate. The distribution of veins, rhyolite dikes and hydrothermal alteration as shown on the geologic map infers the presence of an unexposed stock centered to the east of the district.

Veins range in thickness from 2 inches to 5 feet. The wider veins are predominantly white quartz with minor amounts of carbonates. Smaller veins often exhibit alternating bands of barite-siderite and calcite-hematite. Barite-siderite bands are generally coarser grained with white bladed barite crystals up to 1 inch in length separated by a matrix of rhombohedral gray-brown siderite. Hematite in the adjacent bands is black, fine grained and disseminated through the calcite grains, thus imparting an overall black color to the band.

One short vein observed cutting the tuff of Nipple Mountain about a half mile southwest of the Council Rock ranch has a contrasting, rather unusual mineralogy compared to other veins in the district. As shown in Figure 19, it is a breccia-vein containing partially to completely chloritized clasts of the tuff of Nipple Mountain in a matrix of fine grained quartz, hematite and barite. Hematite commonly forms black outlines around the clasts. A crust of light-gray late-stage fluorite is visible along the top of the specimen. Calcite and siderite are notably absent from this vein.

Sulfide minerals were not observed in any of the vein material in outcrop or as float. A trace of malachite was observed but only in dump material. A few cube shaped

Figure 19. Vein breccia collected near the north end of the Council Rock mining district. Clasts of the Tuff of Nipple Mountain are completely altered to chlorite and quartz where a gray color is found. Note the concentration of black hematite which outlines many of the breccia fragments. Quartz, barite and fluorite make up the remainder of vein material.

vugs were observed in quartz veinlets in an outcrop of silicified tuff of Nipple Mountain just north where it is crossed by Council Rock Arroyo. This, and some associated limonite staining, suggest pyrite may have been a sparse component of the veinlets.

The vein mineral paragenesis from first crystallized to last is: microcrystalline quartz, calcite and hematite, barite and siderite, fluorite, drusy quartz. This order of crystallization is generallized and several exceptions were noted in thin section. In some specimens, barite appears to be older than hematite and in others calcite older than microcrystalline quartz.

Circulation of hydrothermal solutions within the district appears to have had a long history. Veining postdates a rhyolite dike to the southwest of Council Rock. Where intersected by quartz veins, the dike has a light green color due to chloritization of the groundmass minerals. Most vein formation apparently took place in late Oligocene time associated with crystallization of the inferred stock centered to the east of the district and later downfaulted by basin and range faults. A northeast-trending, three-foot-thick quartz vein one mile south-southwest of Council Rock is abruptly terminated by a fault interpreted to be secondary to the major Council Rock fault. However this secondary fault also exhibits minor quartz-calcite veining in an open cut about 2000 feet further to the south. This suggests basin and range faulting may have reactivated minor circulation of hydrothermal solutions. Although apparently separated by a distinct interval of time, it does not seem reasonable to separate these mineralogically similar veins into two episodes of mineralization.

Hydrothermal alteration in the Council Rock district has no recognizable overall zonal characteristics. Greater lateral than vertical permeablilty through the stratigraphic units created sharp discontinuities in the alteration pattern. Some minor quartz veins cutting permeable rocks have associated argillic and propylitic alteration which can be directly attributed to the vein mineralization. In agreement with the generally recognized zonal patterns elsewhere, argillic alteration was closest to the veins and surrounded by propylitic alteration (Creasey, 1966, p. 73). In decreasing order of areal extent, propylitization, argillization, pyritization and silicification are the recognized types of alteration in the district. Pyritization is generally confined to outcrops of the tuff of Nipple Mountain. Disseminated pyrite related to fault zones seems to be considerably more abundant in the hinge-line zone to the south and to the north of the district.

The scarcity of sulfide minerals in veins of the district does not rule out the possibility of base-metal sulfides at depth. Mineralization of the same age has formed valuable zinc, lead, silver deposits in the Kelly district only 12 miles to the east. Inasmuch as the Council Rock mining district is located on the buried flank of a Laramide uplift, it is quite difficult to estimate the depth to the favorable Kelly Limestone. A minimum drilling depth to the Kelly of 6800 feet and maximum depth of 12,300 feet is based on the following estimated stratigraphic section: Lower Spears Formation 1200 feet, Baca Formation 0-2000 feet, Mesozoic rocks 0-3500 feet, Permian rocks 3000 feet, Madera Formation 2000 feet, Sandia Formation 600 feet. The existence of moderate doming, and comparison with the level of emplacement of the Tres Montosas stock, suggests that the roof of the inferred stock may be within 2000 feet of the surface.

Magnetite float which gave the Council Rock district its original name "Iron Mountain district" was derived from metasomatic iron deposits along the north margin of the Tres Montosas stock. This conclusion is supported by magnetite mineralization at the Big John mine on the northwest perimeter of the stock. Information provided by W.B. Walsh (written commun., 1972), co-owner of the mine, indicates that production exceeded 200 tons in 1966. Most of the ore was used in the manufacture of high-density concrete for nuclear shielding. Magnetometer surveys indicate that the greatest concentration of magnetite is to the west of the prospect shaft. Samples from the dump indicate a contact metasomatic origin for the magnetite. The host rock is a medium-grained hedenbergite syenite formed by potassic metasomatism of granodiorite porphyry. Traces of pyrite occur along the edges of magnetite veinlets which vary in thickness from 10 cm to 1 mm. Dark-green hedenbergite occurs as massive clots adjacent to veins and as small grains disseminated through the host rock. Some calcite was also found in association with larger masses of pyroxene.

Minor pyritization and silicification of the A-L Peak

Formation are the only expression of hydrothermal activity related to the proposed Gallinas Springs stock. The absence of doming and veining in the area suggests that the roof of the stock is quite deep. Drilling depths to favorable replacement horizons and (or) the stock are very likely uneconomic.

A wide area of propylitic, argillic and pyritic alteration occurs to the east of the Tres Montosas stock. Three possible sources are:

1. the Tres Montosas stock
2. a deep magmatic source connected to the surface by a major upthrust which formed the monoclinal fold (hinge line) bordering the east flank of the Gallinas uplift.
3. an unexposed pluton(s) to the east in the Mulligan Gulch graben (Chapin and others, in preparation).

The Tres Montosas stock can be eliminated since the alteration patterns are not spatially related to it. Choosing between the second and third sources would require subsurface data not presently available. However the semi-continous occurrence of alteration and mineralization along the hinge line zone from Council Rock south to Cat Mountain favors the second source.

CONCLUSIONS

Volcanic strata exposed in the Council Rock district consist chiefly of welded ash-flow tuffs with minor interbedded lava flows and volcaniclastic sediments. Welded ash-flow tuffs of the upper Spears, Hells Mesa and A-L Peak Formations were produced during a major period of latitic to rhyolitic pyroclastic eruptions in the mid-Oligocene. Field and petrographic observations of the Oligocene volcanic rocks in the study area indicate they are very similar to an equivalent section in the Southern Bear Mountains (Brown, 1972). Notable differences occur in cooling breaks of the ash-flow sheets which may, or may not, be occupied by andesite or basaltic andesite lavas. Thin crystal-rich ash flows interbedded in the A-L Peak Formation in the Southern Bear Mountains were not observed in the study area. Field work by several investigators in the vicinity of the study area indicate the La Jara Peak Andesite is not present on the Gallinas uplift (Tonking, 1957; Givens, 1957; Wilkinson, in preparation).

High-angle faults developed during the Oligocene are attributed to crustal adjustments induced by extrusion or intrusion of large volumes of magma. Reactivation of generally north-northwest-trending basement faults began prior to, or during, eruption of the Hells Mesa and A-L Peak ash flows. Topography developed along the Gallinas Springs fault zone is interpreted to be the cause of an increase in thickness from east to west of the Hells Mesa and also for lava flows interbedded in the A-L Peak Formation. A "welded" fault contact between ash-flow units in the lower A-L Peak Formation helps confirm this interpretation. Several exposed and inferred stocks of late Oligocene age occur along the Gallinas Springs fault zone indicating it was a major control in their emplacement.

Intersections of the Gallinas Springs fault zone with northeast-oriented Oligocene faults are of secondary importance in the emplacement of these stocks. Major basin and range northeast-trending faults also intersect these stocks masking the Oligocene faults with the same trend. The north trending stocks are inferred to be extensions of a 20-mile-long pluton which has been intruded into a major basement zone of weakness along the east side of the Gallinas uplift. This intrusion is expressed at the surface by an easterly sloping monoclinal fold which borders the uplift and follows the west side of the Mulligan Gulch graben. Topography developed along this monoclinal fold may have formed a barrier to westerly flowing lavas of the La Jara Peak Formation during their eruption in mid-Miocene time. This would explain the absence of the La Jara Peak Andesite on the Gallinas uplift. Younger basin and range faults which follow the axis of the monocline have down faulted the east limb of the fold.

Stocks extending from this elongate pluton rose to within 1000 feet of the Oligocene surface. Erosion during the Miocene and Pliocene has exposed the shallowest stock, here named the Tres Montosas stock. Unexposed inferred stocks at Council Rock and the area one mile southwest of Gallinas Springs are indicated by felsic dike swarms, epithermal veins, hydrothermal alteration, local structural features and at the location southwest of Gallinas Springs by a central vent for basaltic-andesite lavas.

Geologic events in the development of the Datil-Mogollon volcanic field appear to be similar in petrologic character, timing and absolute age to that of the San Juan volcanic field (cf. Elston and others, 1973; and Lipman and others, 1970). The composition of ferromagnesian minerals in mafic lavas and a few chemical analyses suggests differentiation from alkali-olivine basalt. Compositional variations in the Hells Mesa Formation indicate that it is an "upside down" compositionally zoned ash-flow sheet. A model of ash-flow eruption presented by Brown (1972) is expanded, upon the basis of the petrologic character of the Tres Montosas stock and data from the literature. Lipman and Friedman (1974) report that large quanities of meteoric water were incorporated in silicic magmas before their eruption to produce a compositionally zoned ash-flow sheet in southern Nevada. Kennedy (1955), Boone (1962), Orville (1963) and Cater (1969) have all stressed the ability of an aqueous vapor-phase to fractionate an alkaline magma into a potassic-rich phase at the top of a magma chamber. A model proposed here suggests that incorporation of abundant meteoric water by a large body of alkali-andesite magma was the essential factor in the production of magmas which were later erupted to form the Hells Mesa and A-L Peak Formation. Once water enters the magma system, the melt is rapidly and effectively fractionated, by a process of "aqueo-alkali" diffusion, into strongly zoned, gas-charged silicic magma.

The process may be described by two related chains of events which take place at different levels in the chamber:

1. Because of pressure gradient the aqueous vapor phase diffuses toward the top of the magma chamber and is concentrated there. Components of alkali feldspar and to a lesser extent quartz are strongly partioned into the vapor phase during the diffusion process to form a low-silica, alkali-rhyolite magma at the top of the chamber. Normal thermal gradients tend to cool the magma but crystallization occurs very late because of the effect of high water content on the liquidus temperature.
2. An approximately opposite chain of events occurs at some lower level in the magma chamber. Although enriched in potassium and silica relative to its original composition, the magma is undersaturated with respect to water and crystallization begins much earlier. As crystallization becomes dominant, so do the liquid-crystal fractionation processes. Together these processes form a crystal-rich quartz latite magma which crystallizes at a much higher temperature than the rhyolite because of significantly lower water content and more mafic composition.

Petrologic observations of the Tres Montosas stock help to confirm this model. The variation in composition of feldspars and their structural state indicate that much of the stock crystallized rapidly with little time for the relatively slow process of fractional crystallization to be effective. However, the stock exhibits a wide range in composition from andesite to granodiorite, to monzonite (quartz and pyroxene), to leucogranite. Rapid crystallization has "frozen" the process of aqueous-potassic enrichment in the border facies rocks so that its effect may still be seen. Phenocrysts of high-temperature andesine enveloped by low-temperature orthoclase are an expression of this process. The concentration of a potash-rich aqueous phase continued throughout the entire crystallization of the stock. This resulted in the formation of a leucogranite core. Although the granite core could be due to another intrusive event there is no indication that it is a "normal" differentiate of the original alkali-andesite parent magma. Plagioclase in the granite is approximately the same composition as that of monzonites in the border facies although of the low-temperature structural variety.

Unexposed stocks at Council Rock and near Gallinas Springs are favorable targets for base-metal sulfide mineralization. The scarcity of sulfides in the Council Rock veins does not eliminate the possibility of replacement or porphyry-type sulfide mineralization at depth. Because the Council Rock mining district is located on the buried flank of a Laramide uplift, the estimated depth to the favorable Kelly Limestone is between the wide limits of 6800 feet to 12,300 feet. Doming and comparison with the level of emplacement of the Tres Montosas stock suggests the roof of the Council Rock stock may be within 2000 feet of the surface. Hematite and siderite are abundant constituents of the epithermal quartz veins at Council Rock. This suggests they may be related to a hydrothermal system at depth similar to that which produced contact (?) metasomatic magnetite mineralization at the Tres Montosas stock. Field relationships around the inferred Gallinas Springs stock indicate the depth to possible mineralization is much greater than that which is presently economically feasible to develop. The occurrence of semicontinous hydrothermal alteration and mineralization in the hinge-line zone (monoclinal fold) from Council Rock to Cat Mountain favors a deep magmatic origin for the hypogene solutions which produced these features.

Basin and range faults, both longitudinal and transverse, follow trends similar to these of earlier Oligocene faults. The close association of the Council Rock fault and the monoclinal fold is attributed to reactivation of the same zone of weakness which controlled formation of the monocline. Overlapping of the longitudinal and transverse faults in space and time has produced a complex fault pattern which is overprinted on the Oligocene structures. Block faulting of the basin and range type first produced a series of north-northwest-trending grabens and horsts. Later branching of the Rio Grande rift to form the San Augustin plain produced an overlapping set of northeast-oriented grabens and horsts. Erosion of these horsts since early Miocene time, with concurrent deposition in the grabens, has produced abundant surficial cover. Pediment gravels in the Mulligan Gulch graben are dominantly derived from the Gallinas uplift. Late Pliocene or Quaternary faulting is expressed by olivine basalt dikes which cut pediment gravels at Council Rock.

APPENDIX

Optical Determination Methods

The composition and structural state of plagioclase were determined with a 5-axis universal stage using the Rittmann zone method (Rittmann, 1929) in combination with 2V angles measured by standard extinction techniques on the universal stage (Emmons, 1943, p. 23-41). J.R. Smith (1968, p. 1191) indicates that the differing nature of variations in 2V with composition for high- and low-temperature plagioclase can be used to identify the correct structural state if the composition of the plagioclase is known. However, this method fails in the composition ranges An_{40} to An_{60} and from An_{90} to An_{100} because of nearly equal 2V values in these intervals. Other methods to distinguish high- and low-temperature plagioclase are described by Slemmons (1962), and Rittmann and El-Hinnawi (1961). These methods employ the measurement of angles between crystallographic axes and the optic indicatrix which involves complex procedures and is complicated by many ambiguities.

The combined Rittmann zone — $2V_z$ method used here to determine the structural state of plagioclase is a modification of that suggested by J.R. Smith (1958). The procedure is as follows:

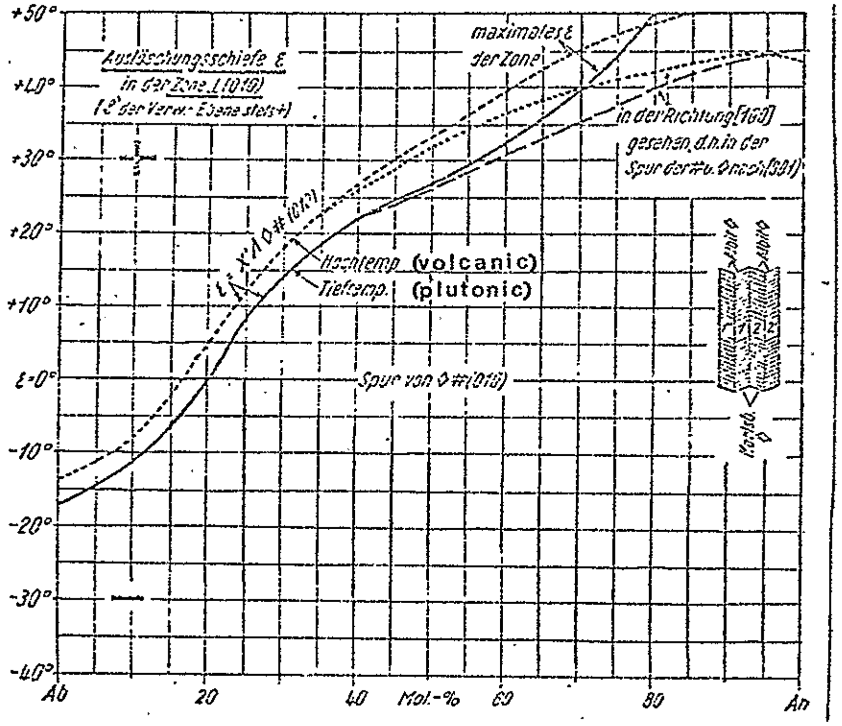
1. Determine the 2V of a suitable plagioclase individual using standard extinction techniques.
2. In the same individual, determine the maximum extinction angle $X' \wedge (010)$ in the zone perpendicular to the $\{010\}$.

3. Enter Rittmann zone, $X' \wedge (010)$, and $2V_z$ curves using extinction and 2V angles determined above and record all the possible anorthite percentage values compatible with the optical data (minimum of 4 values). The values should be separated with respect to high- and low-temperature states.
4. Compare the compositions determined. The true structural state must have composition values that agree within 4 percent anorthite.

Variation curves for the Rittmann zone method and $2V_z$ which differentiate volcanic and plutonic structural states that were used in the determinations are presented in Figures 1A and 1B respectively. Over 30 trials of this method indicate it is a valid means to discriminate between volcanic and plutonic plagioclase in the composition range An_0 to An_{50} (cf. J.R. Smith, 1958). As indicated by Figure 1B, the difference in $2V_z$ for volcanic and plutonic plagioclase in the range An_{40} to An_{50} varies from 2 to 3 degrees, a value which is too near the error involved in a 2V determination. This is why Smith indicates 2V alone can not be used to distinguish the different structural states in calcic andesines. However, inspection of Figure 1A indicates a difference in extinction angles of 6 to 8 degrees for the two structural states in the range An_{40} to An_{50}, which is much greater than the ± 0.5 degree error involved in the measurement. Thus in the composition range An_{40} to An_{50} the method is reversed and 2V is used to estimate the composition with the structural distinction made on the basis

RITTMANN ZONE METHOD

1. A.



2V$_Z$ FOR VOLCANIC AND PLUTONIC PLAGIOCLASE

1. B.

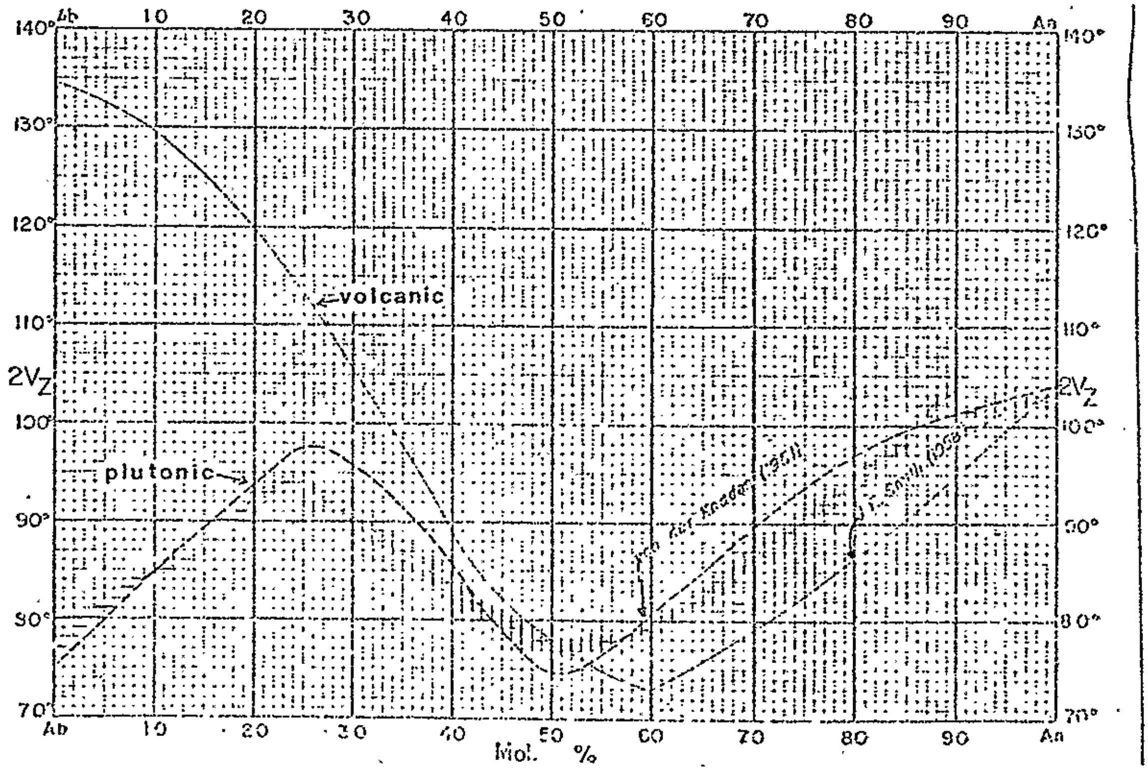


Figure 1. A. Rittmann zone curves for X' (010) versus composition of volcanic and plutonic plagioclase (after Troger, 1959, p. 111).

B. 2V$_Z$ versus composition of volcanic and plutonic plagioclase (after Slemmons, 1962, pl. 11).

of the associated extinction angle. Examples of some determinations made by the writer are listed in Table 1. Samples TM-12 and I-13 illustrate the discriminative capabilities of the method with calcic andesines. As indicated by samples 1-69 and 1-67, determination of 2V also eliminates ambiguous extinction angles of the Ritmann zone method for the composition range An_0 to An_{30}. Compositions determined from extinction angles (Rittmann zone method) are accepted as being more accurate than those determined from 2V. The Rittmann zone method is reported by Emmons (1943, p. 133) to be accurate to ± 3 percent anorthite. The combined Rittmann zone — $2V_z$ method will probably not distinguish plagioclases with a transitional structural state.

The alkali feldspars: sanidine, anorthoclase and orthoclase were differentiated on the basis of 2V measurements and a common physical trait. Although not diagnostic, many investigators have noted that in unaltered rocks sanidine and anorthoclase are characteristically clear while orthoclase is usually clouded. This relationship is well illustrated by the photomicrograph on page 70. The 2V of alkali feldspars varies with their composition, however, the degree of ordering of exchangable cations and the degree of unmixing also control the 2V of feldspars. The latter two variables are primarily regulated by the cooling history of the rock. Studies by MacKenzie and J.V. Smith (1955, 1956) indicate that 2V may be used to estimate Or content to ± 10 percent in mesozonal plutonic and high grade metamorphic rocks, and to ± 20 percent in extrusive volcanic rocks. A later investigation by Emeleus

Table 1. Examples of determinations for structural state of plagioclase made by the combined "Rittmann Zone - 2V$_z$" method.

		Rittmann zone			2V			
sample number	rock type	X' ∧ (010) (± 0.5°)	% anorthite volc.	plut.	2Vz	% anorthite volc.	plut.	inferred structural state & % An
1-69	rhyolite ash-flow tuff	5.0°	13* 21	17 23	125° ± 1°	15	none*	volcanic An$_{13}$
1-67	rhyolite vitrophyre (dike)	8.0°	10 22	14 25	128° ± 1°	12	none*	volcanic An$_{10}$
Tres Montosas stock border facies								
TM-12	andesite	29.5°	44	55	88° ± 2°	40.5 82	14 38 68	volcanic An$_{44}$
I-13	pyroxene diorite	29.0°	43	54	89° ± 2°	40	15 37 69	volcanic An$_{43}$
I-80	quartz monzonite	24.0°	37	44	97° ± 2°	35 92	24 28 80	volcanic An$_{37}$
core								
1-48	granite	17.0°	28	33 0	95° ± 2°	36.5 90	31 21.5	plutonic An$_{33}$

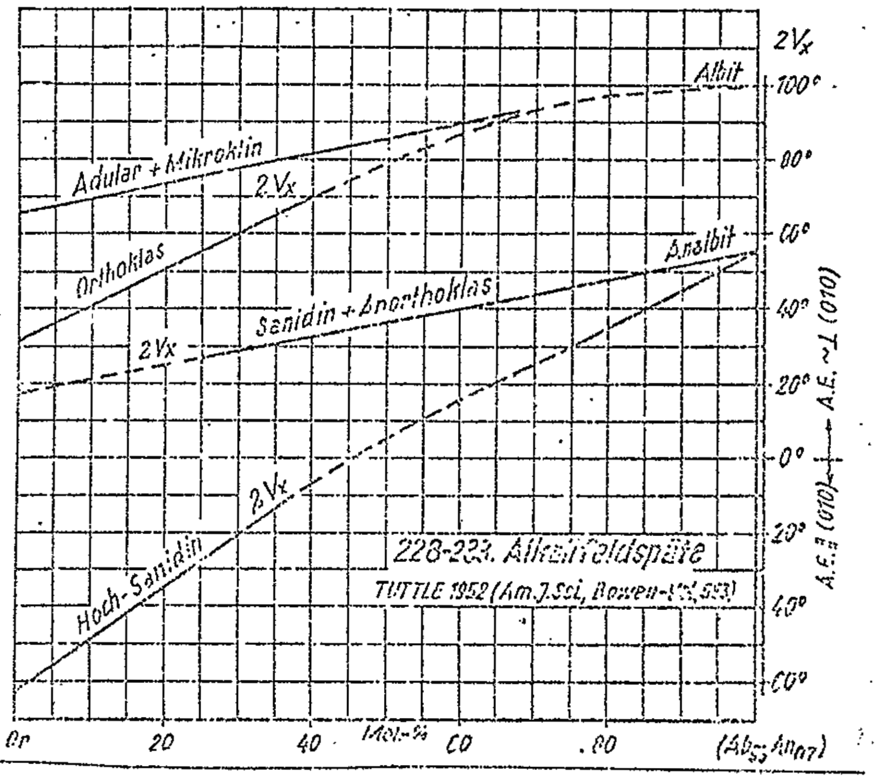
*compositions in agreement are underlined

* not possible according to Fig. 1B

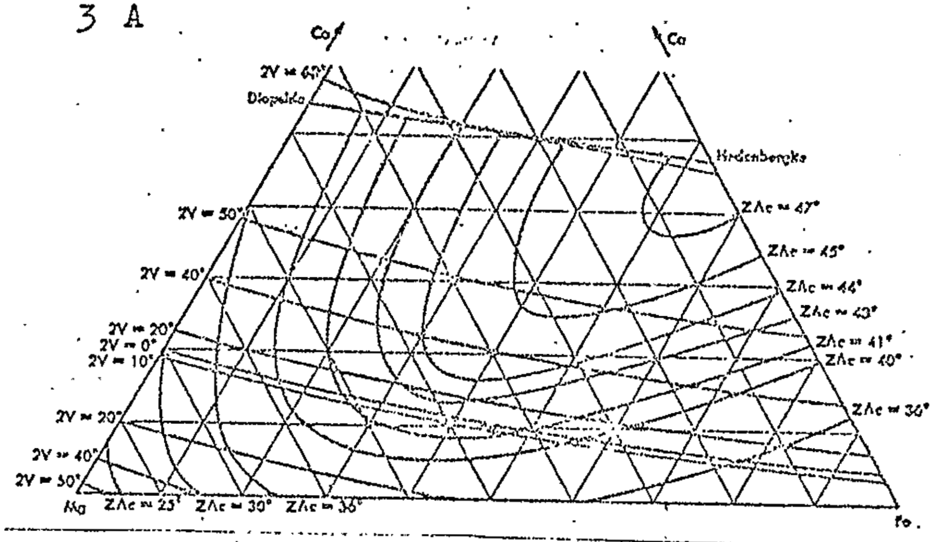
and J.V. Smith (1959) indicates the error involved in estimating Or content using 2V measurements in hypabyssal igneous rocks may be as much as ± 100 percent. Thus the writer has only used 2V measurements of alkali feldspars in ash-flow tuffs of the Hells Mesa and A-L Peak Formations to estimate their composition to ± 20 percent. The diagram shown as Figure 2 was the basis for these estimates of composition.

The approximate composition of clinopyroxene was determined from a combination of 2V and extinction angle ($Z \wedge C$) measurements. Extinction angles were determined from sterographic plots of the optic indicatrix axes and their relationship to the orientation of the (110) prismatic cleavages. The intersection of these cleavages is parallel to the C axis. This data was used to enter the diagram of Figure 3A. When ambiguity in the extinction angle occurred in the use of this diagram, the modal composition of the rock was used to estimate its degree of differentiation. The normal magmatic differentiation trend is to increase the Fe content of associated clinopyroxene with increasing degree of differentiation. Thus a choice between an iron-poor and an iron-rich pyroxene could be made with some degree of validity. The nomenclature of clinopyroxenes as used in this report is illustrated in Figure 3B.

2



3 A



3 B

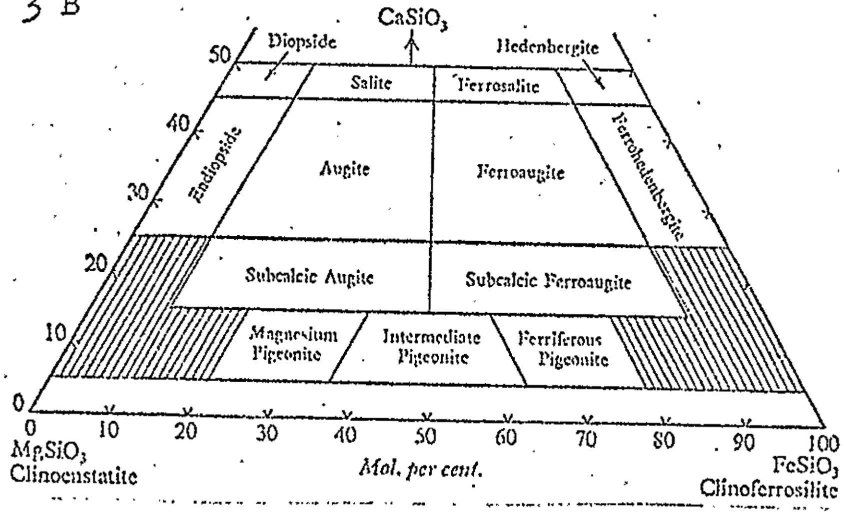


Figure 2. Variation in $2V_x$ of alkali feldspar with composition (after Troger, 1959, p. 96).

Figure 3. A. Variation in $2V_z$ and Z ∧ C in Ca-Mg-Fe clinopyroxenes with composition (after, Heinrich, 1965, p. 218)

B. Nomenclature of Ca-Mg-Fe clinopyroxenes (after Poldervaart and Hess, 1951, p. 472)

REFERENCES

Anderson, A. L., 1948, Monzonite intrusion and mineralization in the Coeur d' Alene district, Idaho: Econ. Geology, v. 44, p. 169-185.

Anderson, E. M., 1937, Cone-sheets and ring-dikes: The dynamical interpretation: Bull. Volcanol., ser. 2, v. 1, p. 35-40.

Aoki, K., and Oji, Y., 1966, Calc-alkaline volcanic rock series derived from alkali-olivine basalt magma: Jour. Geophys. Research, v. 71, p. 6127-6135.

Barker, D. S., 1970, Compositions of granophyre, myrmekite, and graphic granite: Geol. Soc. America Bull., v. 81, p. 3339-3350.

Barth, T. F. W., 1951, The feldspar geologic thermometers: Neues Jahrb. Min., Abhandl., v. 82, p. 143-154.

______________, 1962, The feldspar geologic thermometer: Norsk Geol. Tidsskr., v. 42, (Feldspar Vol.), p. 330-339.

______________, 1968, Additional data for the two-feldspar geothermometer: Lithos, v. 1, no. 4, p. 305-307.

Boone, G. M., 1962, Potassic feldspar enrichment in magma - origin of syenite, in Deboullie district, northern Maine: Geol. Soc. America Bull., v. 73, p. 1451-1476.

Brown, D. M., 1972, Geology of the Southern Bear Mountains, Socorro County, New Mexico: unpublished M.S. thesis, New Mexico Inst. Mining and Technology, 110 p.

Burke, W. H., Kenny, G. S., Otto, J. B., and Walker, R. D., 1963, Potassium-argon dates, Socorro and Sierra Counties, New Mexico: in Guidebook of the Socorro Region, New Mexico Geol. Soc., 14th Field Conf., p. 224.

Cater, F. W., 1969, The Cloudy Pass epizonal batholith and associated subvolcanic rocks: U. S. Geol. Survey Spec. Paper 116, 54 p.

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

______________, 1971b, The Rio Grande Rift, part I: modifications and additions: in Guidebook of the San Luis Basin, New Mexico Geol. Soc., 22nd Field Conf., p. 191-201.

Chapin, C. E., Brown, D. M., Chamberlin, R. M., Krewedl, D. A., and Wilkinson, W. H., in preparation, Exploration framework of the Magdalena-Tres Montosas area, Socorro County, New Mexico: New Mexico State Bur. Mines and Mineral Resources Bull.

Chayes, F., 1952, Notes on the staining of potash feldspar with sodium cobaltinitrite in thin section: Am. Mineralogist, v. 37, p. 337-340.

Christiansen, R. L., and Lipman, P. W., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States. II Late Cenozoic: Royal Soc. (London) Philos. Trans., v. 271, p. 249-284.

Creasey, S. C., 1966, Hydrothermal Alteration: in Geology of the Porphyry Copper Deposits, Southwestern North America, Titley, S. R. and Hicks, C. L. (ed.), Univ. Ariz. Press, 287 p.

Damon, P. E., 1968, Potassium-argon dating of igneous and metamorphic rocks with applications to the basin ranges of Arizona and Sonora: in Radiometric Dating for Geologists, Hamilton, E. I., and Farquhar, R. M. (ed.), Interscience Publ., 506 p.

Deal, E. G., 1974, Development of the Mt. Withington Cauldron, San Mateo Mountains, Socorro County, New Mexico: Geol. Soc. America, Abs. with Programs (Cordilleran Section) v. 6, no. 3, p. 162.

Deal, E. G., and Rhodes, R. C., 1974, Volcano-tectonic structures in the San Mateo Mountains, Socorro County, New Mexico, in Cenozoic Volcanism in New Mexico : Univ. New Mexico Pub. in Geol., no. 8 (in press).

DeSitter, L. U., 1964, Structural Geology: New York, McGraw-Hill, 551 p.

Donnay, G., Wyart, J., and Sabtier, G., 1960, The catalytic nature of high-low feldspar transformations: Carnegie Inst. Washington Year Book 59, 1959-1960, p. 173-174.

Eardley, A. J., 1962, Structural Geology of North America: New York, Harper and Brothers, 743 p.

Elston, W. E., Coney, P. J., and Rhodes, R. C., 1968, A progress report on the Mogollon Plateau volcanic province, Southwestern New Mexico: in Cenozoic volcanism in the southern Rocky Mountains, Epis, R. C. (ed.), Quart. Colorado School Mines, v. 63, no. 3, p. 261-287.

Elston, W. E., and Damon, P. E., 1970, Significance of four new K/Ar dates from the Mogollon Plateau volcanic province, southwestern New Mexico: in Correlation and chronology of ore deposits and volcanic rocks, Univ. Ariz. Ann. Prog. Rept. COO-689-130 to A.E.C. Res. Div., p. A-VI-1 to A-VI-9.

Elston, W. E., Damon, P. E., Coney, P. J., Rhodes, R. C., Smith, E. I., and Bikerman, M., 1973, Tertiary volcanic rocks, Mogollon-Datil province, New Mexico, and surrounding region: K-Ar dates, patterns of eruption, and periods of mineralization: Geol. Soc. America Bull., v. 84, p. 2259-2274.

Emeleus, C. H., and Smith, J. V., 1959, The alkali feldspars. VI. Sanidine and orthoclase perthites from the Slieve Gullion area, Northern Ireland: Am. Mineralogist, v. 44, p. 1187-1209.

Emmons, R. C., 1943, The universal stage: Geol. Soc. America, Mem. 8, 205 p.

Epis, R. C., and Chapin, C. E., 1973, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the Southern Rocky Mountains: Geol. Soc. America, Abs. with Programs (Rocky Mountain Sec.), v. 5, no. 6, p. 479.

Givens, D. B., 1957, Geology of Dog Springs Quadrangle, New Mexico: New Mexico State Bur. Mines and Mineral Resources Bull. 58, 40 p.

Heinrich, E. W., 1965, Microscopic Identification of Minerals: New York, Mc Graw-Hill, 414 p.

Herrick, C. L., 1900, Report of a geologic reconnaissance in western Socorro and Valencia Counties, New Mexico: Am. Geologist, v. 25, p. 331-346.

Hunt, C. B., 1967, Physiography of the United States: San Francisco, W. H. Freeman and Co., 480 p.

Jones, F. A., 1904, New Mexico Mines and Minerals: Santa Fe, The New Mexican Printing Co., 346 p.

Kelly, V. C., and Wood, G. H., 1946, Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Inv. (Prelim.) Map 47.

Kelly, V. C., and Clinton, N. J., 1955, Fracture system and tectonic elements of the Colorado Plateau: Univ. New Mexico Pub. in Geology, no. 6.

Kennedy, G. C., 1955, Some aspects of the role of water in rock melts: in Crust of the Earth, Poldervaart, Arie (ed.), Geol. Soc. America Spec. Paper 62, 762 p.

Kottlowski, F. E., Weber, R. H., and Willard, M. E., 1969, Tertiary intrusive-volcanic-mineralization episodes in the New Mexico region (Ann. Mtgs.): Geol. Soc. America, Abs. with Programs, v.1, no. 7, p. 278-280.

Krewedl, D. A., in preparation, Geology of the central Magdalena Mountains, Socorro County, New Mexico: unpublished Ph. D. dissertation, Univ. of Arizona.

Kuno, H., 1959, Origin of Cenozoic petrographic provinces of Japan and surrounding areas: Bull. Volcanol., ser. 2, v. 20, p. 37-76.

Lasky, S. G., 1932, The ore deposits of Socorro County, New Mexico: New Mexico State Bur. Mines Mineral Resources Bull. 8, 139 p.

Lipman, P. W., Christiansen, R. L., and O'Connor, J. T., 1966, A compositionally zoned ash-flow sheet in southern Nevada: U. S. Geol. Survey Prof. Paper 524-F, 47 p.

Lipman, P. W., Steven, T. A., and Mehnert, H. H., 1970, Volcanic history of the San Juan Mountains, Colorado, as indicated by Potassium-Argon dating: Geol. Soc. America Bull., v. 81, p. 2329-2352.

Lipman, P. W., and Friedman, E., 1974, Oxygen-isotope variations in phenocrysts from compositionally zoned ash-flow sheets, southern Nevada: Geol. Soc. America, Abstracts with Programs, (Cordilleran Sec.), v. 6, no. 3, p. 207.

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

Lowell, G. R., and Chapin, C. E., 1972, Primary compaction and flow foliation in ash-flow tuffs of the Gribbles Run paleovalley, central Colorado: (Ann. Mtgs.), Geol. Soc. America, Abs. with Programs, v. 4, no. 7, p. 725.

MacKenzie, W. S., and Smith, J. V., 1955, The alkali feldspars. I. Orthoclase-microperthites: Am. Mineralogist, v. 40, p. 707-732.

________________________, 1956, The alkali feldspars. III. An optical and X-ray study of high-temperature feldspars: Am. Mineralogist, v. 41, p. 405-427.

Mackin, J. H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, p. 81-131.

Noble, J. A., 1952, Evaluation of criteria for the forcible intrusion of magma: Jour. Geology, v. 60, p. 34-57.

Orville, P. M., 1963, Alkali ion exchange between vapor and feldspar phases: Am. Jour. Sci., v. 261, p. 201-237.

Park, D. E., 1971, Petrology of the Tertiary Anchor Canyon Stock, Magdalena Mountains, central New Mexico: unpublished M. S. thesis, New Mexico Inst. Mining and Technology, 92 p.

Pierce, W. G., 1957, Heart Mountain and South Fork detachment thrust of Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 591-626.

Poldervaart, A., and Hess, H. H.,1951, Pyroxenes in the crystallization of basaltic magma: Jour. Geol., v. 59, p. 472.

Rittmann, A., 1929, Die Zonenmethode. Ein Beitrag zur Methodik der Plagioklasbestimmung mit Hilfe des Theodolithtisches: Schweiz. Min. Petr. Mitt., v. 9, p. 1-46.

Rittmann, A., and El-Hinnawi, E. E., 1961, The application of the zonal method for the distinction between low- and high-temperature plagioclase feldspars: Schweiz. Min. Petr. Mitt., v. 41, p. 41-48.

Schminke, H. U., and Swanson, D. A., 1966, Secondary flowage features in welded pyroclastic flows, Grand Canaria, Grand Canary Islands: Jour. Geol., v. 75, no. 6, p. 641-664.

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

Slemmons, D. B., 1962, Determination of volcanic and plutonic plagioclases using a three- or four-axis universal stage: Geol. Soc. America Spec. Paper 69, 64 p.

Smith, E. I., Aldrich, J. M., Deal, E. G., and Rhodes, R. C., 1974, Fission track ages of Tertiary volcanic rocks, Mogollon Plateau, southwestern New Mexico: New Mexico Univ. Pubs. Geology, no. 8 (in press).

Smith, J. R., 1958, The optical properties of heated plagioclase: Am. Mineralogist, v. 43, p. 1179-1194.

Smith, R. L., 1960, Zones and zonal variations in welded ash flows: U. S. Geol. Survey Prof. Paper 354-F, p. 149-159.

Smith, R. L., and Bailey, R. A., 1966, The Bandelier Tuff: a study of ash-flow eruption cycles from zoned magma chambers: Bull. Volcanol., v. 29, p. 83-103.

Snyder, D. O., 1971, Stratigraphic analysis of the Baca Formation, West-Central New Mexico: unpublished Ph. D. dissertation, Univ. New Mexico, 160 p.

Stewart, J. H., 1971, Basin and Range structure: a system of horsts and grabens produced by deep seated tension: Geol. Soc. America Spec. Paper 62, p. 369-376.

Tonking, W. H., 1957, Geology of Puertecito Quadrangle, Socorro County, New Mexico: New Mexico State Bur. Mines Mineral Resources Bull. 41, 67 p.

Travis, R. B., 1955, Classification of rocks: Quart. Colorado School Mines, v. 50, no. 1, 98 p.

Tröger, W. E., 1959, Optische bestimmung der gesteinbilden Minerale: Teil 1 Bestimmungstabellen: (3rd ed.) Stuttgart, E. Schweizerbart'sche Verlagsbuchandlung, 147 p.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KALSi_3O_8$ - SiO_2 - H_2O: Geol. Soc. America Memoir 74, 153 p.

Weber, R. H., 1963, Cenozoic volcanic rocks of Socorro County: in Guidebook of the Socorro Region, New Mexico Geol. Soc., 14th Field Conf., p. 132-143.

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

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

Wertz, J. B.,1968, Structural elements of ore search in the Basin and Range Province, southeast Arizona, domes and fracture intersections: Soc. Mining Eng. Trans., v. 241, p. 276-291.

Wilkinson, W. H. ~~in preparation~~ 1976, Geology of the Cat Mountain-Tres Montosas area, Socorro County, New Mexico: unpublished M. S. thesis, New Mexico Inst. Mining and Technology.

Winkler, H. G. F., 1965, Petrogenesis of Metamorphic Rock: New York, Springer-Verlag, 219 p.

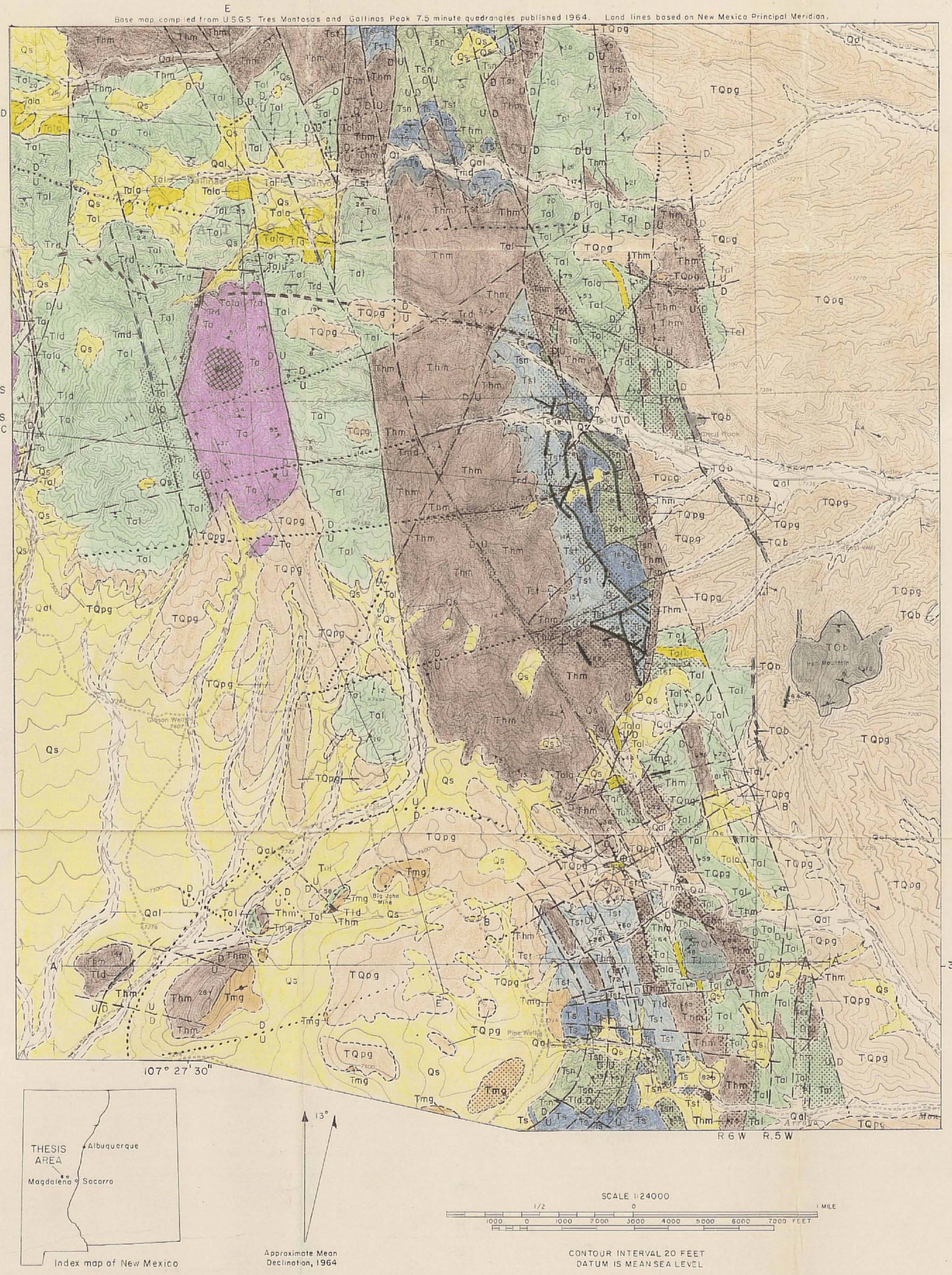
Witkind, I. J., Kleinkopf, M. D., and Keefer, W. R., 1970, Geologic and gravity evidence for a buried pluton, Little Belt Mountains, central Montana: U. S. Geol. Survey Prof. Paper 700-B, p. B63-B65.

GEOLOGIC MAP AND SECTIONS OF THE COUNCIL ROCK DISTRICT
SOCORRO COUNTY, NEW MEXICO

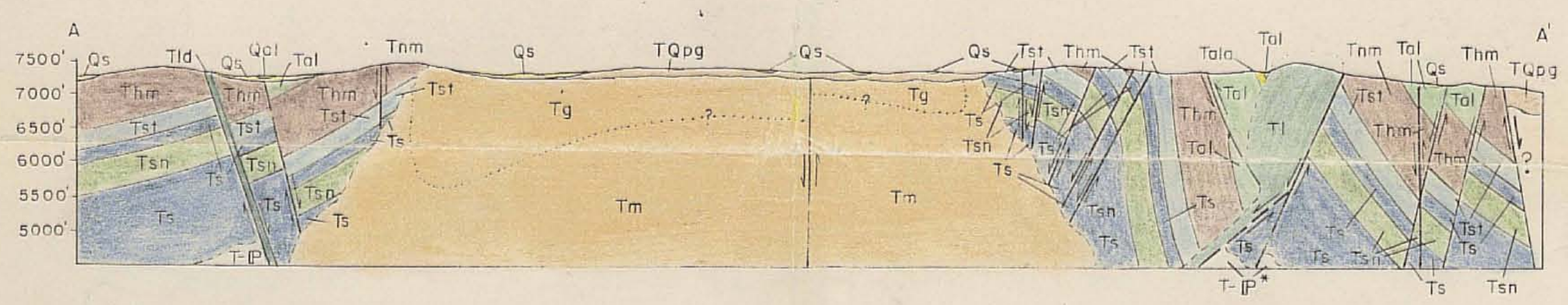
by

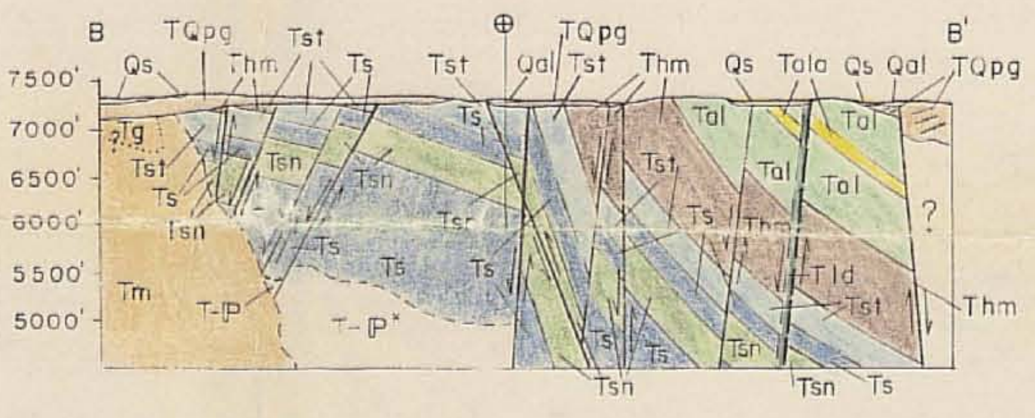
RICHARD M. CHAMBERLIN, 1972

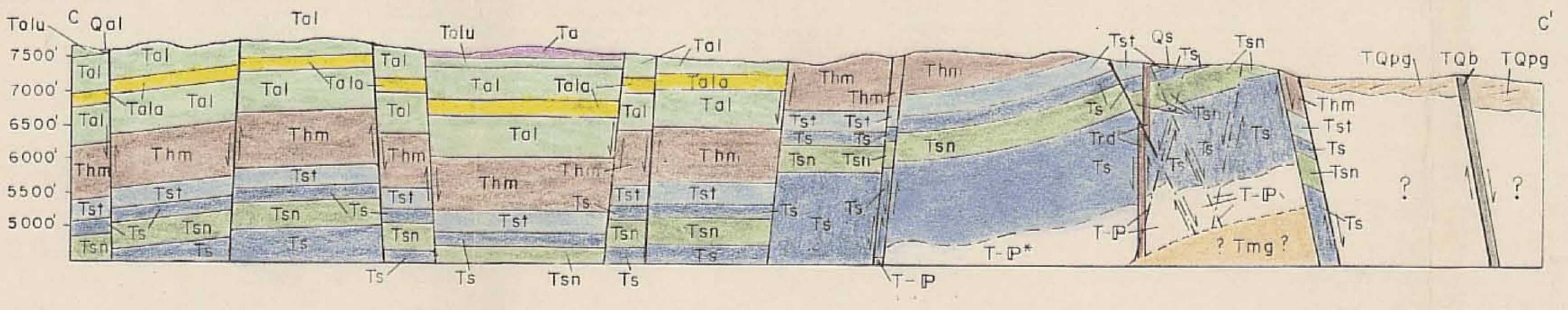
Base map compiled from U.S.G.S. Tres Montosas and Gallinas Peak 7.5 minute quadrangles published 1964. Land lines based on New Mexico Principal Meridian.

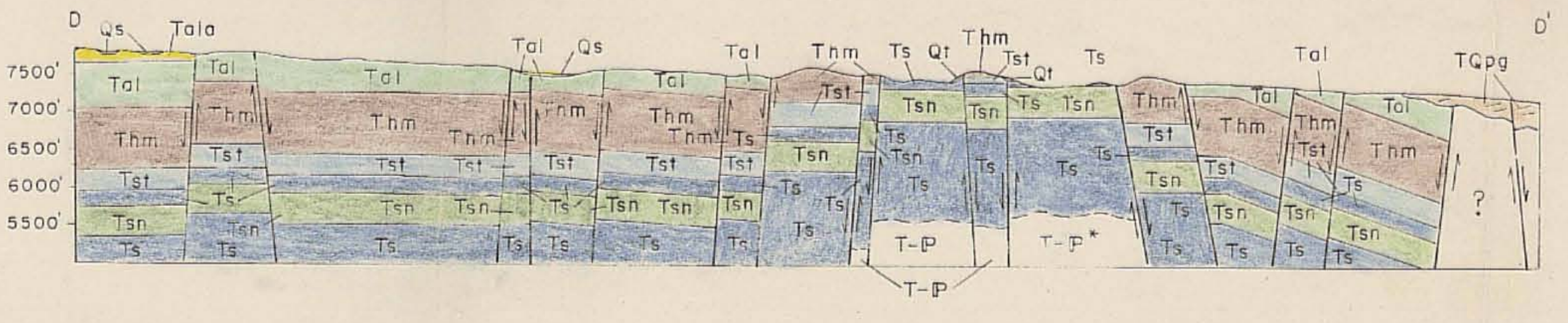


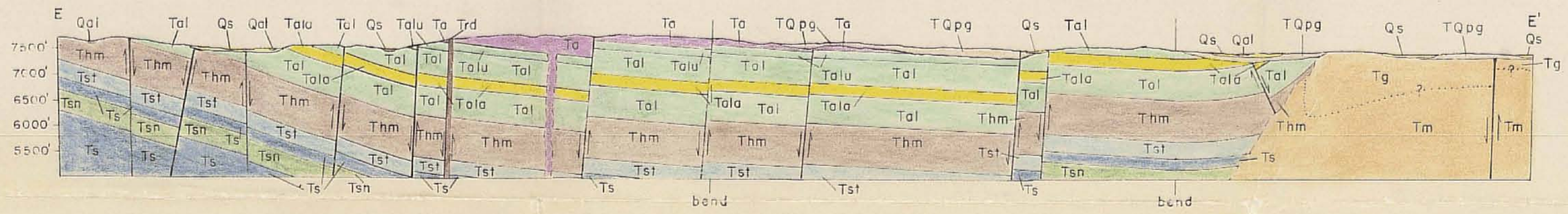
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL











* T-₽: Pre-volcanic sediments

EXPLANATION

QUATERNARY

Qal
Alluvium

Qs
Eolian sand

Qt
Talus

PLIOCENE

TQb
Basalt flows and dikes

TQpg
Pediment gravels

OLIGOCENE

Tmg
Monzonite-granite stock

Tl(d)
Latite porphyry plug and dikes

Trd
Rhyolite dikes

DATIL GROUP

Ta
Andesite dome and platy flows

Talu
Tal
Tala
Tal

Tal: A.L. Peak Formation
Tala: andesite flows
Talu: upper, moderately crystal rich tuffs

Thm
Hells Mesa Formation

Tst
Ts
Tsn
Ts

Ts: Spears Formation
Tsn: tuff of Nipple Mountain
Tst: crystal rich latite tuffs

Tmd
Mafic dikes

Contact
Dashed where approximately located

U
D

High angle fault
U: upthrown side D: downthrown side
dashed where approximately located
dotted where inferred

High angle reverse fault
sawteeth on upthrown block

22
Strike and dip of bedding

27
Strike and dip of foliation

Horizontal foliation

Vertical foliation

60
Overturned foliation

76
Strike and dip of joint

Trend of lineation

Direction of sedimentary transport

Anticlinal axis in contorted ash flow tuff

Silicified shear zone

84
Quartz vein showing dip

Altered rock usually containing disseminated oxidized pyrite
mostly in fault zones

Mineral prospect

Open cut

Shaft

⊕
Diamond drill hole

Volcanic vent

Improved road

Unimproved road

Intermittent stream