GEOLOGY OF THE AREA AROUND THE LANGMUIR LABORATORY, MAGDALENA MOUNTAINS SOCORRO COUNTY, NEW MEXICO

by

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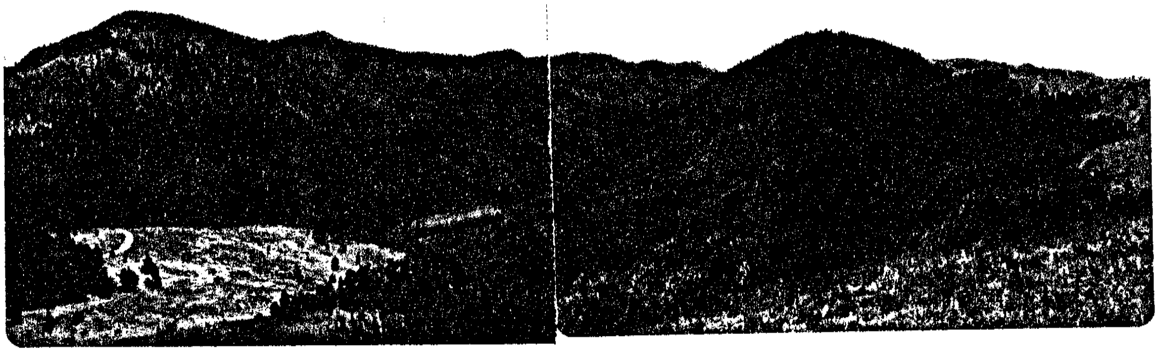

Looking south from the top of South Baldy

Radar Hill is at the extreme right; Langmuir Laboratory at the center right; Sawmill Canyon in the center; and Timber Peak at the left.

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ABSTRACT

The Langmuir Laboratory is located approximately 17 miles west of Socorro in the Magdalena Mountains. The lithologic units include andesite flows, a rhyolite flow, welded ash-flow tuffs of varying composition, air-fall tuffs, minor amounts of sandstone, a laharic breccia, and a minor amount of Recent alluvium. Extensive faulting tends to obscure some of the lithologic relationships. The major faults trend either N 33° W, N 10° W, N 10-15° E, or N 44° E. They dip steeply to the west and the southeast; one is nearly vertical. The lithologic units are moderately altered by late stage hematitization, carbonitization, silicification, and argillization. The radium content of the major lithic units is essentially independent of rock type. This may be a result of leaching of uranium by carbonate-bearing solutions during hydrothermal alteration or of regional variations in uranium content of igneous rocks. Radium values in the rocks analyzed average 0.31×10^{-6} ppm for the andesites and 0.40×10^{-6} ppm for the rhyolites. Radioactive sources cannot be related to individual mineral species. The Purple Rhyolite does contain metamict zircon crystals, however most of the radioactivity appears to be randomly distributed in the groundmass of the rock.

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INTRODUCTION

Purpose

The purpose of this thesis is to study the geology of the South Baldy--Sawmill Canyon area of the Magdalena Mountains in central New Mexico (see figure 1). The Irving Langmuir Atmospheric Physics Laboratory of the New Mexico Institute of Mining and Technology is situated on the crest of the range about one mile south of South Baldy Peak. The particular interest of the laboratory is the study of thunderstorms. Radon-222 emanations around the laboratory also have been closely studied by one of the atmospheric physics groups. The geology and petrology of the area was studied in order to delineate possible radium distributions in the various rock types. Radon-222 is the principal daughter product of radium-226, and thus the radium content of the rocks is critical to an understanding of radon emanation.

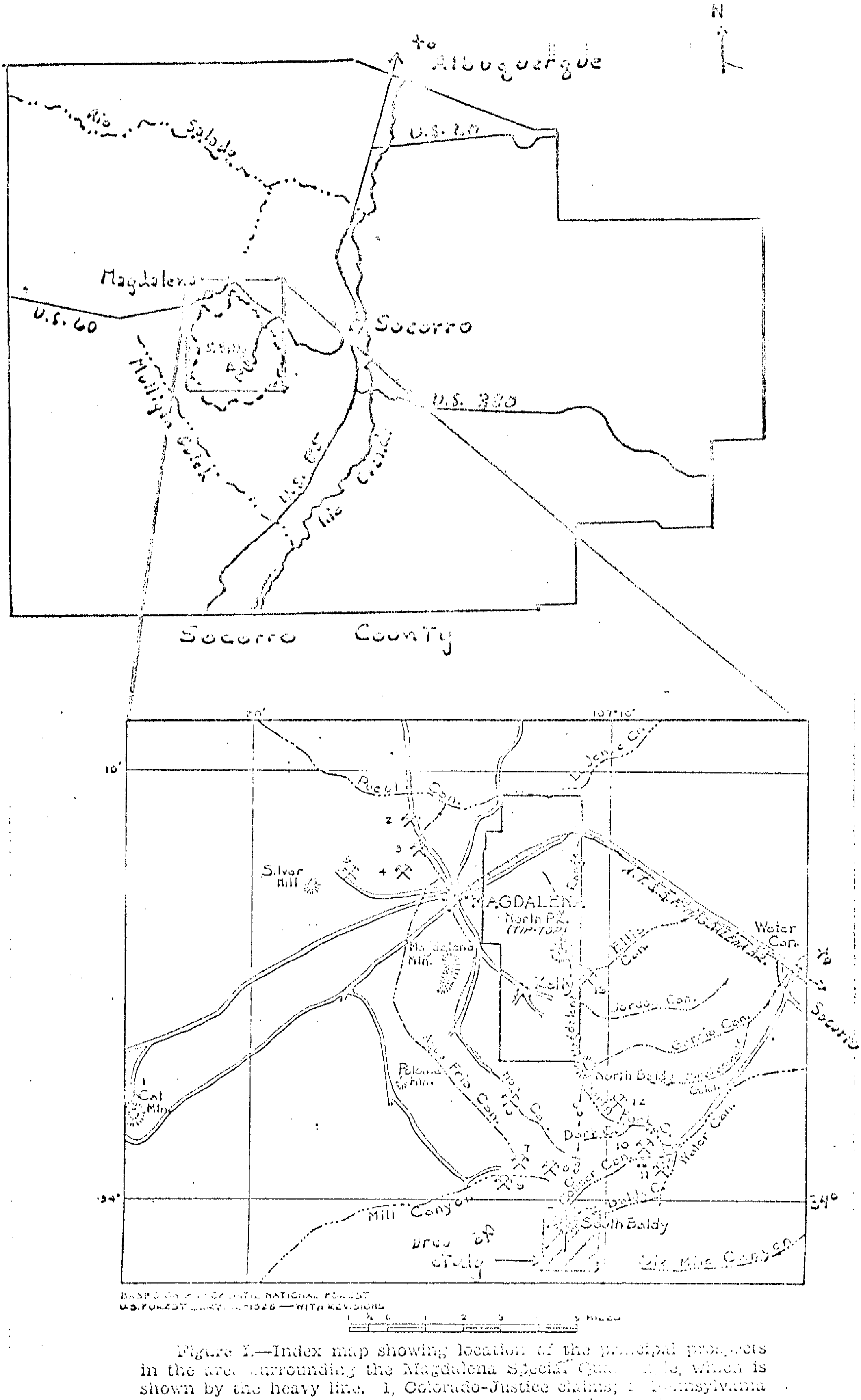


Figure 1.—Index map showing location of the principal prospects in the area surrounding the Magdalena Special Quadrangle, which is shown by the heavy line. 1, Colorado-Justice claims; 2, Pennsylvania group; 3, Jack Frost and Night Hawk groups; 4, Pleasant View group; 5, Copper Belt Silver & Copper Mining Co. property; 6, Hop Canyon district; 7, Cuprite (Wheel of Fortune) mine; 8, Iron Cap vein; 9, Old Soldier vein; 10, Hall-Lytton property; 11, Buckeye mine; 12, Nutter lease; 13, Ellis Canyon prospect. [Lasky, 1932]

Location and Accessibility

The region studied is located in the south-central portion of the Magdalena Mountains, Socorro County, New Mexico. Langmuir Laboratory is 30.9 miles by road from Socorro. By air this region is approximately 17 miles west and south of Socorro and 10 miles southeast of the town of Magdalena. The area studied lies within an area bounded by longitudes 107° 07' 30" and 107° 12' 30", and latitudes 33° 57' 30" and 34° 00' 00".

The Water Canyon Road to Langmuir Laboratory makes the area accessible to vehicles. This road is reached by driving west on U.S. Highway 60 from Socorro. Two foot trails skirt the area studied. On the west is the Hardy Canyon Trail which continues north along the crest of the mountains to North Baldy. On the east is the Sawmill Canyon Trail.

Methods of Study

The base map for the area studied is the United States Department of Interior, Geological Survey unpublished topographic map of the South Baldy Quadrangle, Socorro County, New Mexico, 7½ minute series, scale 1:24,000. The pertinent section of the map was enlarged four times to a scale of 500 feet per inch for mapping purposes. The field work was done during the summer of 1967. Thunderstorms were particularly frequent from the end of July through August, and interfered with field work. Fog prevented field work early in September. Outcrop positions were determined in one of three ways, or by a combination of methods. A Brunton compass was used for triangulation and for compass traverses to the outcrops. A compass traverse was done only when there were no landmarks visible for triangulation. The third method was to use a bearing on one visible landmark in conjunction with an elevation reading on an aircraft altimeter. The altimeter was also used in determining the heights of various outcrops.

In the laboratory, fifty-five thin sections were studied as well as the corresponding hand specimens. Thin section identifications are based upon works by Carrigy and Mellon (1964); Deer, Howie, and Zussman (1962); Heinrich (1958); and Kerr (1959). Plagioclase compositions were determined mainly by the Fouqué method and occasionally by the Michel-Lévy method. Mineralogic composition percentages are visual estimates. Petrological classifications follow those of Williams, Turner, and Gilbert (1954). The radium content of the volcanic units was determined by a modified version of the proceedure described by Rosholt (1957) (see page 55 of thesis).

Previous Work

The only previous work which mentions specifically the geology near Langmuir Laboratory is the roadlog

(Budding and Gross, 1963) for field trip 10 of the 1963 New Mexico Geological Society field conference. Geologic studies have been made of the Magdalena Mining District (Loughlin and Koschmann, 1942; and Titley, 1959) and other districts in the Magdalena Mountains (Lasky, 1932). The Water Canyon area was the subject of a master's thesis (Kalish, 1953) and has also been studied by students in the New Mexico Institute of Mining and Technology's summer field geology course. In a brief survey of the Cenozoic volcanic rocks of Socorro County Weber (1963) cites exposures in the Magdalena Mountains.

Topography and Drainage

The Magdalena Mountains have precipitous relief. The highest elevation, South Baldy Peak, is 10,780 feet above sea level. To the west of the peak slopes exceed 1900 feet per mile in the first mile; to the east the relief is not so abrupt. About five miles northeast, the elevation of the mouth of Water Canyon is only slightly greater than 6000 feet. Within the area mapped, elevations range from 8400 feet in Sawmill Canyon to 10,630 feet at Langmuir Laboratory and 10,780 feet at South Baldy; the relief averages 2500 feet per mile. Twenty-to fifty-foot cliffs in stair-step fashion are common. East of the laboratory a cliff averaging 200 feet in height is the most prominent feature.

The general drainage pattern is radial from the ridge connecting South Baldy and the laboratory. Some of the streams are fault controlled; for example, Water Canyon in the region studied by Kalish. Sawmill Canyon is also controlled to some extent by faulting. In the region examined the only flowing water observed was in Sawmill Canyon immediately above and below the dam (see plate I), at the spring by the old Forest Service cabin on the south side of South Baldy, and at the spring south of the laboratory at an elevation of about 9300 feet. The stream in Sawmill Canyon may be described as a perennial interrupted stream. From a few hundred feet below the Forest Service cabin spring to a few hundred feet above the dam there is only intermittent, influent flow.

Climate and Vegetation

The climate of the South Baldy-Langmuir Laboratory area is cool with many thunderstorms during the summer and snow in the winter. Weather data has been recorded since July, 1962. Table 1 lists the temperature ranges and total precipitation recorded during this period of

Table 1. Temperature & Precipitation Data, 1962-1967

temperature °F	1967	1966	1965	1964	1963	1962
maximum	76	82	77	79	80	
mean maximum	48.6	50	49	48.6	50.8	64*
minimum	-6	-7	-8	-6	-10	
mean minimum	31.0	31	31	29.3	31.7	36*
total precipitation (inches)	18.67	16.74	23.56	16.92	18.15	12.78*

*July through December

of five and a half years at the laboratory. During 1967 approximately one-fourth of the total precipitation was snow; there was a light snowfall on May 31. Approximately ten inches of precipitation fell in June, July, and August. Table 2 summarizes the data for summer, 1967.

Table 2. Temperature & Precipitation Data summer 1967

Temperature °F	June	July	August
maximum	72	76	72
mean maximum	61	69	63
minimum	28	40	38
mean minimum	41	47	45
Precipitation (inches)	1.93	3.81	4.34

In the Magdalena Mountains the vegetation ranges from the cholla, prickly pear, and yucca of the Upper Sonoran Zone (Kalish, 1953) in the lower foothills to the Hudsonian life zone around South Baldy Peak. Windswept spruce grows on South Baldy and on the ridge south to the laboratory mixed aspen-spruce-fir forest occurs along the slopes below the wind swept ridges. Evergreen species noted are Englemann Spruce (_Picea engelmanni Parry_), Blue Spruce (_Picea pungens Engelm._), Douglas Fir (_Pseudotsuga taxifolia_), Limber Pine (_Pinus flexilis_), and Ponderosa or Yellow Pine (_Pinus ponderosa_) (Little, 1950). Quaking Aspen (_Populus tremuloides_) is extensive around the laboratory and the top of the mountain. The groves extend down old talus slides. Gambel Oak (_Quercus gambelii_) was observed on the slope south of the laboratory at an elevation of 9200 feet, and also in Sawmill Canyon.

Mountain Mahogany and chokecherry shrubs were also observed. Thus, within the area mapped the vegetation types generally belong to the Canadian and Hudsonian life zones (Little, 1950). Sunny, well-drained slopes often had a small cactus of the hedgehog variety. In the sunny meadows wild iris, wild onions, eidelweiss, paintbrush, and asters grow. In the shadier areas primroses, shooting stars, violets, maidenhair fern, and mosses flourish.

Acknowledgments

The author wishes to express her deep appreciation for the aid and suggestions given by Drs. Clay T. Smith and Charles E. Chapin. She also desires to thank Dr. Marvin H. Wilkening for the suggestion of this project and Mr. E.M. Jercinovic for aid in the radium determinations. Recognition also goes to Dr. Lawrence R. Hathaway for his help with the chemistry. This study was supported in part by the National Science Foundation grant GP5437.

LITHOLOGY AND STRATIGRAPHY

Regional Lithology

The Magdalena Mountains are a typical horst of the Basin and Range geologic province and lie in the southeast extension of this province. The north-south trending range consists of tilted and faulted volcanic and sedimentary rocks which, in the northern portion, unconformably overlie Precambrian rocks. The sedimentary and Precambrian rocks do not outcrop south of Water Canyon. The sedimentary rocks are limestones, shales, and quartzites of Carboniferous (Loughlin and Koschmann, 1942) and Permian (Kalish, 1953) age. The Precambrian rocks include granite, greenstone (Kalish, 1953), gabbro, felsite, diabase, and argillite (Titley, 1959). The Tertiary igneous rocks are both extrusive and intrusive; granite and monzonite stocks are found at the northeastern end of the mountains while volcanic rocks predominate from Water Canyon south.

The volcanic rocks belong to the Datil-Mogollon volcanic field. The Datil Formation is the most widespread of the volcanic units in this field (see figure 2) (Weber, 1963). The Magdalena Mountains are part of the eastern edge of this field. In this general region of Socorro County, the Datil Formation consists of two units; a lower latitic unit--the Spears Member, and an upper rhyolitic unit--the Hells Mesa Member. The Hells Mesa Member is

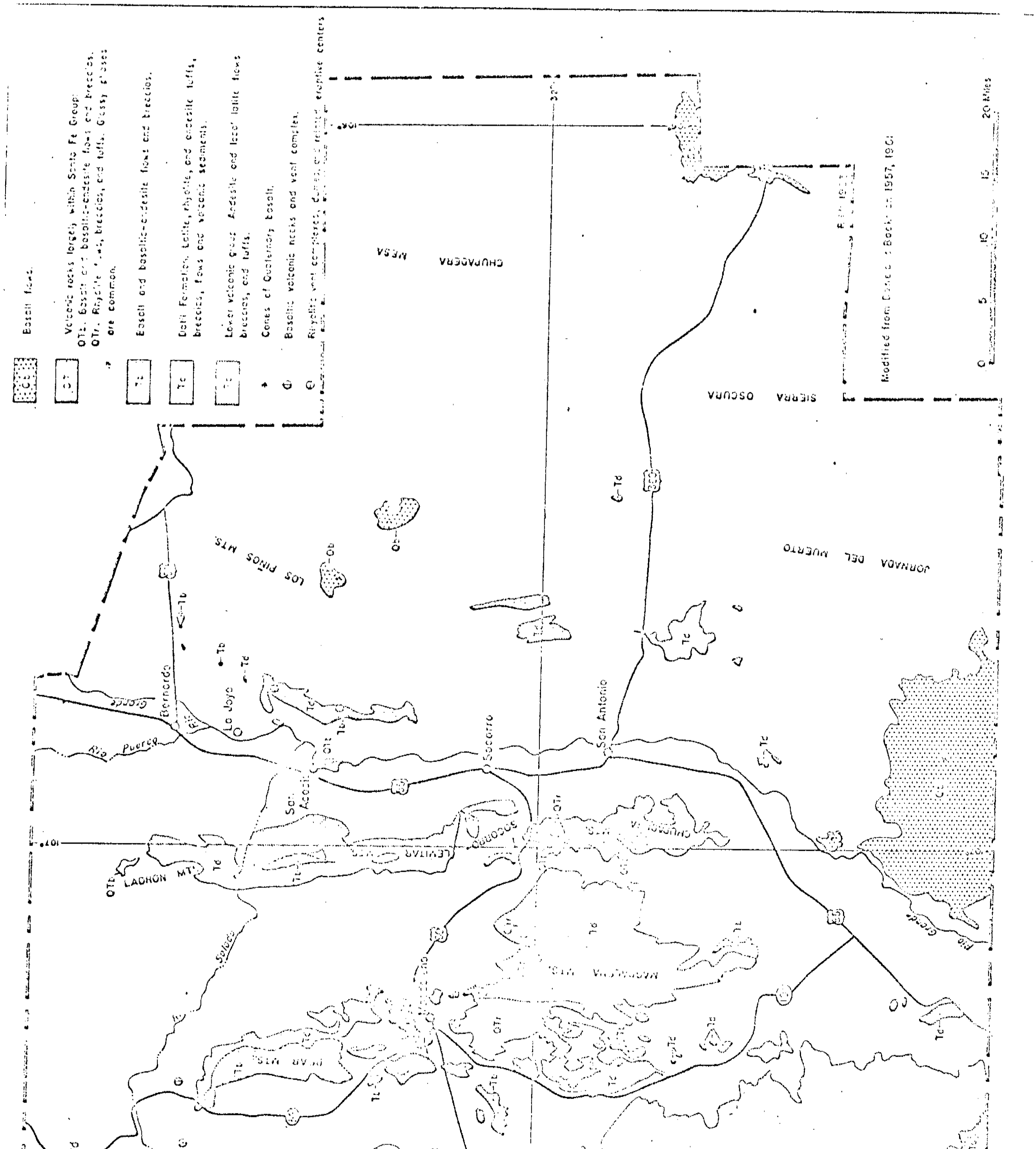


Figure 2
Distribution of volcanic rocks in Socorro County, New Mexico.
(Weber, 1963)

predominantly a crystalline tuff with andesitic and pyroclastic units locally present (Willard, personal communication, 1968). Welded tuffs are especially prominent in outcrops. Locally, volcanic sediments are interlain with the tuffs. Colors of the highly-welded tuffs and flows vary from dark red and purplish shades to brown. The less welded ones may be white; however, pinkish shades, pale grays, and tans are the most common colors for the whole member. The thickness of the Hells Mesa Member varies from approximately 250 feet in the northern Bear Mountains to more than 2000 feet elsewhere. In the San Mateo Mountains the thickness of the unit is is of the order of several thousand feet and the rhyolite is interlain with rocks of andesitic and latitic composition (Weber, 1963).

Potassium-argon dating has given ages of 32.2 and 32.6 million years for a semiwelded rhyolite tuff of the basal unit of the Hells Mesa Member, and 31.9 and 32.3 million years for a vitric crystal tuff of this member (Burke, Kenny, Otto, and Walker, 1963). Another potassium-argon date on biotite from a welded tuff in the Bear Mountains type section of the member gave dates of 29.4 and 31.8 million years (Weber and Bassett, 1963). This places the Hells Mesa Member in the Oligocene.

The Spears Member of the Datil Formation is a sequence of quartz latite tuffs, agglomerates, breccias, flow breccias, and volcanic sediments. Colors vary from shades of green, blue, and gray to red and purple. Interbedded flow breccias, andesite flows, and minor tuffs are common in the upper part of this member and also interfinger slightly with the overlying rhyolitic sequence of welded tuffs. In the San Mateo Mountains latite breccias and flow-banded latites are the predominant units. A massive rhyolite tuff underlies them. The thickness of this portion of the Datil Formation is about 1350 feet at the type section at Hells Mesa. Potassium-argon ages indicate that the Spears Member is Oligocene-Upper Eocene in age (37.1 million years) (Weber, 1963).

Local Lithology

No attempt is made in this paper to compare the units studied with either the Hells Mesa Member or Spears Member of the Datil Formation. However, with the exception of the Quaternary Alluvium, all the rock units are believed to have been deposited within the Oligocene and Upper Eocene Epochs of the Tertiary Period since Weber (1963) includes the volcanic rocks of the Magdalena Mountains in the Datil Formation.

Dark Gray Andesite

The Dark Gray Andesite is the oldest unit in the stratigraphic column. It crops out south of Langmuir Laboratory with the best exposures near the top of the unit. It is interpreted as a massive lava flow. Its thickness was not determined.

The Dark Gray Andesite has both aphanitic and vesicular zones with the latter being most common in the uppermost exposures. The aphanitic areas are occasionally very finely porphyritic. Phenocrysts in the vesicular portions are larger, but do not exceed 1 mm in average diameter. The crystals are both euhedral and anhedral. The texture is trachytic. Table 3 shows its composition. No plagioclase zoning was observed. The

Table 3. Composition of Dark Gray Andesite

Composition	Vol. %
Phenocrysts	20
plagioclase	18
potash feldspar	1
magnetite & hematite	1
Groundmass	50
plagioclase	40
magnetite, hematite, & augite	10
Secondary alteration	30

plagioclase falls within the oligoclase-andesine composition range, i.e., in the range An 20 to An 50. Most of the hematite is derived from alteration of the magnetite. Occasionally there are large crystals that have completely altered to clays, zeolites, and hematite. The shape suggests that they are relicts of hornblende. The zeolites are fine grained with a radiating, fibrous habit. Most of the plagioclase crystals are altered to clay and replaced by calcite. The vesicles are filled

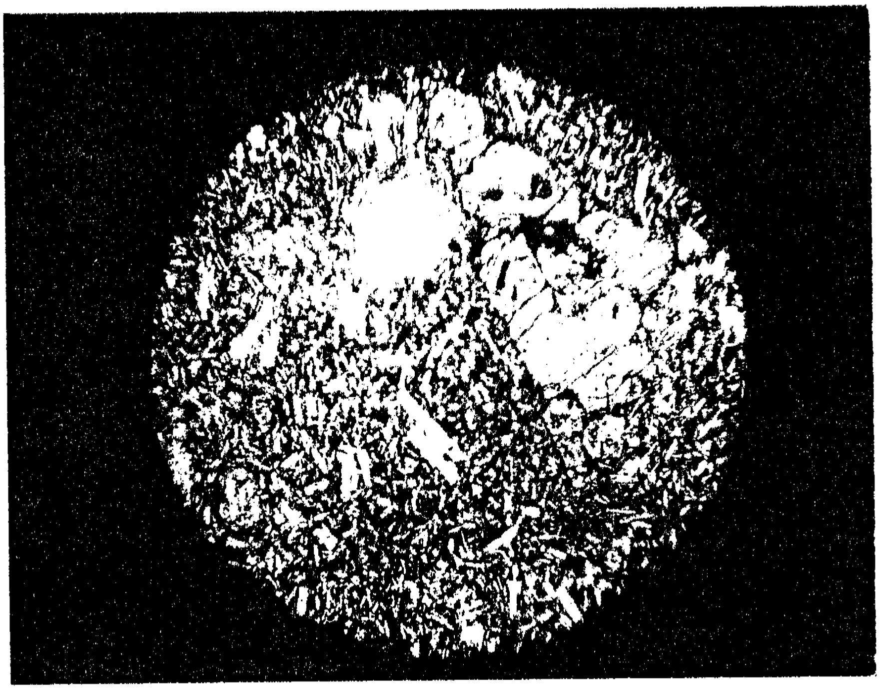


Plate IV. Dark Gray Andesite
Trachytic texture. Vesicle filled with clay and zeolites. The large crystal is altered to clay and outlined with hematite. X 25

with clay, zeolites, calcite, and quartz. The quartz was the last product to form. The vesicles vary from about 2 mm to 10 mm in diameter. The color of a fresh surface varies from medium light gray (N 6) to grayish black (N 2) while a weathered surface is mostly a dark gray (N 3) (Rock-color Chart, 1963).

The Dark Gray Andesite is a dense, non-porous rock, and serves as a barrier to ground water movement. This is indicated by a spring at the contact between this unit and the overlying Tuffaceous Unit. The contact between the two units is sharp and trends N 39° W within the area mapped.

The Tuffaceous Unit

The Tuffaceous Unit is located immediately above the Dark Gray Andesite south of the laboratory. It is seen in no other location in the area mapped. This unit consists of four subdivisions--an interbedded tuff breccia and volcaniclastic sandstone at the base, a rainbow-hued air-fall tuff immediately under a red, welded ash-flow tuff, and a white air-fall tuff at the top. The interbedded tuff breccia is quite resistant to weathering and forms a distinct outcrop along the slope. Topographically it is expressed by an abrupt steepening in the slope. The two middle members of the unit are not as resistant. Thus there is a more gentle, bench-like slope between the tuff breccia and the white air-fall tuff which is again resistant. The white air-fall tuff crops out like a retaining wall along the mountainside. The tuff breccia is the most limited in extent and pinches out to the west against the Dark Gray Andesite. The Tuffaceous Unit has a maximum thickness of about 480 feet. However, faulting and erosion cause it to have an outcrop thickness of approximately 100 to 140 feet.

The interbedded tuff breccia and volcaniclastic sandstone is the basal member of the Tuffaceous Unit and overlies the Dark Gray Andesite. This member is very well-bedded with the beds striking north-south and dipping 30° E. The individual beds vary in thickness from 3/4 of an inch to six inches. The total thickness of the member is approximately six feet. Resting immediately upon the andesite is a fine grained, dark brownish gray (5 YR 4/1) volcanic graywacke (Williams, Turner, and Gilbert, 1954). Its median grain diameter is .07 mm; the size range is from .03 mm to .20 mm, i.e., from a coarse silt to the upper size boundary for fine sand. The grains are very angular and are tightly packed. The sorting is poor. Its mineralogic composition is given in Table 4. This volcanic graywacke bed has a thickness of two inches. The other sandstone layers belong more to the volcanic arenites. They are also lighter in color, being either reddish or grayish brown. Some layers contain abundant lithic fragments along their bottom boundaries. The common thicknesses are 3/4 and one inch.

Plate V. Tuffaceous Unit
Dr. Clay T. Smith by the outcrop of the interbedded tuff breccia and volcaniclastic sandstone.

Plate VI. Tuffaceous Unit
Close-up of the interbedded tuff breccia and volcaniclastic sandstone. The hammerhead is resting upon the underlying Dark Gray Andesite.

Table 4. Composition of basal graywacke
Tuffaceous Unit

Composition	Vol. %
Framework Grains	62
plagioclase	10
sanidine	15
quartz (some chert)	17
magnetite	10
andesite fragments	10
Matrix	38
clay	30
ash	8

The tuff breccia layers average 5 to 6 inches in thickness. Commonly the boundary is slightly gradational from sandstone to tuff breccia; occasionally it is sharp. However, tuff breccia never grades into sandstone; that boundary is sharp. Within the tuff breccia layers there are gradations from a more lithic to a more crystalline character. Rock fragment content varies from 30 to 50% and the crystal content varies from 20 to 5%. The groundmass or matrix remains at 45 to 55% of the rock. The rock fragments are small, ranging from .40 mm to 2.80 mm in diameter. Also there are some of about .06 mm diameter that are included in the matrix. Typically the lithic inclusions are predominantly pumice or glass; subordinate andesite and rhyolite fragments are present in about equal amounts. The rhyolite shows various characteristics of flow and welded rocks. Glass fragments, lithified ash, chert, and tuff breccia are also present. The lithic fragments are all angular, and the phenocrysts are broken. Feldspars are the dominant phenocrysts. Sanidine is

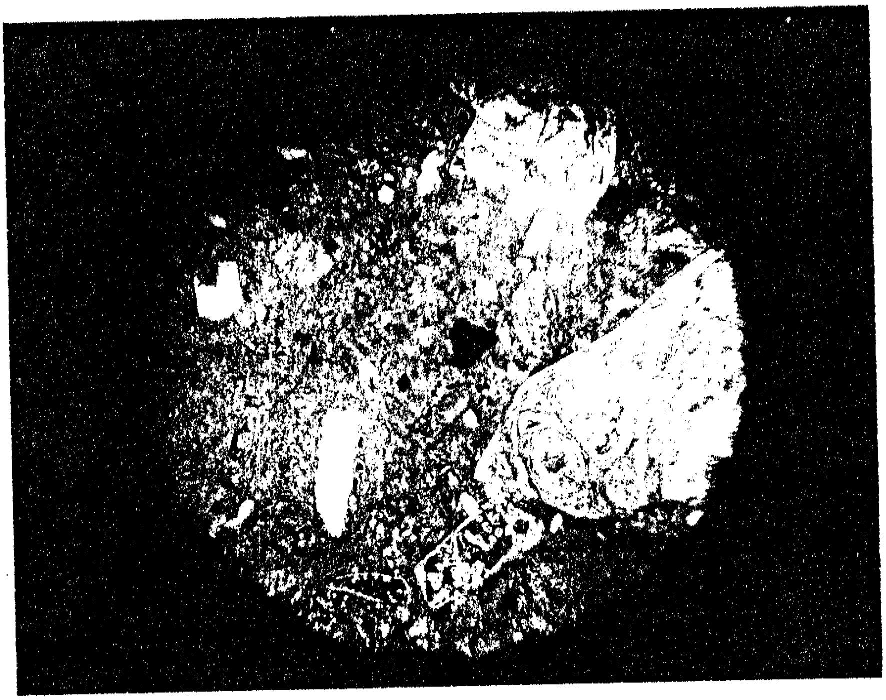


Plate VII. Tuffaceous Unit
Tuff Breccia. Perlitic cracks in glass fragments; ash in the groundmass. X 25

slightly more common than plagioclase. A few zoned plagioclase crystals were noted. The plagioclase is oligoclase. The quartz crystal content varies from an abundance equal to the feldspars to only a few scattered crystals. In some layers magnetite and hematite are quite common along with biotite. In other layers these minerals are scarce. The content of the groundmass is varied. Clay minerals are common to all layers. Shards, undeformed or only slightly deformed, are present in some layers. Small crystals and ash from .04 to .02 mm in diameter are commonly present as is also hematite. Some layers have a green coloration from chlorite. The outcrop as a whole has a light gray appearance. Individual layers of the tuff breccia may vary from a very light gray (N 8) to pale red (5R 6/2, 10R 6/2) to pale brown (5YR 5/2).

Immediately overlying the tuff breccia is a vividly orange-pink air-fall tuff. The tuff is most vividly colored (a moderate reddish orange (10R 6/6) and light red (5R 6/6)) above the tuff breccia; around the slope to the west it fades to a moderate pink (5R 7/4) and a grayish orange-pink (5YR 7/2) which then interfingers with a pale grayish yellow green (5GY 7/2) color. Above the green and flesh colored portions is a light grayish blue (5PB 6/2) air-fall tuff. The green to orange-pink tuff varies in thickness from about 40 feet to approxi-

Plate VIII. Tuffaceous Unit
Float of orange-pink air-fall tuff that immed-
ately overlies the interbedded tuff breccia and
volcaniclastic sandstone.

mately 200 feet. The blue portion has an estimated thickness of 70 feet. Both the colored tuffs and the tuff breccia pinch out to the west against the Dark Gray Andesite. Exact thicknesses and relationships between the colored tuffs are obscured by faulting but the units seem to thicken toward the east.

A fresh surface of the vivid, orange-pink tuff is a paler version of the weathered color. This tuff contains about 3% of small, 2-5 mm diameter, rhyolite and andesite fragments. Pumice, again of very small size, may be as much as 10 to 15%. Phenocrysts average about 25% of the rock and are mostly feldspar with some biotite, magnetite or hematite, and quartz. The crystals and lithic inclusions are randomly oriented, but the pumice seems to be in a roughly parallel arrangement. The feldspars and the matrix are intensely altered, probably to clay.

Table 5 lists the composition of the green variant of the tuff. The matrix was mostly ash and is now clay,

Table 5. Composition, green tuff, Tuffaceous Unit

Composition	Vol. %
Phenocrysts	15
plagioclase	4
sanidine	7
quartz	1
magnetite & hematite	3
Lithic fragments	35
pumice	20
glass	10
andesite	3
rhyolite	2
Groundmass	50

chlorite, and calcite. The green coloration is a result of the chlorite content. The pumice and glass are devitrified.

The grayish-blue air-fall tuff also varies to a pinkish-gray color occasionally. Fresh surfaces are lighter and a bit more gray (N 5) in color. Crystals and rock fragments are randomly oriented. Most of the rock fragments are quite small with the largest being about 10 mm in diameter. The rock has a distinct vitroclastic texture with a few perlitic cracks. This is completely unlike that of the green variant. Its composition is given in Table 6. The rock has been

Table 6. Composition, blue-gray tuff
Tuffaceous Unit

Composition	Vol. %
Phenocrysts	7
feldspar	5
magnetite	2
quartz & biotite	trace
Lithic fragments	10
pumice	7
andesite	3
rhyolitic welded ash flow tuff	trace
tuff breccia	trace
Groundmass	80
shards	50
ash	30

silicified; tiny quartz veins are present. The glass shards are not deformed but have completely devitrified. The pumice has also devitrified and the ash has altered to clay. All the feldspars have been replaced by quartz.

The red, welded ash-flow tuff overlies the blue air-

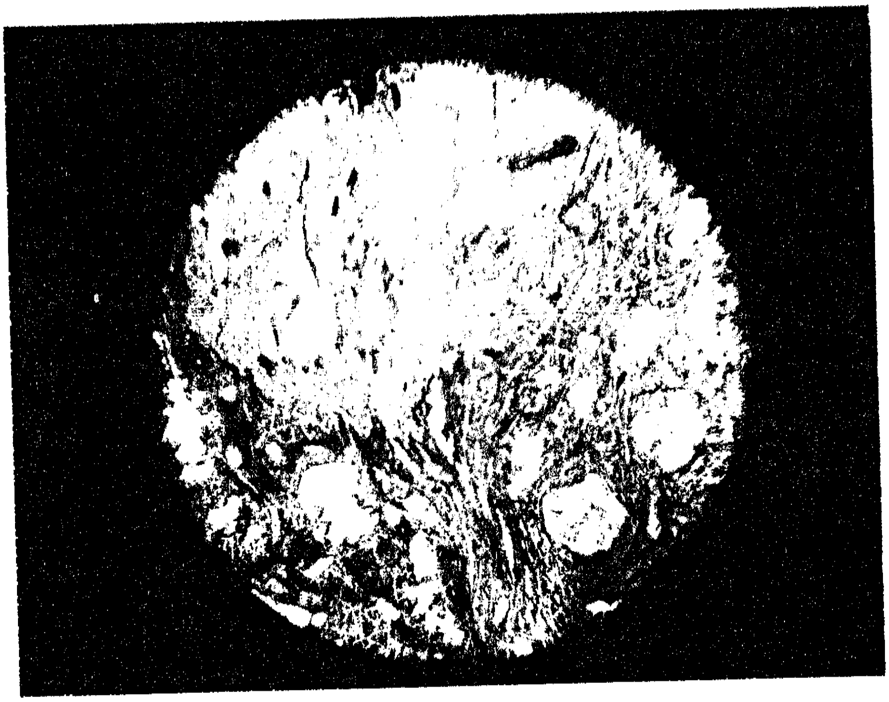


Plate IX. Turfaceous Unit
Red, welded ash-flow tuff. Perlitic cracks in groundmass; elongated glass shards. X 25

fall tuff and underlies the white air-fall tuff. It has a thickness of about 140 feet. Its weathered surface ranges in color from a pale red (5R 6/2) to a pale reddish brown (10R 5/4) to a grayish red (5R, 10R 4/2) while a fresh surface is a pale red-purple (5RP 6/2). Lithic inclusions and flattened pumice are prominent with the latter marking a definite flow lineation. The biotite also has an orientation roughly parallel to that of the pumice. The glass shards are compacted and elongated. The crystals are broken and served as seeds for devitrification of the groundmass. There are some spherulites or axiolites present, and the groundmass is marked by perlitic cracks. Mineralogic composition is given in Table 7. The sanidine is altered to clay; the edges of

Table 7. Composition, ash-flow tuff
Tuffaceous Unit

Composition	Vol. %
Phenocrysts	30
sanidine	21
quartz	6
magnetite	2
biotite	1
Lithic Fragments	20
pumice	18
andesite	2
Groundmass	50
shards	40
ash	10

the magnetite, to hematite; and the pumice has devitrified completely and has been partially replaced by chert. The flattened pumice contains quartz and biotite crystals. Silicification is evident from cross-cutting quartz veins. The shards are compacted and devitrified; the very fine ash is now clay. Some alteration in the groundmass has resulted in the formation of zeolites.

The upper member of the Tuffaceous Unit is a white air-fall tuff. It has massive bedding with a minimum of two feet between rough bedding planes. It varies in thickness from approximately 60 to 100 feet. It forms a resistant ridge along the mountainside and marks the change from a gentle bench to a steep slope. In color the weathered surfaces vary from very light gray (N 8) to pinkish gray (5YR 8/1) to a pale yellowish brown (10YR 6/2); fresh surfaces are a very light gray (N 8) or a grayish pink (5R 8/2). This member is characterized by bronze biotite grains and dipyramidal quartz crystals. The crystals are either euhedral, often with broken ends, or broken anhedral grains. Except for the edges of a few feldspar crystals, the rock is unaltered. Most of the crystals are about .90 mm in diameter with the largest attaining a 1.90 mm diameter. The composition is listed

Table 8. Composition, white air-fall tuff
Tuffaceous Unit

Composition	Vol. %
Phenocrysts	40
sanidine	20
quartz	15
biotite	4
magnetite	1
Lithic fragments	1
angular tuff fragments	1
Groundmass	59
(mostly clay)	

in Table 8. There are some minute crystals and ash in the groundmass.

Rosy Sandstone

The Rosy Sandstone unit unconformably overlies the Tuffaceous Unit and unconformably underlies the Pyroxene Andesite south of the laboratory (see plate I). Even though the sandstone is well lithified, it is less resistant than the volcanic units and forms a bench in the slope. It is thinly bedded, most of the layers ranging from $1\frac{1}{4}$ to 6 in. in thickness with some being as thin as $\frac{1}{4}$ inch. Some beds exhibit a gradation from fine to coarse grains of sand and then grade back to fine. Other layers show cross bedding and very poor sorting. Occasional volcanic rock inclusions about 8 cm in diameter are present. Quartz veins crosscut the beds. In places the veins do not completely fill the fracture and quartz crystals line the sides of the opening. Iron stains also crosscut the beds. The sandstone surface varies in color from a light brownish gray (5YR 6/1) to pale red (5R, 10R 6/2) to a dark rosy-beige (10R 4/2). Weathered surfaces are usually a warm reddish color but fresh surfaces are beige (5YR 7/1, 5R 8/2, 10R 6/2). The sandstone varies in thickness from approximately 50 to 100 feet.

The sandstone is well cemented and exhibits laminations and very thin bedding ($\frac{1}{8}$ to $1\frac{1}{4}$ in.) in thin section. Texturally it has 5% gravel and 95% sand size grains; a median diameter of .30 mm and a size range of 3.70 to .06 mm; very poor sorting with varied rounding--

grains are both angular and rounded; the packing is loose; porosity and permeability are poor; there has been suturing of crystal boundaries; and feldspars have been replaced by authigenic kaolinite. Mineralogically it consists of 55% quartz, 15% sanidine, 5% rock fragments--intergrown quartz and volcanic rocks, 3% miscellaneous transported constituents--biotite, hematite, magnetite, and zircon (there are lenses with up to 10-15% mafic grains); and 22% authigenic kaolinite. According to the Williams, Turner, and Gilbert sandstone classification (1954, p. 293) it is a feldspathic arenite.

Sawmill Canyon Rhyolite

The Sawmill Canyon Rhyolite is located in the bottom of Sawmill Canyon east of the laboratory. It is best seen in the stream bottom. Weathered surfaces vary in color from a grayish red-purple (5RP 4/2) to a medium light gray (N 6) and a brownish gray (5YR 4/1), and have iron and manganese stains. Phenocrysts and andesitic rock fragments are prominent. The thickness of this unit is unknown, but it is certainly greater than 200 feet. Examination of a thin section shows highly flattened glass shards that are difficult to distinguish from flow lines. There are compaction structures around phenocrysts and pumice. The groundmass is generally marked by perlitic cracks. The flattened pumice is roughly parallel while the phenocrysts are randomly oriented. The crystals are

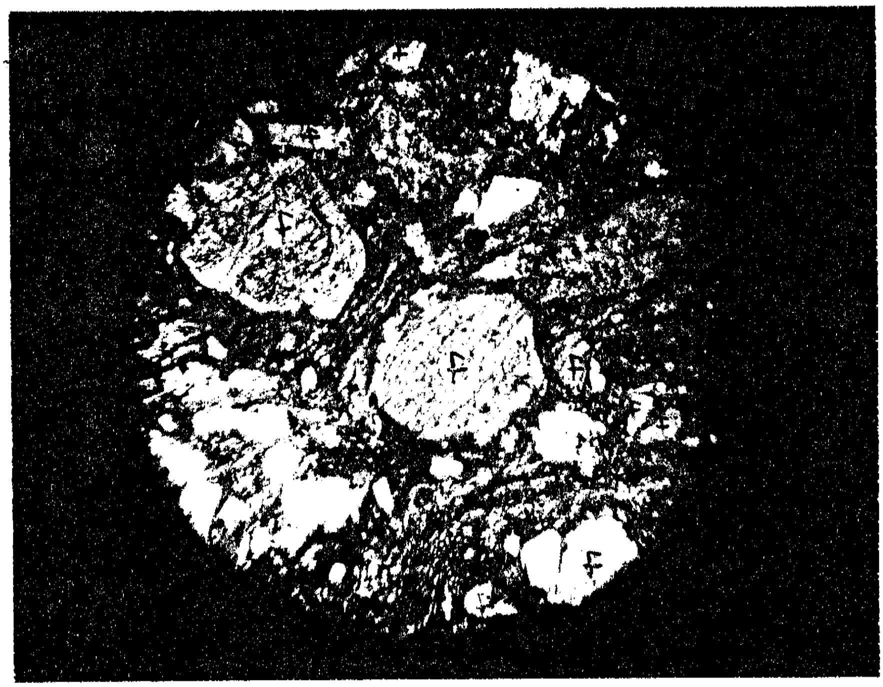


Plate X. Sawmill Canyon Rhyolite
Groundmass: welded shards, clay. Phenocrysts: f- altered feldspars. X 25

Table 9. Composition of Sawmill Canyon Rhyolite

Composition	Vol. %
Phenocrysts	40
plagioclase	10
sanidine	22
quartz	8
magnetite	trace
Lithic fragments	30
pumice	20
andesite (5-8 mm	10
rhyolite diameter)	trace
Groundmass	30
shards (devitrified)	15
clay	15

mostly anhedral and are broken. Table 9 gives the mineralogic composition of this unit. Phenocrysts are large; diameters of 1.90 mm are common. Relict plagioclase laths are replaced by calcite; sanidine is replaced by calcite, clay, and some quartz. The pumice is devitrified and is replaced by clay, zeolites, and some quartz. The rhyolite is intensively altered. The order of replacement is clay by quartz, some of which is strained, and finally calcite. The rhyolite originally was a welded ash-flow tuff.

Sawmill Canyon Andesite

The Sawmill Canyon Andesite is a composite unit of andesite flows with a small layer of air-fall tuff of silicic composition. It is located to the east and northeast of the laboratory in the bottom of Sawmill Canyon. The best exposures of the unit are in the stream bottom. The unit overlies the Sawmill Canyon Rhyolite unconform-

Plate XI. Sawmill Canyon Andesite
The stream forms a tiny waterfall over a
resistant outcrop of the basal flow andesite.

Plate XII. Sawmill Canyon Andesite
The porphyritic portion of the basal flow andesite.

ably and underlies the Purple Rhyolite unconformably; it has a total thickness of 780 feet.

The basal member of this unit is a very fine-grained to porphyritic andesite. It is a grayish blue (5PB 4/2) to medium dark gray (N 4) rock with hematite and limonite stains and spots of green in the dark aphanitic zones. Other zones are quite porphyritic with the phenocrysts having a generally parallel orientation. The total thickness is 240 feet. It is thought to be composed of several flows since the aphanitic and porphyritic zones seem to be in horizontal layers. There is also a small inclusion on one side of the streambed of an unconsolidated tuffaceous conglomerate. The conglomerate has a white clayey matrix and purple lithic fragments which range in size from 1 to 4½ inches. Texturally the aphanitic zones appear somewhat crushed or brecciated, and the euhedral crystals are broken and in a random orientation. This may vary to a pilotaxitic texture

Table 10. Composition, basal member Sawmill Canyon Andesite

Composition	Vol. %
Phenocrysts	7-31
(average size .45-.05 mm)	
plagioclase	2-25
sanidine	0- 1
pyroxene, hornblende, magnetite	5- 7
Groundmass	69-93
cryptocrystalline	25-47
clay, disseminated hematite	40-46
calcite	5

with parallel orientation of the dark minerals in the porphyritic zones. The composition is given in Table 10. The plagioclase falls within the oligoclase-andesine range, i.e., An 24 to An 37. 65-75% of the unit is altered. The feldspars were altered to clay and have been partially replaced by calcite; the mafic minerals have been altered to clay and hematite and are now relict shapes; the groundmass has been hematitized, carbonitized, and partially altered to clay.

The grayish yellow green (5GY 7/2) tuff is the next member of the unit. It has a thickness of approximately 10-15 feet. It outcrops along the east side of the stream at a fairly constant elevation. A rough, thin bedding is prominent. The pumice has parallel orientation. Most of the crystals are anhedral and there are perlitic cracks in the glassy lithic fragments. Its composition is given in Table 11. The plagioclase is altered to clay; sanidine is corroded at the ends; and

Table 11. Composition, green tuff
Sawmill Canyon Andesite

Composition	Vol. %
Phenocrysts	23
plagioclase	2
sanidine	20
quartz	1
magnetite	trace
Lithic fragments	18
pumice	15
lithified ash & glass	2
andesite	1
Groundmass	59
clay	39
chlorite	20

quartz has replaced some of the feldspars. The pumice is devitrified and altered to clay and chlorite. Some of the zeolitic alteration may have been derived from glassy fragments. The whole rock has undergone chloitization which accounts for the green coloration. Often the grayish green (10GY 5/2) chlorite is concentrated in the pumice.

The next member is a medium bluish-gray (5B 5/1) rock very similar to the basal member. It has a 300 foot thickness. Its texture is hyalopilitic, and it has subhedral crystals. Table 12 gives its composition. The

Table 12. Composition of upper andesite Sawmill Canyon Andesite

Composition	Vol. %
Phenocrysts	6
pyroxene relict shapes	4
augite	2
Groundmass	94
plagioclase	45
clay	25
magnetite & hematite	15
calcite	10
augite	trace

pyroxenes are altered to clay outlined by hematite; the augite is not completely altered. There was carbonitization, hematitization, silicification, and albitization of the rock. The flattened vesicles in the andesite are filled with calcite and zeolites; the walls are lined with small crystals of quartz, feldspar, and a manganese mineral (see plate XIII B). The manganese mineral is acicular, opaque, very dark brown in color, and

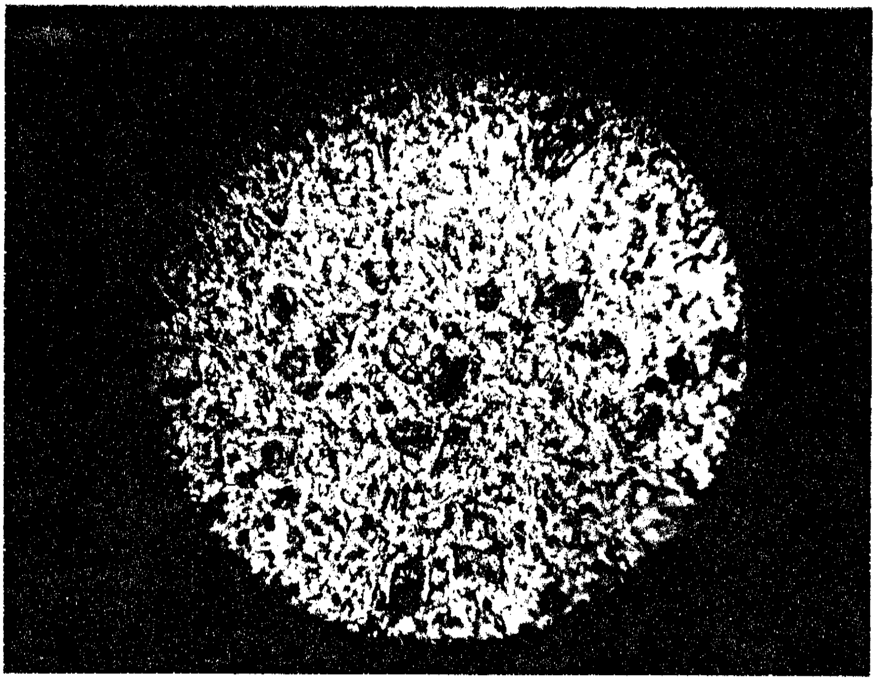
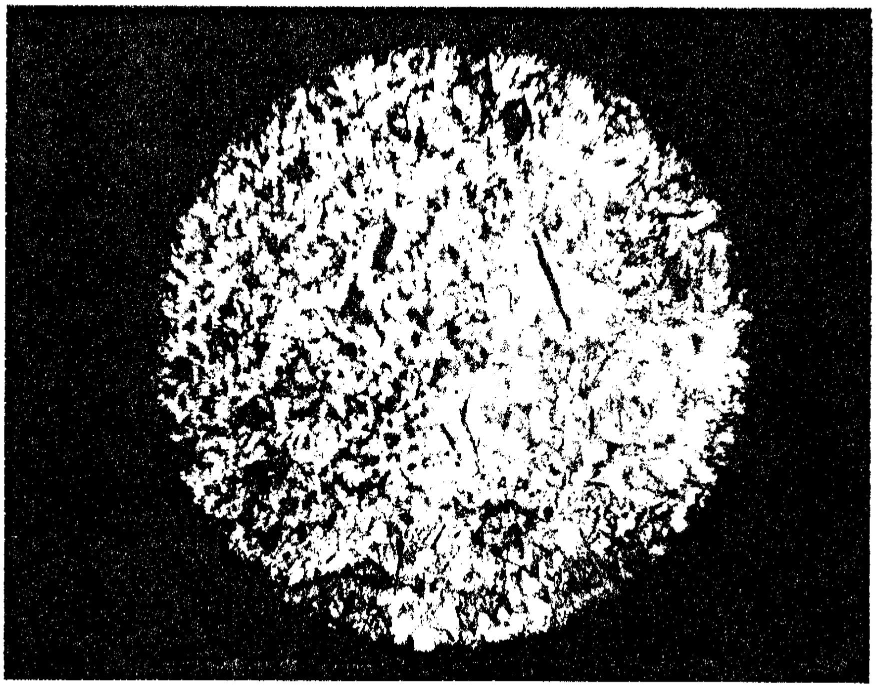


Plate XIII. Sawmill Canyon Andesite
A. Hyalopilitic texture. Phenocrysts: a-augite, others-pyroxene relicts. X 25



B. Right half of the picture: acicular manganese mineral in other alteration products. X 25 has an earthy luster.

The top 200 feet of the unit is a medium light gray (N 6) porphyritic dacite. Most of the crystals in the dacite are euhedral. The largest phenocrysts have a 10-13 mm diameter while most are about 2-3 mm. Table 13 lists its composition. The feldspars and groundmass

Table 13. Composition, dacite Sawmill Canyon Andesite

Composition	Vol. %
Phenocrysts	44
plagioclase	23
potash feldspar	7
quartz	6
pyroxene & hornblende	6
biotite	2
Lithic fragments	1
andesite	1
Groundmass	55

are altered to clay. Silicification is indicated by quartz veins cutting the outcrops.

Southwestern Basal Group

Unconformably underlying the Purple Rhyolite southwest of the laboratory is the Southwestern Basal Group (see plate I). It has a minimum thickness of 120 feet. None of its members are very resistant compared to the other volcanic rocks in the area mapped. A flow andesite immediately underlies the Purple Rhyolite. It is a medium dark gray (N 4) to brownish gray (5YR 6/1) aphanitic rock. It has undergone hematitization and silicification. It appears to have a thickness of 60 feet. Underlying part of the andesite is a light brownish gray (5YR 6/1), rhyolitic, air-fall tuff. It is best seen by the side of the Hardy Canyon Trail at about the 9600 foot level. It has a thickness of 15 to 20 feet and does not extend to the east. About 15% of it is pumice; 3% plagioclase; 25% potash feldspar; and 5% quartz. There are occasional andesitic fragments of 1 to 2 inches in size. Except that it has not undergone alteration to chlorite, it is very similar to the pale green tuff found in the bottom of Sawmill Canyon. Underneath this air-fall tuff is a medium dark gray (N 4), tuffaceous wacke. To the east it underlies the flow andesite. Pumice, largely altered to chlorite, comprises approximately 10% of the rock. The rest of the rock consists of 30% plagioclase altered to clay; 2% potash feldspar only partially altered; and 5% angular andesitic inclusions of a 5-15 mm size. The matrix is quite clayey; and varies from semi-consolidated to lithified.

Pyroxene Andesite

The Pyroxene Andesite is located south of Langmuir Laboratory. The Upper Sandstone unconformably overlies it, and it seems to overlie the Rosy Sandstone unconformably. The andesite is of limited extent and is bounded to the east and west by faults. Because of the faulting and limited outcrops an accurate estimate of its thickness was not possible. The best outcrop has a height of 50 to 60 feet while the entire unit may have a thickness of 120

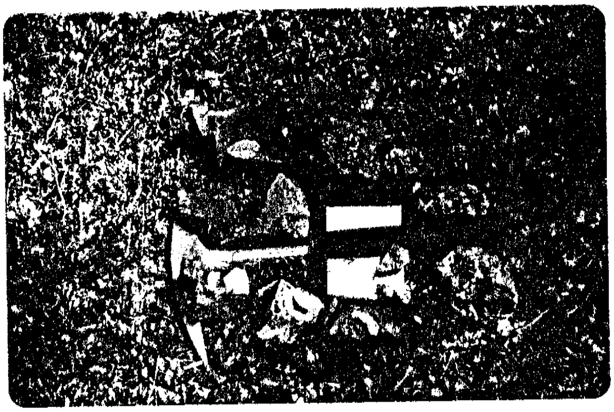


Plate XIV. Pyroxene Andesite
Handspecimens showing the different aspects of this unit; the vesicle fillings; and the iron coatings.

feet. The andesite is quite scoriaceous near the top of the outcrop. Elsewhere a dense, aphanitic appearence with 1½ inch diameter vugs alternates with pockets of vesicular material. The upper portion of the andesite is heavily impregnated with minerals of probable deuteric origin. Almost all the vesicles and all the vugs are filled with either quartz, calcite, or a combination of the two. A dusky green (5G 3/2) to grayish green (5G 5/2) iron mineral forms a coating around the vesicles and vug fillings. The calcite is often coarsely crystalline with rhombohedral cleavage visible. Quartz crystals line some of the cavities and may be as long as 6 or 7 mm. Specular hematite is on some surfaces and red hematitic stains are common along joints. Rafted sandstone was observed in the center of the unit. It has no visible relation with either the over- or underlying sandstone.

The andesite has a trachytic texture with approximately 90% groundmass. The crystals are euhedral and subhedral, and most are broken. The vesicles are flattened and in parallel orientation. In places the vesicles comprise 10 to 25% of the rock. Relicts of hornblende, pyroxene, and amphiboles are the most abundant phenocrysts and comprise 5 to 6% of the rock. The pyroxene may have been hypersthene. Magnetite and hematite varies from a trace to 1% of the rock. Originally there may have been olivine present. Most feldspar phenocrysts

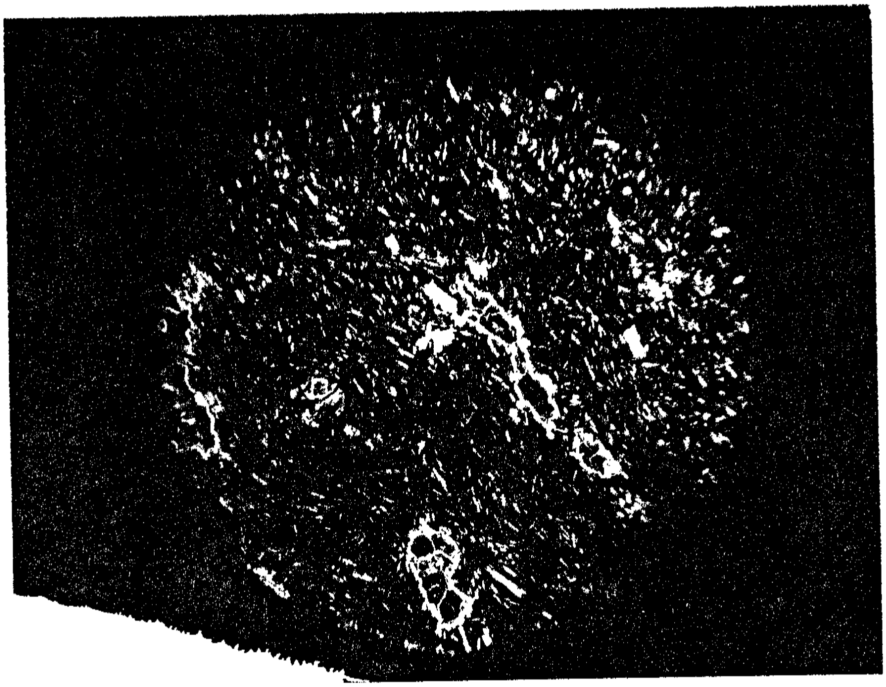


Plate XV. Pyroxene Andesite
Trachytic texture. Vesicles filled with clay, lined with chlorite. X 25

are plagioclase with an occasional sanidine crystal. The largest feldspar has a .10 mm width. There are a few small lithic inclusions. The groundmass has traces of augite and 7% disseminated hematite. Pyroxene, amphibole, and hornblende are altered to hematite, chlorite, clay, or a small amount of zeolite. Most of the feldspar, whether in the groundmass or as phenocrysts, has altered to clay with a small amount of zeolite. The vesicles are lined with either a chlorite or clay, and filled with calcite, clay, calcite-clay mixture, chlorite, or zeolite.

Upper Sandstone

The Upper Sandstone unconformably overlies the Pyroxene Andesite and unconformably underlies the Purple Rhyolite. It is quite localized in extent. It has a thickness of approximately 3 to 10 feet. It is a well cemented, pale red (5R 6/2) to grayish red (5R 7/2, 4/2) to pale grayish brown (5YR 6/2, 5/2) sandstone. The sandstone is less resistant than the enclosing volcanics and forms a small bench in the slope. The thickness of the beds varies from .5 to 20 cm. There is some graded bedding present. The sand grains filled in all the rough areas of the andesite flow surface. Texturally it has 100% sand size grains, median diameter about .08 to .12 mm, size range of .06 to .30 mm; it is moderately sorted with angular and very angular grains; the grains are moderately to tightly packed; porosity and permeability are poor; and the mafic minerals and rock fragments are altered to hematite. Mineralogically it consists of 50% quartz, .5% potash feldspar, 13% plagioclase, 15% volcanic rock fragments--some from the underlying andesite, 7% magnetite with a small amount of biotite 80% altered, and 10-25% cement. The cement consists of hematite, opaline silica, and a small amount of clay. It is a volcanic feldspathic lithic arenite.

Feldspathic Andesite

This unit has been called the Feldspathic Andesite because of a predominance of feldspar phenocrysts in it and a lack of feldspar phenocrysts in the other andesites. The Feldspathic Andesite apparently underlies the Purple Rhyolite but faulting obscures the exact relationship. The Laharic Breccia unconformably overlies it (see plate I). It is only moderately resistant and does not form a massive outcrop. The andesite has an incomplete thickness of 120 feet because extensive faulting masks the relationships. It is medium dark gray (N 4) to brownish gray (5YR 4/1) in color with fresh surfaces being medium gray (N 5). Reddish iron stains and thin quartz veins cut the outcrop. Its texture is hyalopilitic. The crystals are mostly euhedral and some are broken. There is a very rough parallel orientation of the feldspar laths as a result of flow in the lava. Its compo-

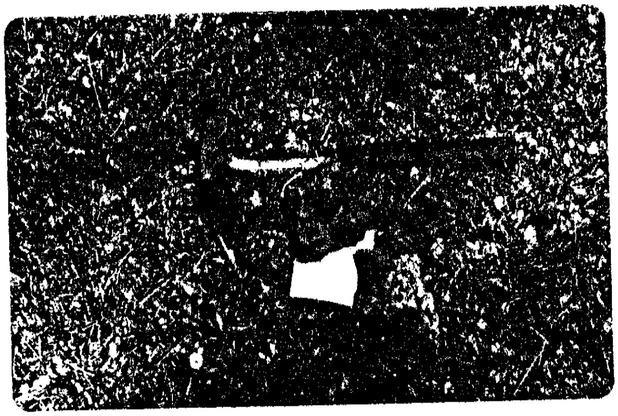


Plate XVI. Feldspathic Andesite
Laharic Breccia
The center handspecimen is Laharic Breccia from an outcrop at the top of the Feldspathic Andesite. The other handspecimens are the Feldspathic Andesite.

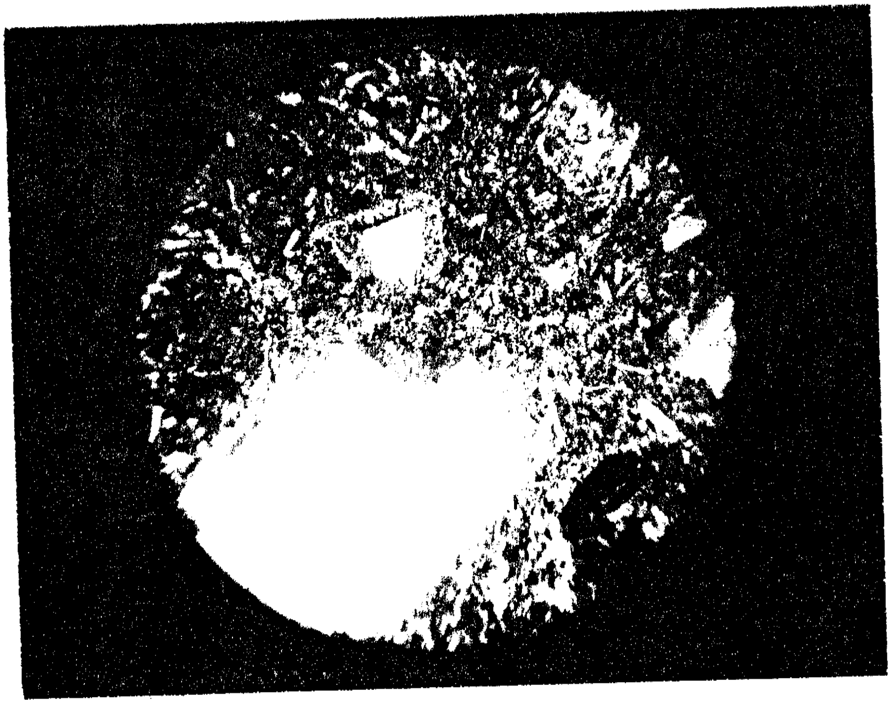


Plate XVII. Feldspathic Andesite
Hyalopilitic texture. Rimed plagioclase; the large plagioclase crystal is zoned. X 25

Table 14. Composition of Feldspathic Andesite

Composition	Vol. %
Phenocrysts	31
plagioclase	23
sanidine	1
quartz	trace
magnetite & hematite	5
amphibole & pyroxene	2
Groundmass	69
devitrified glass	44
feldspar	20
magnetite	5

sition is given in Table 14. The groundmass is altered to or replaced by clay and calcite. Most of the magnetite is altered to hematite. The amphiboles and pyroxenes are relict shapes with the original minerals being completely replaced by hematite and clay. The feldspar phenocrysts are 70-80% altered to clay and replaced by calcite. Some of the plagioclase crystals are zoned and many have potash feldspar rims. The larger and less altered plagioclase phenocrysts fall within the labradorite range, i.e., An 50 to An 65. In a zoned plagioclase the center was An 64 and an outer zone, An 32. Zoned plagioclases are not abundant.

Purple Rhyolite

The Purple Rhyolite is the most extensive of the units mapped. Langmuir Laboratory is situated upon this unit. Roughly the rhyolite occupies a central position in the area mapped with the other units generally around its periphery (see plate I). The outcrops form 40-to-200 foot cliffs with extensive talus slopes. The slopes are steep where there are no outcrops. The Mohawk Peak Rhyolite, the South Baldy Andesite, the Laharic Breccia, and the Quaternary Alluvium unconformably overlie the Purple Rhyolite. It in turn conformably overlies the Feldspathic Andesite, the Upper Sandstone, the Rosy Sandstone, the Sawmill Canyon Andesite, and possibly the Sawmill Canyon Rhyolite. In thickness the Purple Rhyolite varies from a minimum of 850 feet to approximately 1300 feet. This rhyolite is a multiple flow, compound cooling unit, welded ash-flow tuff.

The Purple Rhyolite has three obvious variations. They are vertically gradational and cannot be delineated sharply. They are best exposed down the ridge to the south of the laboratory. Broadly the upper portion is a phenocryst-rich, densely welded ash-flow tuff; the middle section is a pumiceous, welded ash-flow tuff; and the bottom portion is a more lithic, phenocryst-poor, less welded ash-flow tuff. There is also a color change from purple through a grayish purple to a distinctly reddish purple.

In color the weathered surfaces of the upper portion of the Purple Rhyolite vary from grayish red purple (5RP 4/2) to moderate reddish brown (10R 4/6) to lavendar (5P 5/2) with occasional pale pink (5RP 8/2) areas unrelated to any pumice. Fresh surfaces vary from grayish red purple (5RP 4/2) and dark yellowish brown

Plate XVIII. Purple Rhyolite
Handspecimens of the upper portion and of the red, siliceous vein showing aphanitic and phaneritic portions. Dendrites of pyrolusite show on the weathered surface of the upper right rock. Specimens are from under the laboratory.

Plate XIX. Purple Rhyolite
The handspecimen on the right is of the pumiceous portion of the unit. The lower left rock is a sample of the basal, lithic member. The upper left specimens show the brecciation and carbonitization found along the Calcite Fault which cuts the outcrop.

(10YR 4/2) to light brownish gray (5YR 6/1). The matrix is fine-grained and phenocrysts are not prominent except where the rock has been intensely weathered. Crystals are anhedral and subhedral with all being broken. They are in haphazard orientation. Pumice when present is small, flattened, and not readily recognizable at an outcrop. The shards are so greatly flattened and stretched out that it is difficult to determine that they are shards and not flow lines of a lava. The shards do show compaction around the phenocrysts. The groundmass is completely devitrified and often has shrinkage or perlitic cracks. Table 15 lists the composition of this member.

Table 15. Composition of upper member Purple Rhyolite

Composition	Vol. %	
	average range	range
Phenocrysts	55	45-65
plagioclase	trace	
potash feldspar (mostly sanidine)	10-40	
quartz	2-25	
biotite	3- 5	
magnetite & hematite	2- 5	
zircon	.4- 1	
sphene	trace	
Lithic fragments	3-10	3-25
pumice	7-10	
chert	0- 3	
volcanic rocks	.3- 1	
Groundmass	30-35	20-50

The feldspars are notable because the plagioclases are very rarely twinned and carlsbad twinning is not common in the potash feldspars. Most of the zircon is biaxial

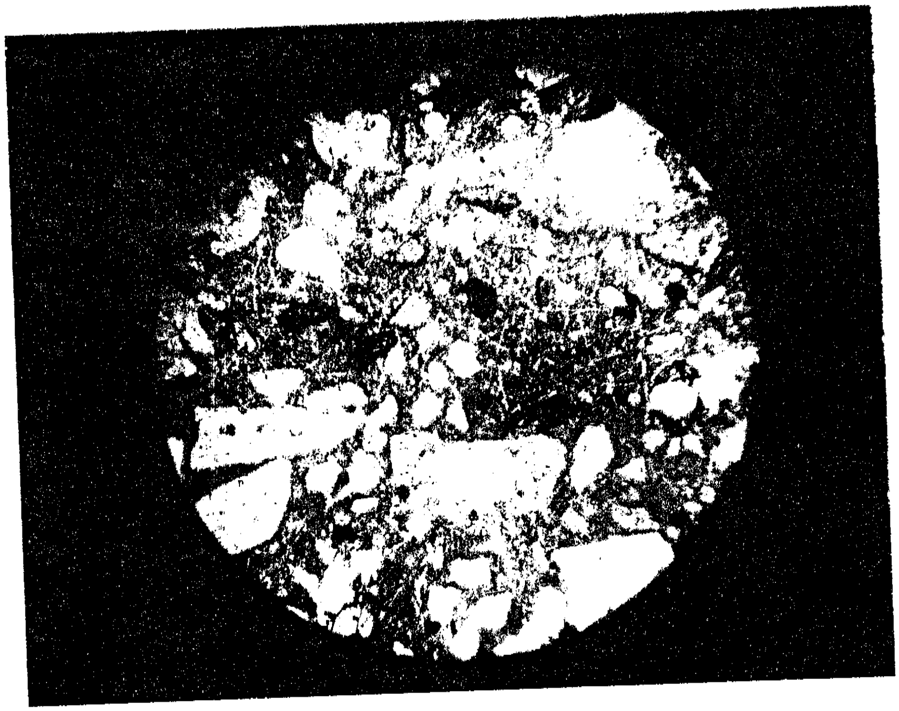
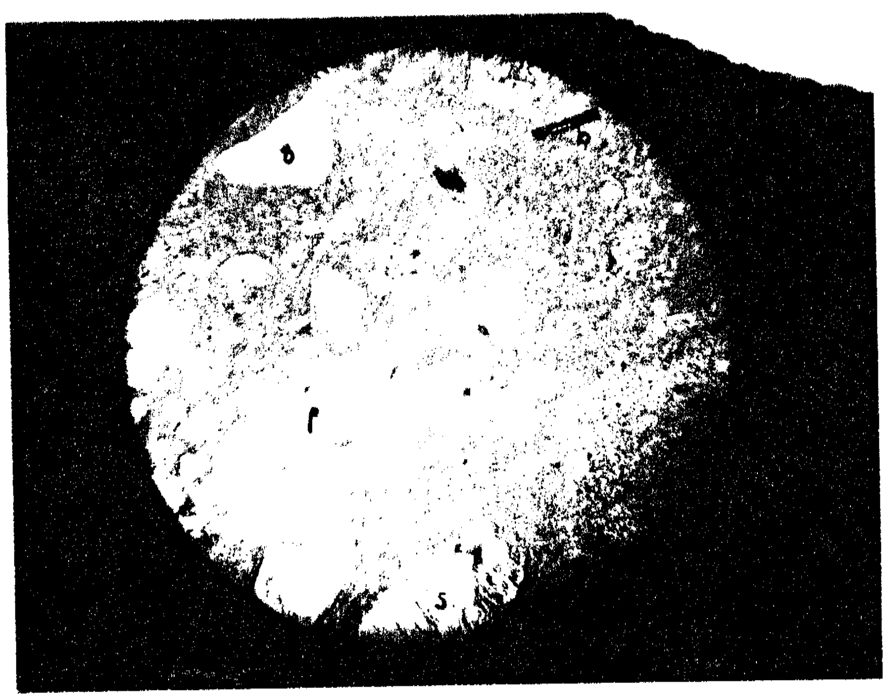


Plate XX. Purple Rhyolite

A. Upper member. Perlitic cracks; abundant phenocrysts with feldspars altered to clay. X 25



B. Pumiceous member. Broken, angular fragments of phenocrysts, q-quartz, s-sanidine, b-biotite, p-pumice. Distorted shards in groundmass. X 25 as the result of metamict alteration. The groundmass is at least 50% devitrified pyroclastic material of dust size. Deformed shards comprise the remainder, along with disseminated hematite.

The middle pumiceous member has a grayish purple (5P 4/2) to very dusky purple (5P 2/2) color with moderate and grayish orange pink (5YR 7/2 & 5YR 8/4) streaks representing the pumice. It is a fine-to-medium-grained rock. The lithic inclusions are small, usually less than 25 mm in diameter although they may be as large as 75 mm. The crystals are mostly anhedral with a few euhedral ones; all are broken. The biotite has an orientation approximately parallel to that of the pumice. Flattened, distorted shards are observed along with perlitic cracks. The composition of the middle pumiceous member is listed in Table 16; its thickness may vary from 80 to 120 feet.

The lower member is predominantly grayish red

Table 16. Composition of pumiceous member
Purple Rhyolite

Composition	Vol. %
Phenocrysts	30
(may be as much as	50)
plagioclase	trace
sanidine	27-35
quartz	2-10
biotite	1- 7
magnetite & hematite	1- 6
zircon	trace
sphene	trace
Lithic fragments	20-25
pumice	20-25
Groundmass	50
shards	25
dust	25

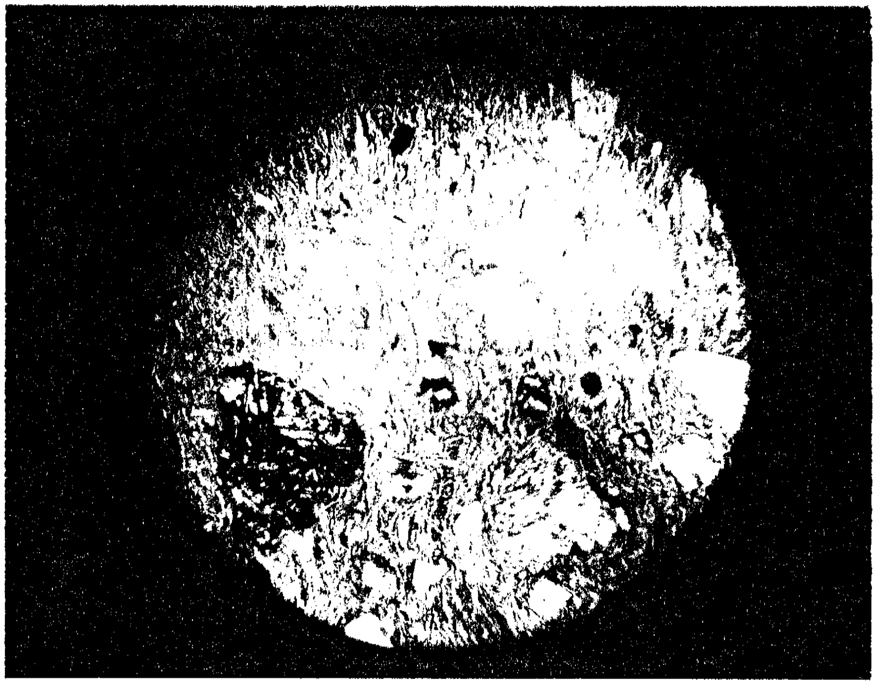
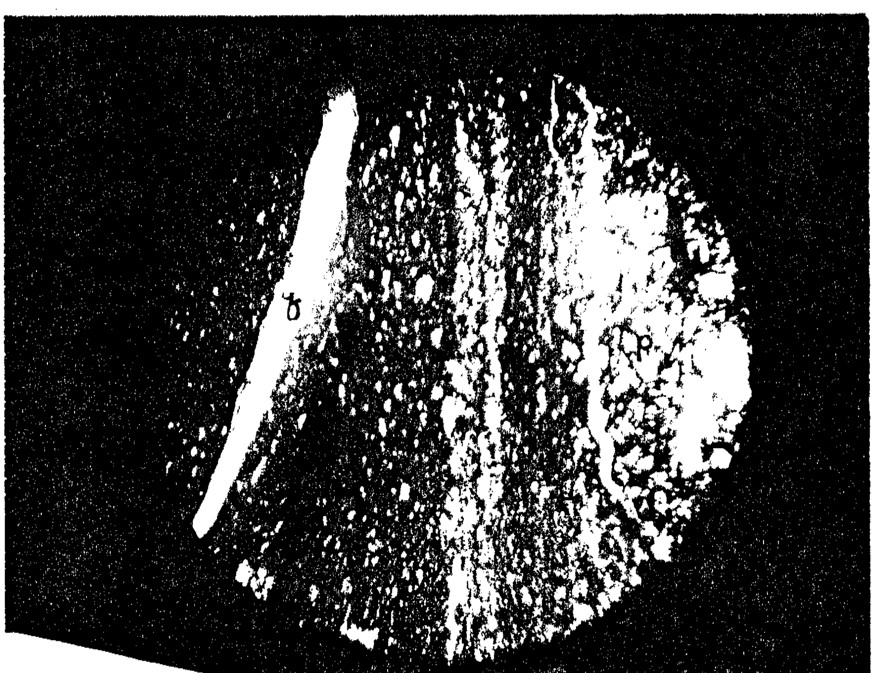


Plate XXI. Purple Rhyolite

A. Basal member. Slightly welded shards in groundmass; Broken angular fragments of phenocrysts; A-andesite inclusion. X 25



B. Red, siliceous vein. q-Quartz vein cutting aphanitic siliceous vein; p-finely phaneritic portion. X 25

(5R 4/2) to grayish red purple (5RP 4/2) in color; fresh surfaces are grayish red (5R 4/2) to pale purple (5P 6/2). The composition is given in Table 17. A very dark andesite

Table 17. Composition of basal member Purple Rhyolite

Composition	Vol. %
Phenocrysts	28
sanidine	25
quartz	2
biotite & magnetite	1
Lithic fragments	7-13
pumice	4- 8
andesite	3- 5
Groundmass	65
shards	44
dust	21

is the commonest type of lithic inclusion; the pumice is generally small. Alteration of the feldspar phenocrysts overemphasizes the abundance of crystals in the rock. In the groundmass the shards are only slightly flattened or distorted. Disseminated hematite colors the matrix of volcanic dust between the shards. This is the basal member of the Purple Rhyolite and unconformably overlies the Pyroxene Andesite and Southwestern Basal Group andesite. It has an approximate thickness of 120 to 200 feet.

The Purple Rhyolite has undergone much alteration. The order of alteration and replacement is first devitrification, then alteration to clay and hematization, and lastly, extensive silicification. There was observed some barite on fracture surfaces. The pumice after devitrification alters to clay and in some cases the central portion of the pumice lapilli is replaced by quartz. The groundmass is extensively altered to clay and has undergone hematitization. In places chert has replaced the clay. Most of the feldspars are converted to clay. Corrosion is particularly noticeable at crystal ends and along cleavage surfaces and other cracks. There has been some replacement by calcite; and near or along veins there has been replacement by quartz. Quartz overgrowths are also present. The principal clay mineral is kaolinite or occasionally montmorillonite. The biotite and magnetite have undergone partial to almost complete alteration to hematite with clay being present at times.

Veinlets of quartz, quartz porphyry, and an aphanitic, red siliceous material permeate the Purple Rhyolite. The quartz may be massive, form coatings of minute crystals, form veins of interlocking crystals, or even form coatings of larger crystals from 7 to 10 mm length. In places the veins have been brecciated and recemented with quartz. In other places they have some evidence of autobrecciation. The thickness of the veins varies from approximately 1 mm to 1 or more meters. Mostly they vary from about 1 mm to 75 mm in thickness. The veins commonly lack structural control and cut through the Purple Rhyolite at random angles to flow lines. At times they follow joints or other fractures.

The pale reddish brown (10R 5/4) siliceous veins are aphanitic; occasionally there are portions that are finely phaneritic with crystals of about .12 mm diameter.

Flow structure is observed and perlitic cracks sometimes are present in the glassy groundmass. Mineralogically they contain a minimum of 40% free quartz; a trace of plagioclase; traces of magnetite with hematite halos; and a trace of metamict zircon. Lithic fragments include chert, quartz strained and welded together; tiny bits of volcanic rocks; and oval fragments of the aphanitic portions. The red color is a result of a large amount of disseminated hematite.

The quartz porphyry has a pyroclastic appearance when seen in thin section. The groundmass is composed of small to minute quartz crystals, glass that is altered to clay, and disseminated hematite. Chert, 2 mm in size, comprises 21% of the rock; 4% is volcanic rock fragments. Quartz comprises a minimum of 50% of the rock, and there are traces of biotite and perthitic feldspar. Chert has formed as an overgrowth on or has replaced some quartz.

Barite crystals have been found along joints or fracture surfaces throughout the entire unit. They do not occur on the same surface with any of the vein material. Red hematite stains are very common along joints and fractures, and may penetrate as much as 19 mm into the rock from the fracture. Black stains are common on rock surfaces and along cracks in the rocks. These stains are probably a combination of hematite and a manganese mineral because specular

Plate XXII. Purple Rhyolite
Ubiquitous limonite stain on the surfaces of the outcrops.

hematite is observed in places and dendritic coatings typical of pyrolusite are common. In intensely brecciated and weathered areas, a white coating of a caliche-like substance is very common. The most common and ubiquitous surface stain is an orange colored film of limonite (see plate XXII).

Mohawk Peak Rhyolite

The Mohawk Peak Rhyolite is located northwest of the laboratory and forms a small peak in the main ridge. The unit has an oval shape and a maximum thickness of 160 feet. It unconformably overlies the Purple Rhyolite and nonconformably underlies the Laharic Breccia. It weathers a grayish red purple (5RP 4/2) with black manganese stains near the top of the unit and has a light brownish (5YR 6/1) to medium dark gray (N 4) coloration near the bottom of the unit. Small quartz veins and hematitic veins lace through the rhyolite. Phenocrysts are more prominent and numerous in the lower portion of the flow. Most of the crystals are euhedral. Quartz filled vesicles and andesitic lithic inclusions are present in a scoriaceous area near the top of the peak. The groundmass is aphanitic. Compositionally plagioclase accounts for no more than 1% of the phenocrysts, while potash feldspar is 70% of the phenocrysts, quartz crystals comprise 25% and diopsidic augite is 4% of the phenocrysts.

Plate XXIII. South Baldy Andesite
Copper mineralization along the fracture zone near the eastern boundary of the unit.

Plate XXIV. South Baldy Andesite
Juxtaposition of two zones in the andesite along a minor fault. The hammer is resting in the fault; slickensides are seen just to the left of the hammerhead.

South Baldy Andesite

The South Baldy Andesite is located north of the laboratory and forms South Baldy Peak. The weathered surfaces are a grayish red purple (5RP 4/2) to medium dark gray (N 4), while fresh surfaces are a grayish red (5RP 4/2) to brownish gray (5YR 4/1). The thickness varies from 400 to 600 feet. It overlies the Purple Rhyolite unconformably and underlies the Laharic Breccia unconformably. Near the boundary with the Laharic Breccia there is an area that shows autobrecciation. Along the road exposures exhibit a dense zone on top of a scoriaceous (large vesicles) zone which in turn overlies another scoriaceous (small vesicles) zone. The large vesicles show planar flattening. Many of the small vesicles in the lowest scoriaceous zone are filled with clay and some calcite. Quartz veins crosscut the outcrops. Copper mineralization is noticeable in two old prospects (see plate I). The weathered surfaces of the malachite have a light blue green (5BG 6/6) color. One of the two prospects is very near the east boundary of the unit. Here the copper was deposited in a fracture zone trending N 18° E with a 88° W dip.

The texture of the flow andesite varies from felty to pilotaxitic. Table 18 shows the mineralogic composition. The relict shapes of pyroxene suggest that it was hypersthene. Some of the possible hypersthene and some feldspar grains are altered to tremolite-actinolite. Most of

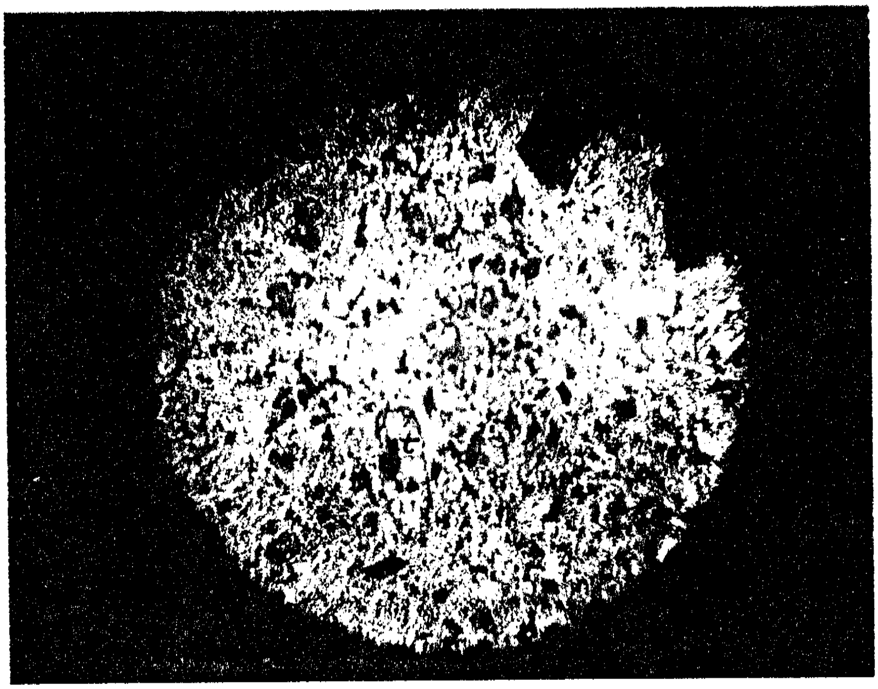


Plate XXV. South Baldy Andesite
Pilotaxitic texture. t-Phenocryst is hypersthene altered to tremolite-actinolite. X 25

Table 18. Composition of South Baldy Andesite

Composition	Vol. %
Phenocrysts	6-10
plagioclase	0- 2
relict pyroxene & amphibole	6
relict hornblende	trace-1
magnetite	3- 6
Groundmass	90
plagioclase	50
clay	20
magnetite	10

the relict shapes of pyroxene, and all of amphibole and hornblende relicts are altered to clay and hematite. At least half of the plagioclase in the groundmass is altered to clay. Clay fills even the small vesicles seen in thin section. The groundmass has abundant disseminated magnetite and hematite. Silicification is indicated by a few quartz crystals with clay rims.

Laharic Breccia

The Laharic Breccia is situated along the crest of the mountain ridge north of the laboratory. It forms an abundant rocky colluvium which tends to obscure the outcrops. Its thickness varies from 50 to 370 feet. It overlies unconformably the Feldspathic Andesite, Purple Rhyolite, Mohawk Peak Rhyolite, and the South Baldy Andesite. Except for the Quaternary Alluvium in the bottom of Sawmill Canyon it is the youngest lithic unit. However, hydrothermal quartz veins cut the Laharic Breccia indicating that it was deposited before the end of igneous activity. The weathered matrix of the breccia

Plate XXVI. Laharic Breccia
Typical ground debris of the Laharic Breccia. Notice variety of lithic fragments present.

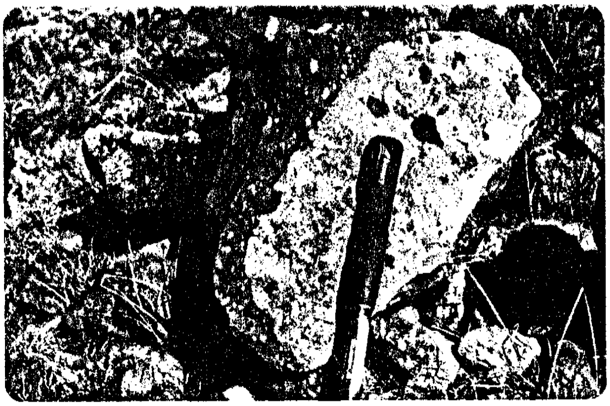


Plate XXVII. Laharic Breccia
Close-up of typical lithic inclusion in the breccia. Notice the clastic matrix.

Table 19. Criteria for recognition of laharic breccias

Lithic fragments	Matrix
heterolithic angular diameter--an inch to several feet	30-90% of vol. sand to clay size composition comminuted rock glass crystals clay minerals
Binding agent	
silicification clay possibly calcification	

(Curtis, 1954)

varies from a pale reddish brown (10R 5/4) to moderate reddish brown (10R 4/6) or grayish red (5R, 10R 4/2). The basic criteria for laharic breccias are listed in Table 19. The characteristics of the laharic breccia that is in the area mapped are shown in Table 20.

Table 20. Composition of Laharic Breccia

Lithic fragments	50%
heterolithic andesite; rhyolite ash-flow tuff (most common type); light gray, flow-banded felsite; minor amounts of pumice mixture of angular and rounded fragments size--1 inch to 24 inches	
Matrix	50%
30% clay 15% crystals (angular; plagioclase, potash feldspar; quartz) 5% comminuted rock	
Binding agent	
clay silicification in some areas some carbonitization	

Quartz of probable hydrothermal origin fills a fissure along the boundary between the Laharic Breccia and

Plate XXVIII. Laharic Breccia: Epithermal Quartz
The quartz deposit grades into the breccia at the top of the picture. Note prominent banding of the quartz vein parallel to the walls of the fissure.

the Purple Rhyolite (see plate I). This vein has characteristics of a very shallow epithermal deposit, i.e., open vugs, drusy mineral linings, banding of quartz with a dark carbonate and some barite, and the presence of typical epithermal minerals. In addition to quartz, SiO_2 is also present in the low temperature forms chert and chalcedony. Limonite stains and a black coating--possibly a combination of specular hematite and manganese oxides, are common. The vein has an average thickness of six feet and grades laterally into highly silicified laharic breccia.

Laharic breccias have been observed elsewhere in Socorro County. According to Dr. Chapin, very similar breccias as the one in the area mapped are found at the mouth of Water Canyon, along highway 60 east of Sedillo Hill, on Socorro Peak, and in Corkscrew Canyon (oral communication, 1968).

Quaternary Alluvium and Talus

There are three minor deposits of Quaternary Alluvium in the bottom of Sawmill Canyon. They are separated from each other by stretches of bedrock or by bedrock thinly covered by colluvium. The alluvium is composed of rounded boulders (18 to 30 inches) of Purple Rhyolite and various andesites, gravel, and sand. The thickness of the alluvium varies from three to four feet below the dam to 10 to 15 feet below the South Baldy

Plate XXIX. Quaternary Alluvium
Sawmill Canyon; the stream has incised
about 3½ feet into the alluvium.

spring.

Extensive talus slopes in the area mapped are relatively unstable and subject to creep. In most areas the talus contains 35-40% air space, but in places it may contain as much as 55% air space. To the east of the laboratory a rock glacier has formed. Its toe is seen on the bench about 200 feet above the dam. Another less well defined rock glacier is found south of the laboratory. It laps over the bench formed by the Rosy Sandstone on the east side of the Calcite Fault. Other rock streams may be seen below Purple Rhyolite outcrops. Rock glaciers and talus slopes are composed entirely of blocks of Purple Rhyolite.

STRUCTURAL GEOLOGY

Regional Structure

The structural geology of the Magdalena Mountains has been throughly discussed by Loughlin and Koschmann (1942), and the following summary is largely dependent upon their work.

The principal structural features of the Magdalena Mountains began developing during the Laramide Revolution. The mountains are principally a faulted monocline with a general attitude of N 15° W, 40-65° W. The major amount of vertical uplift occurred after the Oligocene. The major faults trend north-south, paralleling the orientation of the mountain block. Locally transverse faults interrupt the longitudinal ones. In the northern area of the mountains stocks have intruded along fault intersections. Also numerous dikes have been observed in the Magdalena Mining District and in the Water Canyon area. Folding has not been intense in the mountain block.

Local Structure

Folding

There is little folding evident in the area mapped. The Rosy Sandstone and the underlying white air-fall tuff are slightly warped because of drag on a major fault cutting them. Faulting has also tilted other units. A structural tilt to the southwest is indicated by flow layering in the Purple Rhyolite but faulting obscures the detailed relationships.

Faulting

Faulting is complex in the area mapped. It complicates the relationships between some of the lithologic units and in turn faults are obscured by the brecciated nature of some of the rock units. It is particularly difficult to determine amounts of offset because of lack of distinct marker beds. There are three major faults of several hundred feet displacement and several less extensive faults.

A major fault hereafter referred to as the Calcite Fault cuts across the Tuffaceous Unit, the Rosy Sandstone, a corner of the Purple Rhyolite, and the Feldspathic Andesite. The fault zone is characterized by brecciation and a dark calcite cement. It trends N 10° W and dips 80° W. The brecciated zone is silicified and cemented with calcite. The dark coloration of the calcite is due to disseminated manganese oxides. Part of this fault may be offset by another fault; the portion of the fault exposed in the Feldspathic Andesite is correlated with the main exposure through the dark calcite cement in the brecciated zone. Offset of the Rosy Sandstone indicates an apparent vertical displacement of 360 feet along a reverse fault.

The Calcite Fault marks the west boundary of exposures of the Pyroxene Andesite and Upper Sandstone Units. The east boundary of these units is another fault. It is probably a branch of the Calcite Fault but it is not marked by the brecciation and calcite cement. It trends N 35° W and dips 60-72° SW. It also is a reverse fault with an apparent 80-100 foot vertical offset.

The "A" fault cuts across the Purple Rhyolite just north of the laboratory (see plate I). It has an attitude of N 44° E, 70° SE. It appears to offset the Calcite Fault and it is offset by the "B" fault on the east side of the crest. The "B" fault on the east trends N 33° W near the laboratory and swings to a N 10-15° E trend near the old Forest Service cabin. The general strike is irregularly north-south with the dip being nearly vertical and changing from an easterly to westerly direction. A minor fault in the South Baldy Andesite is located just below the crest on the east side of the mountain 50 feet below the road; it strikes N 15° W and dips 75° W. It is a reverse fault with an estimated offset of 15 feet. The fault along which there has been copper mineralization in the saddle east of South Baldy Peak and above the road strikes N 20° E and dips 74° E. Hydrothermal quartz has filled fractures whose origin is not clear. Silicification has obscured any evidence of movement.

Plate XXI. Jointing in Purple Rhyolite
Cliffs
These prominent cliffs are east of the laboratory. Extensive talus slopes spread below them.

Jointing

The more prominent jointing appears to be genetically related to the tectonic history. The greatest number of joints strike from N 36° W to N 20° E. The major fault trends are N 33-35° W, N 10-20° W, north-south, and N 10-20° E. The N 44° E fault has joints paralleling it and spreading from N 33° E to N 56° E. There are minor concentrations of joints striking N 73-88° W and N 61-84° E. The Sawmill Canyon Andesite has joints striking N 65-68° W which may be primary in the unit. The Sawmill Canyon Rhyolite is extensively fractured by sub-parallel sheet joints which permeate the entire unit. The sheeting trends N 13-20° E and has two principal dip planes, 42° SE and 57° SE.

Jointing is best developed in the Purple Rhyolite; the joints are irregular fractures. An outcrop generally has joint sets with 70-90° between the joint directions. Tectonic adjustments caused slickensides to form on some joint surfaces.

Flow Layering

All the andesitic units and the Mohawk Peak Rhyolite originated as lava flows. Autobrecciation, scoriaceous zones, euhedral crystals--both phenocrysts and in the groundmass, parallel orientation of crystals, all suggest flowage. The South Baldy Andesite has planar flow structures trending approximately N 40° E and dipping 10° NW,

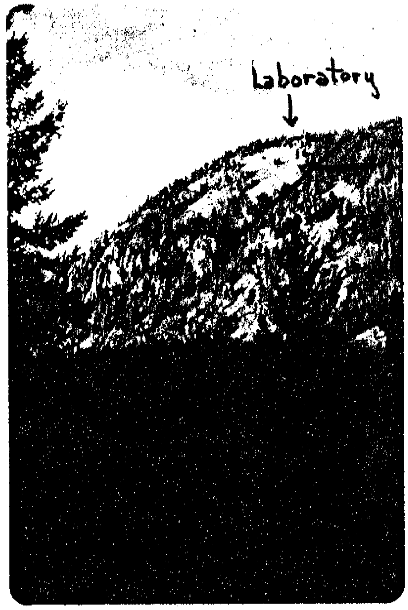


Plate XXXI. Langmuir Laboratory
Showing the extensive talus slopes and the faults on the east side of the laboratory. The toe of the rock glacier is at the bottom of the talus extending into Sawmill Canyon.

Plate XXXII. Sawmill Canyon
The toe of the rock glacier. The laboratory is up the mountain to the left.

and N 70° E, 12° NW. The Pyroxene Andesite has attitudes of N 30° E, 30° SE and N 75° W, 14° NE.

The Purple Rhyolite, Sawmill Canyon Rhyolite, and the second youngest member of the Tuffaceous Unit are welded ash-flow tuffs. Again faulting has deformed and obscured the original flow attitudes. The general trend of flow planes in the Purple Rhyolite is N 24-48° W. The dip varies from 2° SW to 49° SW but generally is from 13° to 30° SW.

RADIUM-226 IN THE MAJOR ROCK UNITS

Radium and Uranium in Volcanic Rocks

A brief consideration of the general geochemistry of uranium is necessary to provide a background for the understanding of the distribution of radium in volcanic rocks. Radium-226 is one of the daughter products in the uranium-238 radioactive decay series. Uranium-238 has a half life of 4.5×10^9 years, while radium has a half life of only 1622 years (Eisenbud, 1963). There is no primordial radium-226 present in any rocks at the present time; hence the radium present in any rock older than approximately 8000 years (five half lives of radium-226) is the result of radioactive decay of uranium-238. Any radium originally present in the rock would have decayed almost completely in that period of time.

According to Rankama and Sahama (1950) uranium is a pronouncedly lithophile element, i.e., it is enriched in the silicate crust and has an affinity for oxygen. During magmatic differentiation uranium becomes concentrated in acidic rocks because of its chemical characteristics. During most of the differentiation process uranium is in the tetravalent state and has an ionic radius of 0.89 Å (Faul, 1954). The charge is too high to allow substitution of significant amounts of uranium in the common rock forming minerals. It may substitute for zirconium, ionic radius 0.80 Å, in zircon and for calcium, ionic radius).99 Å, in sphene and apatite (Faul, 1954). Heinrich (1958) includes thorium, ferrous iron, and the rare earths with the elements that may be diadochic with uranium. Uranium is prevented from substituting for calcium in plagioclase because of coordination requirements. Radioactive zircons (the Th/U ratio is 3.5/1, thus approximately 53% of the activity is from the thorium-232 radioactive decay series) have been reported by Clark and Botset (1932), Rankama and Sahama (1950), Faul (1954), Neuerburg (1956), and Heinrich (1958). According to Neuerburg (1956) in addition to being diadochic with those elements, uranium may be located in minor quantities in structural defects of minerals, adsorbed on crystal surfaces or on surfaces within crystals, and dissolved in fluid inclusions in minerals. According to Faul (1954) and Rankama and Sahama (1950), the solubility of uranium is reduced in the later stages of the magmatic cycle and the UO_2 minerals uraninite and pitchblende may form.

Rankama (1954) has discussed the removal of uranium from igneous rocks by alteration and selective solution. Uranium is leached from minerals in an oxidizing environment while, at the same time, radium has a tendency to be fixed in the rocks. Radium is leached from the rocks according to the solubility of the radium bearing minerals.

Generally the differences in uranium content between extrusive and plutonic rocks of the same clan are small. This comparison is beneficial because there is much more data on the uranium content of plutonic igneous rocks than there is on extrusive igneous rocks. Andesites belong to the intermediate clan, and rhyolites to the granitic clan. According to Heinrich (1958) the sources of radioactivity in extrusive rocks are either in the accessory minerals zircon, sphene, allanite, apatite, and fluorite; or radioactivity randomly distributed in the plagioclase, pyroxene, hornblende, biotite, and glass.

It is possible to calculate the radium content of rocks from their uranium content using the equation

$$N_U \lambda_U = N_{Ra} \lambda_{Ra}$$

and assuming that there is radioactive secular equilibrium. Reported uranium values for rhyolitic rocks range from 1.0 ppm to 15 ppm (Larsen, Phair, Gottfried, and Smith, 1956; Faul, 1954). The corresponding range in calculated values of radium content is from 0.36×10^{-6} to 5.4×10^{-6} ppm. Based upon the accepted average value (4 ppm) of uranium content of rhyolites is the calculated average value of 0.65×10^{-6} ppm radium. Values reported for intermediate clan rocks range from 0.2 to 6 ppm uranium. Calculated values for the radium content range from 0.08 to 2.1×10^{-6} ppm (Larsen, Phair, Gottfried, and Smith, 1956). Based upon accepted average values (1.5 ppm) for uranium in andesite is an average content of 0.36-0.61 x 10^{-6} ppm radium. Faul (1954) reported average radium contents of 0.51 ± 0.05 x 10^{-6} ppm in intermediate intrusive igneous rocks, and 1.37 ± 0.17 x 10^{-6} ppm in granitic rocks of North America.

Determining the Radium Content of Rocks

There are two basic methods of determining the radium content of rocks. One method is to chemically separate the radium from the other constituents and then to directly count the activity of the radium. The other method is known as the emanation method. In this method the activity of radon gas is determined after it is isolated from its radium source, and then the amount of radium present is calculated from the radon activity again assuming secular equilibrium. The emanation method was used in this study.

A specific technique for the direct counting of radium has been described by Rosholt (1957). Depending upon total activity and ease of solution one gram or less of sample is fused with four or five grams of sodium peroxide. The melt is dissolved in water, diluted to 100 ml and the acidity is adjusted to 1.0 N in hydrochloric acid. The radium is chemically separated from the solution by precipitating it with barium sulfate. The precipitate is collected upon the counting planchet.

Since several isotopes of radium are present in the sample precipitated with the barium sulfate, the planchet is set aside for thirty days so that any radium-223 and radium-224 impruities with the radium-226 may decay completely or to insignificant amounts. The half-lives of radium-223 ($t_{\frac{1}{2}}$ = 11.2 days) and radium-224 ($t_{\frac{1}{2}}$ = 3.84 days) are very short compared to that of radium-226 ($t_{\frac{1}{2}}$ = 1622 years) (Eisenbud, 1963). After determining the counting efficiency and then the activity of radium-226, the radium content may be calculated using the equation

$$\frac{dN}{dt}Ra = -\lambda N_{Ra}$$

where $\frac{dN}{dt}Ra$ is the activity of the radium, λ is the decay constant of radium, and N_{Ra} is the number of radium atoms present.

The chemical procedure used to determine the radium content of the major rock units in the area studied was a modified version of the procedure described by Rosholt (1957). Rock samples were mechanically ground to a very fine powder. One gram of sample was fused with five grams of sodium peroxide; the melt was dissolved in water; and the solution was diluted to 100 ml while adjusting the acidity to 0.1 N. The solution was then sealed in a flask and set aside for a minimum of 16 days while the radon accumulated.

The radon activity is determined after the production and disintegration of radon atoms becomes equal. The growth of radon activity is expressed by the following equations in which $\lambda_{Ra}N_{Ra}$ represents the production rate of radon from radium and $\lambda_{Rn}N_{Rn}$ is the decay rate of N_{Rn}.

$$\frac{dN_{Rn}}{dt} = \lambda_{Ra}N_{Ra} - \lambda_{Rn}N_{Rn}$$

thus $$N_{Rn} = \frac{\lambda_{Ra}}{\lambda_{Rn} - \lambda_{Ra}} N_{Ra_o}(e^{-\lambda_{Ra}t} - e^{-\lambda_{Rn}t}) + N_{Ra_o}e^{-\lambda_{Rn}t}$$

since $N_{Ra_o} = 0$ and $\lambda_{Rn} \gg \lambda_{Ra}$

then $$N_{Rn} = \frac{\lambda_{Ra}}{\lambda_{Rn}} N_{Ra_o}(1 - e^{-\lambda_{Rn}t})$$

since at equilibrium

$$N_{Rn_o} = \frac{\lambda_{Ra}}{\lambda_{Rn}} N_{Ra_o}$$

then $$N_{Rn} = N_{Rn_o}(1 - e^{-\lambda_{Rn}t})$$

As the term $1 - e^{-\lambda_{Rn}t}$ approaches the limit of 1, the activity of the radon approaches the original radium activity and the growth curve levels off. This occurs after about 16 days in a sealed container.

The decay of radon can be expressed by

$$\frac{N_{Rn}}{N_{Rn_o}} = e^{-.693\ t/T_{\frac{1}{2}}}$$

where t = the time elapse from t = 0

$T_{\frac{1}{2}}$ = 3.82 days, the half life of radon-222

$.693/3.82 = \lambda_{Rn}$

After $t = 4 \times T_{\frac{1}{2}}$ or approximately 16 days, $e^{-.693t/T_{\frac{1}{2}}}$ approaches the limit of 1, and the production and disintegration of radon atoms becomes equal.

The Johnston Laboratories, Inc. RCTS - 2 (Radon Collection and Transfer System) was used in the removal of the radon gas in equilibrium with the radium in solution. Nitrogen was used to flush the radon gas from the flask. The radon was collected on a charcoal trap after being filtered to remove CO_2 and water vapor. It was then transferred to a counting chamber. There was a time elapse of 3 to 4 hours between the first flushing of the flask and the counting of the radon activity. This time elapse allowed equilibrium to be reached between radon-222 and its short lived daughter products. From the measured alpha activity the original radium content of the flask was calculated. The following is an example of a calculation: N = number of atoms at a given time t, λN_o = initial activity, λN = activity at time t, Δt = time elapse from condensation to the midpoint of the counting period.

Using $\lambda N = \lambda N_o e^{-\lambda \Delta t}$

where $\lambda N = 107$ cph

$\lambda = 0.181 \text{ sec}^{-1}$

and $\Delta t = 314$ min.

then $\lambda N_o = 111$ cph

To convert counts per hour to pico-curies a standard correction factor, the calibration of the counter, of 35.4×10^{-4} was used (Jercinovic, personal communication, 1968).

$$111 \text{ cph} \times 35.4 \times 10^{-4} \text{ pc/cph} = 0.39 \text{ pc}$$

Since 1 curie = activity from 1 gram of radium (3.7×10^{10}

disintegrations per second) (Rankama, 1954), then 1 pico-curie equals 1 pico-gram.

The radioactive equilibrium between radium-226 and its daughter product, radon-222, may be expressed by

$$N_{Ra}\lambda_{Ra} = N_{Rn}\lambda_{Rn}$$

The decay constant of radium is not equal to that of radon, but their activities are equal. Thus, the 0.39 pc of radon activity equals 0.39 pc of radium, and equals 0.39 pg of radium. The results of the radium determinations are presented in Table 21.

There are three basic sources of error in the procedure followed in the determination of the radium content. There is a $\pm$ 7.5% error for the chemical procedure based upon a repeated measuring of alpha activity of one sample. Control blanks or control samples with known quantities of radium were not run with the unknown solutions; however, Dr. Wilkening and Mr. Jercinovic have reported a 98+% recovery of radium from a radium chloride solution (personal communication, 1968). The second major source of error was loss of radon through diffusion from the sample flasks. The diffusion was a result of imperfect seals between the rubber stoppers and either the glass neck of the flask or the glass tubing through the stoppers. This diffusion should affect both andesite and rhyolite samples in the same manner. The results would indicate a lower radium content than is actually present due to

Table 21. Radium 226 Content of the Major Lithic Units

Unit	Date of sealing of flask	Condensation date	Initial activity cph	Amounts of radium ppm x 10^{-6}
Purple Rhyolite upper portion	5-16-68	7-17-68	53	.18
	5-16-68	7-17-68	111	.39
	5-19-68*	6-11-68	85	.30
	5-19-68*	6- 4-68	102	.36
	6- 4-68	7-16-68	89	.31
red, siliceous vein	5-19-68	6-11-68	114	.40
	5-19-68	6- 7-68	86	.30
composite pumiceous & basal lithic	5-20-68	7-16-68	191	.66
	5-20-68	6- 5-68	147	.51
South Baldy Andesite	5-19-68	6- 6-68	91	.32
	5-19-68	6-12-68	86	.30
Feldspathic Andesite	5-20-68	6- 6-68	105	.37
	5-20-68	6-13-68	135	.47
Sawmill Canyon Andesite	5-20-68	7-16-68	109	.38
	5-20-68	6-11-68	182	.63
Sawmill Canyon Rhyolite	5-20-68	6- 6-68	79	.28

(* duplicate samples)

diffusion of radon from the flask to the room (Jercinovic, personal communication, 1968). The statistical counting error is approximately ± 10% since most of the samples were counted for one hour at a rate of about 100 cph. This is calculated by $\sigma = \pm\frac{\sqrt{n}}{n}$ where n = total number of counts.

The radium distribution in the major lithic types around Langmuir Laboratory does not appear to vary according to rock type. From table 21 it is seen that the andesites and the rhyolites analyzed have radium contents of the same order of magnitude. The radium content of the red, siliceous vein material also falls within the same range of values. The composite sample of the middle pumiceous member and basal lithic member of the Purple Rhyolite has the highest radium-226 content relative to the other units analyzed.

In most of the units mapped radioactive sources cannot be related to individual mineral species. The Purple Rhyolite contains trace to 0.3% amounts of metamict zircon and trace amounts of sphene. Most of the metamict zircon observed is in the upper member of the unit. The metamict zircon and possibly the sphene serve as some of the sources of radioactivity in this unit.

The rocks studied have a lower radium content by a factor of two or three than the average values given for volcanic rocks. Faul (1954) reported average radium values of 0.51$\pm$ 0.05 x 10^{-6} ppm in intermediate intrusive igneous rocks, and 1.37$\pm$ 0.17 x 10^{-6} ppm in granitic rocks. Andesite belongs to the intermediate clan of igneous rocks and rhyolites to the granitic clan. Radium values in the rocks analyzed average 0.31 x 10^{-6} ppm for the andesites and 0.40 x 10^{-6} ppm for the rhyolites. The lower values may be the result of a regional anomaly. Coats (1956) has reported nonrandom regional variations in uranium content in rhyolitic and dacitic rocks in the Cordilleran region. In northern Nevada, northwestern Utah, and southern Idaho 66% of the rocks studied contained more than 5 ppm uranium and 70% of the rocks had between 4 ppm to 10 ppm uranium. To the south in the Mojave desert and western Arizona area only 20% of the rocks studied had an uranium content greater than 5 ppm while 80% of them fell within the range of 3 ppm to 5 ppm uranium. Another probable cause of the lower uranium values is leaching of the uranium while alteration of the rock units occurred. Uranium is highly soluble in low temperature, aqueous solutions containing carbonate (Heinrich, 1958). The pervasive alteration of the rock units, the carbonitization, and the nature of the epithermal quartz indicate that there was ample opportunity for uranium to be dissolv ed in low temperature, carbonate-bearing solutions.

SUMMARY AND CONCLUSIONS

The Langmuir Laboratory area is approximately 17 miles west and south of Socorro in the Magdalena Mountains. The mountain range has a precipitous relief and trends north-south. The highest elevation, South Baldy Peak, is 10,780 feet above sea level and lies within the area mapped. Structurally the Magdalena Mountains belong to the Basin and Range geologic province. Weber (1963) has mapped on a reconnaissance basis the volcanic rocks of the Magdalena Mountains as part of the Datil Formation of the Datil-Mogollon volcanic field. Elston, Coney, and Rhodes (1968) have studied the Mogollon Plateau, a major volcano-tectonic structure to the southwest of the Magdalena Mountains. There the Datil Formation is the oldest of three major ash-flow sequences and occurs only around the edge of what is considered to be the high-level equivalent of a ring-dike complex. The Datil Formation was deposited approximately 29 to 38 million years ago during the Oligocene and Upper Eocene Epochs of the Tertiary Period.

The lithologic units within the area studied include andesite flows, a rhyolite flow, welded ash-flow tuffs of varying composition, air-fall tuffs, minor amounts of sandstone, a laharic breccia, and a minor amount of Quaternary alluvium. All the rock units are moderately altered by late stage hematitization, carbonitization, silicification, and argillization. Hydrothermal activity is indicated by a quartz vein with epithermal characteristics.

The Purple Rhyolite is the most extensive of the units mapped (see plate I) and is the foundation rock for the laboratory. The Purple Rhyolite is a multiple flow, compound cooling unit of welded ash-flow tuffs. Three members are recognized. The basal flow is more lithic and less crystalline than the top flow. The degree of crystallinity increases upward from 28% by volume in the basal member to approximately 55% in the top flow. This unit suggests progressive emptying of a compositionally zoned magma chamber as described by Lipman, Chritiansen, and O'Connor (1966). The sequence of welded ash-flows is inverted from the compositional zonation in the chamber. The radium values for the composite sample of the middle pumiceous and basal lithic members of the unit are almost twice as great as those for the upper member of the unit suggesting that uranium was relatively concentrated in the upper compositional zones in the magma chamber. Metamict zircons were observed only in the Purple Rhyolite. They are present from trace amounts to about 0.3% of the rock and are most abundant in the upper member of the unit. Since the upper member has only half the radium content of the lower two members this suggests that the zircons are a relatively unimportant source of radium.

On the crest of the ridge north of the laboratory is the youngest volcanic unit, the Laharic Breccia; the Quaternary Alluvium in Sawmill Canyon is the only mapped deposit which is younger. The Laharic Breccia fills low areas in the Purple Rhyolite and laps onto the Mohawk Peȧk Rhyolite and the South Baldy Andesite. It forms abundant rocky colluvium which obscures outcrops.

The Tuffaceous Unit crops out nearly 1000 feet below the laboratory and its interbedded tuff breccia and volcaniclastic sandstone--the oldest and least extensive members--may signify a minor vent area. Dr. Chapin has found similar stratified tuff breccicas in the Guffey caldera of Colorado only in the vicinity of vents (oral communication, 1968). The interbedding of tuff breccia and volcaniclastic sandstone suggests repeated eruptions.

From the time of eruption of the Tuffaceous Unit to that of the Purple Rhyolite there was an alternating sequence of volcanic and non-volcanic deposition. The non-volcanic intervals represent times of quiescence, erosion, and deposition of sediments. Later stage volcanic events from sources definitely outside the area studied were responsible for the Mohawk Peak Rhyolite and South Baldy Andesite flows, and for the Laharic Breccia. Volcanic activity in the region closed with weak mineralization represented by quartz veins in areas of probable hot springs.

The principal faulting occurred after cessation of volcanic activity. Faulting has continued up to the present time as indicated by the fault scarp cutting the alluvium at the mouth of Water Canyon, and by the incision of both the Water Canyon and the Sawmill Canyon Streams into the alluvium. Within the area mapped there are three major faults of several hundred feet displacement. The Calcite Fault is characterized by brecciation and a dark calcite cement. It trends N 10° W and dips 80° W. The "A" fault has an attitude of N 44° E, 70° SE and appears to offset the Calcite Fault. The "B" fault has a general strike irregularly north-south and a nearly vertical dip. It offsets the "A" fault.

Much of the jointing appears to be genetically related to the tectonic history. The greatest number of joints strike from N 36° W to N 20° E. Jointing is best developed in the Purple Rhyolite. The Purple Rhyolite outcrops in 40-to-200 foot cliffs and forms the extensive talus slopes noticeable from the air. The talus is blocky and generally is estimated to contain from 35 to 40% air space. Together the talus breccia and joint surfaces provide large surface areas for radon emanation (one of the areas of research interest at Langmuir Laboratory).

Samples representing major lithic types and vein fillings were analyzed for their radium-226 content. Radium distribution does not appear to vary according to rock type. Both the andesites and the rhyolites analyzed have radium contents of the same order of magnitude (see table 21). The rocks studied have a lower radium content by a factor of 2 or 3 than average values given for volcanic rocks (Faul, 1954). This is possibly a result either of leaching of uranium by carbonate-bearing solutions during hydrothermal alteration or of regional variations in uranium content of igneous rocks. Heinrich (1958) notes that regional variations in uranium are nonrandom. In the western United States rocks of northern Nevada and northwestern Utah have high mean uranium contents, and the mean uranium content has been observed to decrease southward and westward. Radioactive sources in most of the units mapped cannot be related to individual mineral species. The Purple Rhyolite contains metamict zircon crystals, however most of the radioactivity appears to be randomly distributed in the groundmass of the rock.

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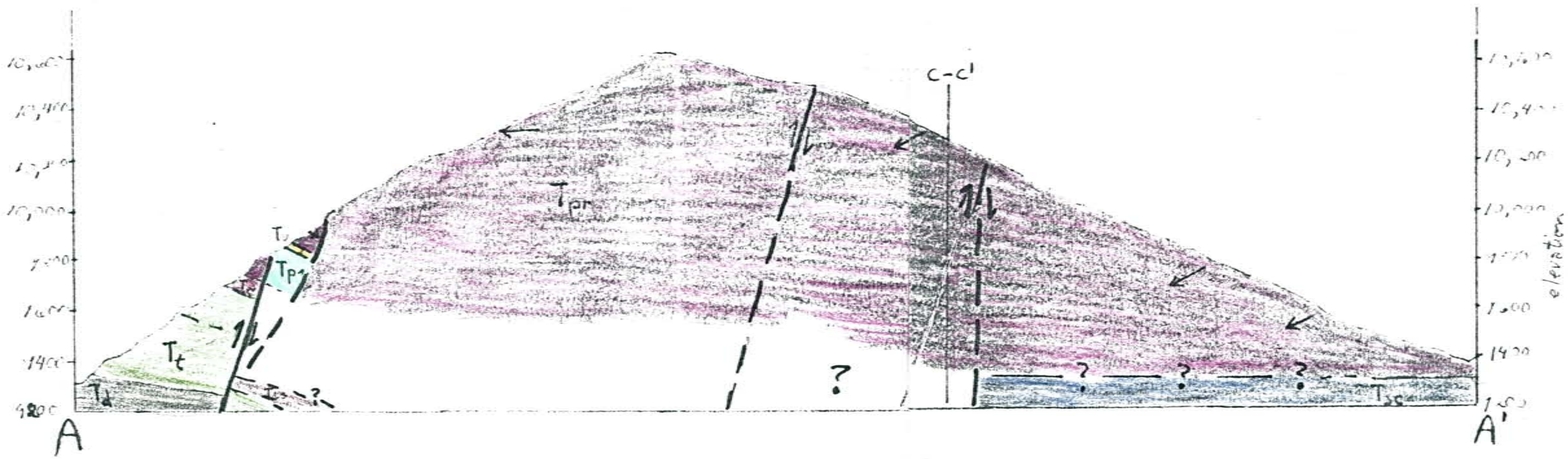
Date: Sept 5, 1969



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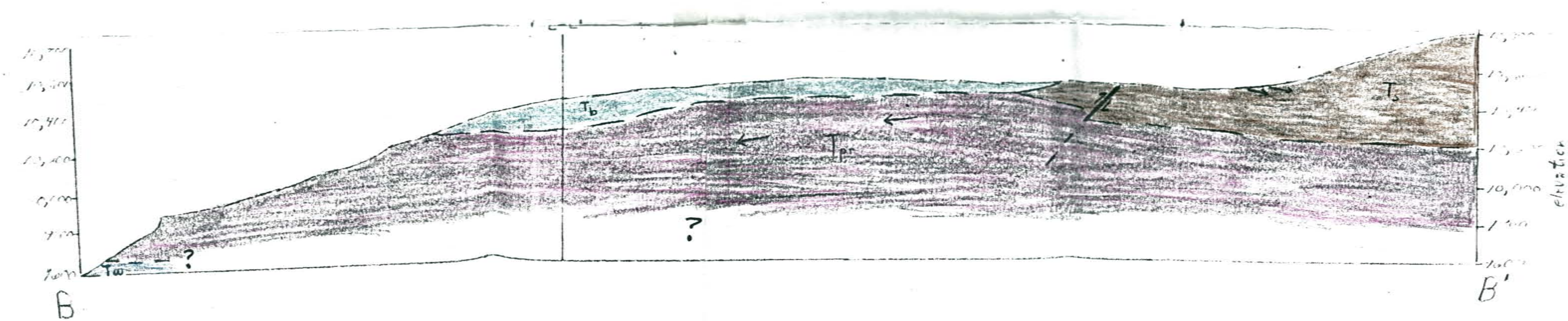

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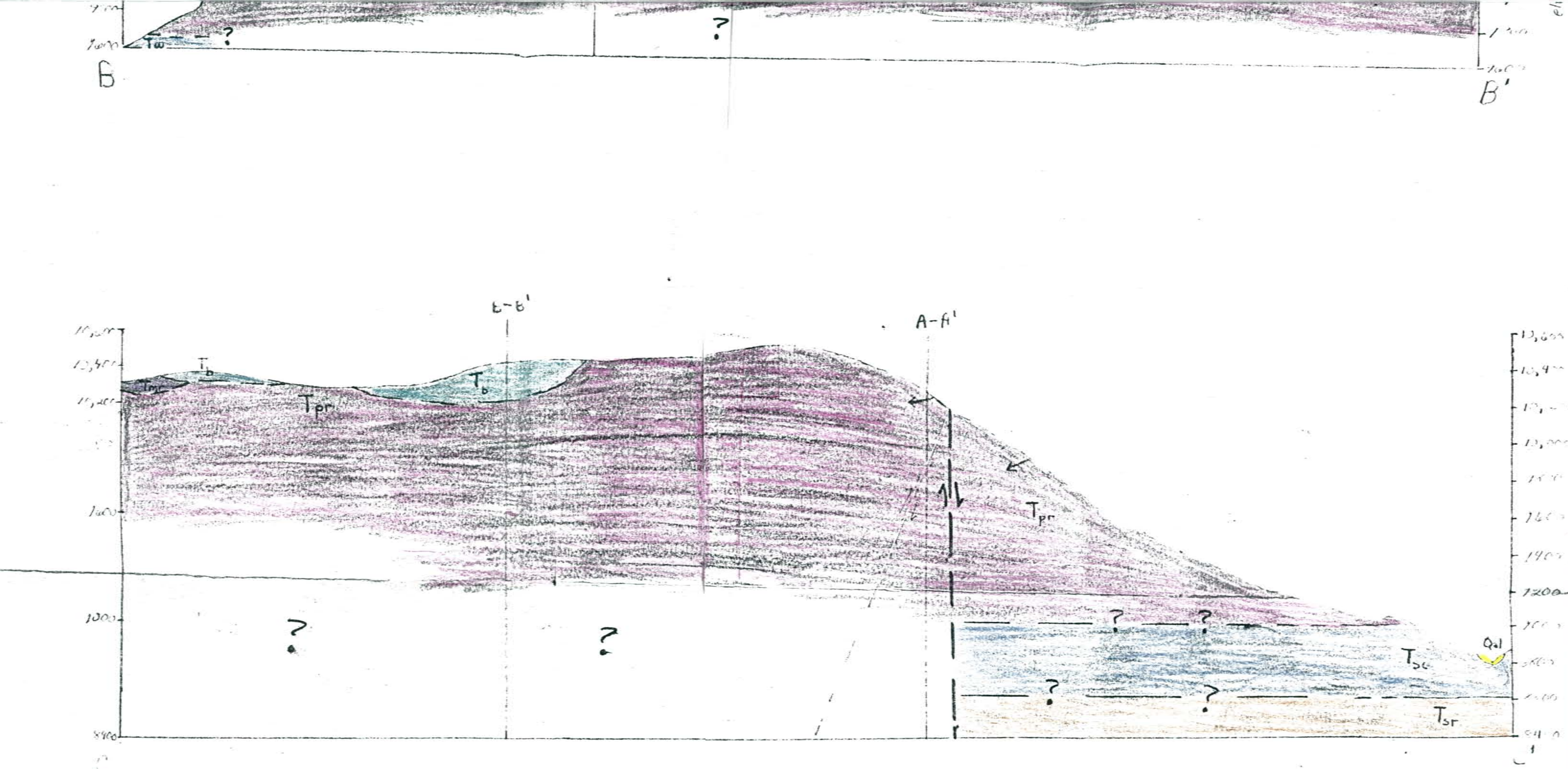

Structure Sections

Plate II