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The thesis area occupies an area of approximately 28 square miles in the Pine Forest Mountains of Humboldt County, Nevada. The area is in the extreme northwestern part of the Basin and Range Province and is characterized by large normal faults that bound tilted fault block mountain ranges.

Triassic and Early Jurassic marine sedimentary rocks, arkosic arenites and shales, were subjected to regional metamorphism during an orogenic episode in Middle and Late Jurassic time. Intrusion of diorites and granodiorites during Early Cretaceous time and subsequent contact metamorphism obscurred the effects of regional metamorphism present in the country rock near contacts with these plutons.

Middle and late Tertiary volcanic rocks unconformably overlie

the metamorphic and plutonic rocks. The basal unit of the volcanic sequence is a thick olivine andesite flow which is overlain by a rich pebbly volcanic sandstone. This is followed by an ignimbrite. The ignimbrite is overlain by a very thick sequence of olivine basalt flows with minor interbedded ash flow and air fall tuffs.

Major block faulting began after the period of volcanism and ceased during Pleistocene time. This faulting produced closed basins surrounded by mountains. Deposition in the basins and erosion of the mountains has been continuous since the features were formed.

The General Geology of the Northernmost Part of the Pine Forest Mountains, Humboldt County, Nevada

by

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THE GENERAL GEOLOGY OF THE NORTHERNMOST PART OF THE PINE FOREST MOUNTAINS, HUMBOLDT COUNTY, NEVADA

INTRODUCTION

Location, Size and Accessibility

The thesis area is located in the northernmost part of the Pine Forest Mountains, approximately four miles south of Denio, Nevada. Located in northwestern Humboldt County in parts of T. 45, 46 and 47 N., R. 28, 29, and 30 E.,the area includes nearly 28 square miles (Figure 1). Denio is located along U. S. Highway 140 approximately 100 miles northwest of Winnemucca, Nevada. Locally, access is by Nevada State Highway 8a, and a number of prospect roads and Bureau of Land Management access roads.

Topography and Drainage

The northern part of the Pine Forest Mountains is surrounded by flat-floored valleys on three sides and is separated from the main mass of the mountain range to the south by a broad saddle. The maximum relief is 2111 feet, the difference in elevation between the top of the major peak just south of Cold Spring and the high water level of Continental Lake (Plate 1). The mountains are deeply

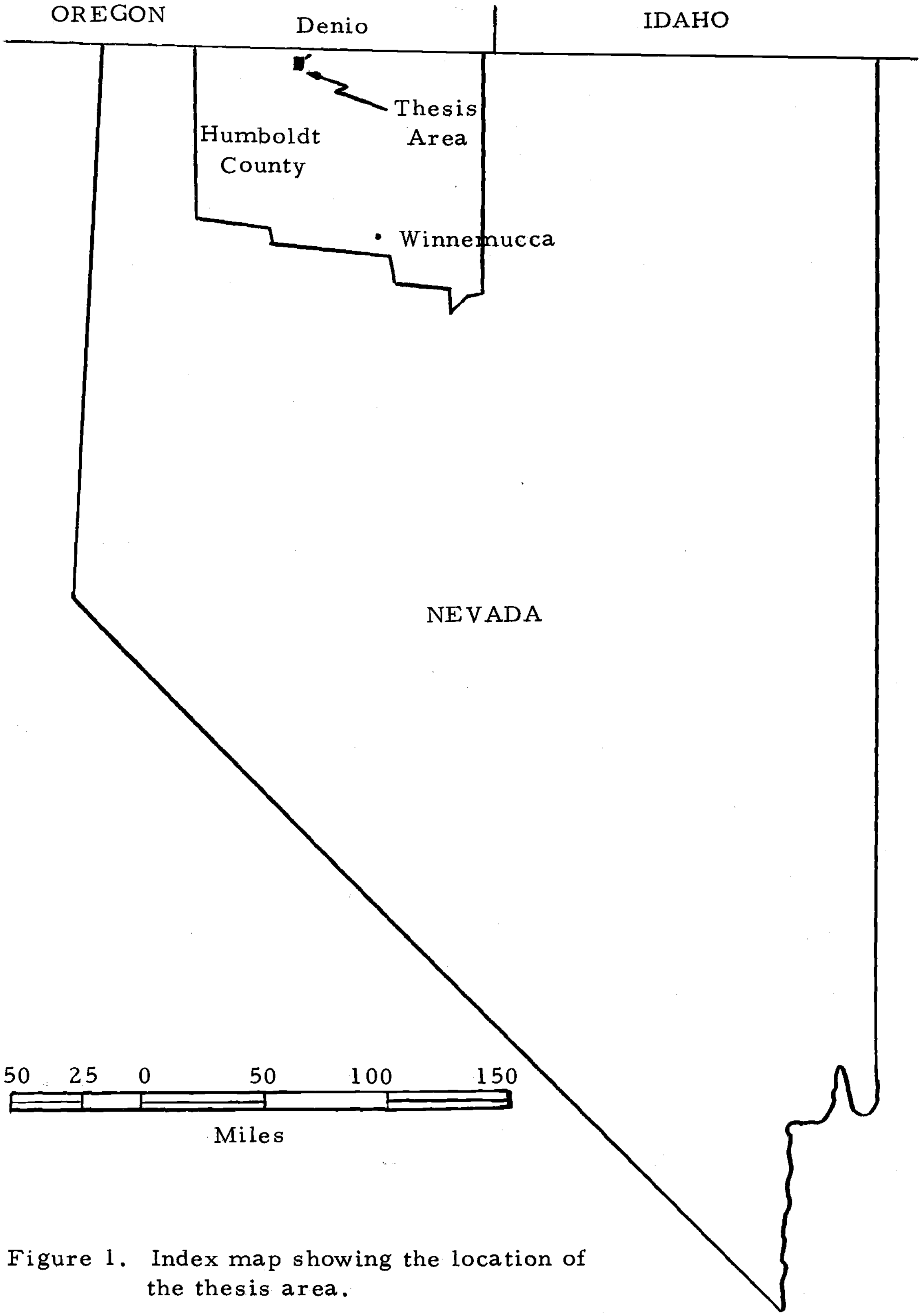

Figure 1. Index map showing the location of the thesis area.

dissected and have very rugged topography characterized by steep dry washes and sharp ridges and spurs.

The drainage is characterized by intermittent streams that flow into the structural basins surrounding the mountain range. Drainage in Antelope Valley (Plate 1) on the east side of the mountains is toward the north, whereas the basin west of the mountains is occupied by a playa lake.

Climate and Vegetation

For the period 1951 through 1960, the average yearly precipitation reported for Denio, Nevada was 8.31 inches. May is the wettest month with an average of 1.42 inches during this ten year period; the remainder of the months averaged less than one inch (U. S. Weather Bureau, 1965). During the summer months, the days are quite warm, often with temperatures exceeding 100 degrees Fahrenheit. Nights are generally much cooler with temperatures often falling below 40 degrees. The area is a desert as the yearly precipitation averages less than ten inches and evaporation potential exceeds precipitation.

Sagebrush is the most common vegetation but short grasses are also abundant. Clumps of willow and aspen grow wherever there is adequate water to support their growth.

Purpose and Methods of Investigation

The purpose of this investigation was to map and describe the various rock units and structures that occur within the thesis area. From the investigation of of the geologic features of the area, conclusions concerning the geologic history were reached.

Field work was accomplished during August, September, and October 1968. A geologic map of the area was constructed using a United States Geologic Survey seven and one-half minute quadrangle topographic map for a base map. A stratigraphic section was measured by use of a Jacob's Staff and Brunton compass. High altitude, scale- 1:60,000, aerial photographs were of assistance, especially in structural mapping.

Fifty thin sections of the plutonic, metamorphic and volcanic rocks were prepared and studied during the academic year of 1968-1969. The volcanic sediments were studied primarily with the binocular microscope.

Previous Work

Robert Willden (1964) included the thesis area in a reconnaissance report entitled The Geology and Mineral Deposits of Humboldt County, Nevada. Included in this report was a cursory discussion of the geology of the Pine Forest Mountains and a reconnaissance geologic map of the entire county.

Terminology

The classification of the metamorphic rocks used in this paper is that proposed by F. J. Turner (1968). Different facies of metamorphism are defined in terms of pressure and temperature and are recognized by characteristic mineral assemblages. Igneous rocks, both volcanic and plutonic, are classified according to Williams, Turner and Gilbert (1954). The classification of volcanic sedimentary rocks follows the system proposed by R. L. Hay (1952). These detrital volcanic rocks are classified on the basis of both particle size and percent of volcanic material present in the rock.

Geologic Setting

The Pine Forest Mountains are located in the extreme northwestern part of the Basin and Range Province. The mountain range is a tilted fault block bounded by a large normal fault along its eastern edge. The thesis area is underlain by Triassic and Early Jurassic quartzites and schists. These rocks were subjected to regional metamorphism during Jurassic (?) time and later contact metamorphism, associated with intrusion of a sequence of diorite and granodiorite plutons, in Early Cretaceous time. These crystalline basement rocks are unconformably overlain by a sequence of middle Miocene volcanic rocks at least 2600 feet thick. The volcanic sequence consists of a basal andesite flow, a volcanic sandstone, an ignimbrite and a series of olivine basalt flows with minor interbedded ash flow and air fall tuffs.

METAMORPHIC ROCKS

General Statement

Metamorphic rocks crop out over an area of approximately four and one-half square miles in the central part of the thesis area (Plate 1). Exposures are generally good except in the broad upland valleys where outcrops are covered by alluvium. The quartzose meta-sediments commonly form topographic highs whereas the schistose rocks form valleys and saddles between more resistant types.

These rocks have been assigned an age of Triassic-Jurassic on the basis of stratigraphic and fossil evidence in the southern part of the Pine Forest Mountains (Willden, 1964). The rocks are divided into two major units on the basis of composition. The quartzofeldspathic rocks are termed arkosic quartzites (Grout, 1932). The schistose rocks, rich in hornblende and biotite, are termed hornblende biotite schists. These two rock types often occur together in the same outcrop and appear to be interlayered. Where this relationship occurs, the unit is named on the basis of percentage of quartzite to schist. Arkosic quartzites contain up to 25 percent schist; hornblende biotite schists contain more than 25 percent schist. Also, two very small isolated outcrops of amphibolite occur in the central part of sec. 7, T. 46 N., R. 30 E. These outcrops are included within the schists as they are too small to be mapped separately. The units will be discussed in an arbitrary order as relative ages of intercalated rocks are meaningless.

Arkosic Quartzite

Field Description

The quartzite unit crops out in an approximately two-square-mile area in the central part of the thesis area (Plate 1). The outcrops occur in an elongate belt trending approximately N. 30 E. All of the high knobs or peaks in the central part of the area are composed of quartzite.

The color of the arkosic quartzite is variable and appears to be determined, at least in part, by the content of hematite. Those specimens richest in iron have weathered surfaces colored grayish-red (5 R 4/2) and fresh surfaces moderate red (5 R 4/6). Others are grayish-orange-pink (5 YR 7/2) on weathered surfaces and light brown (5 YR 6/4) on fresh surfaces. Light bluish-gray (5 B 7/1) colors are common in the rocks with low iron content.

The arkosic quartzites are generally finely-crystalline and have a granoblastic texture. Near contacts with the schist, a foliation defined by the parallel alignment of platy biotite crystals is often developed. This foliation parallels the contact between these two rock types.

Petrography

The texture of the quartzites is xenoblastic granular. Individual crystals range from 0.1 to 4 mm in size and are subhedral to anhedral in form.

A typical arkosic quartzite is composed of quartz (90 percent), plagioclase feldspar (5 percent), microcline (2 percent), biotite (1 percent) and muscovite (1 percent). Minor amounts of magnetite, sphene, epidote, apatite and zircon are also present. Quartz crystals typically lack inclusions and have undulatory extinction. Although some of the original quartz grains are visible, the relic shapes are usually obliterated by recrystallization as indicated by quartz overgrowths and sutured grain boundaries. Plagioclase feldspar is andesine. The crystals are relic clastic grains that have undulatory extinction indicating that they have been strained. Quartz and biotite inclusions are common and reaction rims of myrmekite exist where plagioclase and microcline crystals are in contact. Plagioclase is highly altered to reddish-brown kaolin and to sericite. The optical axial angle for microcline is generally much smaller than normal, perhaps due to strain. Inclusions are quartz and rarely biotite. Microcline is not as highly altered as plagioclase, but the same alteration products are present. Biotite crystals, which are elongate in shape, are pleochroic from light greenish- or reddish-brown to black and occur either individually or in felty masses. Biotite alters to chlorite and inclusions of magnetite and sphene are often present along cleavage planes. Muscovite occurs as both primary detrital flakes that are very pale green in color and as sericite after plagioclase. Magnetite is the most common accessory mineral and occurs as euhedral to subhedral crystals that are altered to hematite and often are surrounded by granular masses of sphene. Epidote occurs as small subhedral crystals that are included in or have altered from plagioclase and have altered to clay. Apatite and zircon crystals occur as minute inclusions in plagioclase and biotite.

Hornblende Biotite Schist

Field Description

The schistose rocks crop out in an area of approximately 2.5 square miles in the thesis area. The schists are not as resistant as the quartzite and exposures occur mostly in saddles along ridge tops or form low, rounded hills.

Included in the hornblende biotite schist are outcrops of chlorite schist and andalusite schist. The chlorite schist is exposed near a fault located just north of the west end of Emigrant Pass (Plate 1). This rock grades into hornblende biotite schist away from the fault and probably is an altered phase of the hornblende biotite schist. The andalusite schist is located near the quartz diorite-schist contact, approximately one-eighth mile east of Cold Spring.

Weathered surfaces of the hornblende biotite schist are grayish-black (N 2) and fresh surfaces are dark gray (N 3). The chlorite schist is dark greenish-gray (5 GY 4/1) on weathered surfaces and medium bluish-gray (5 B 5/1) on fresh surfaces. Andalusite schist is the same color as the hornblende biotite schist. Andalusite porphyroblasts are light bluish-gray (5 B 7/1).

Schistosity in these rocks is defined by the parallel orientation of platy biotite crystals and bladed hornblende crystals. Near contacts with the plutonic rocks, the schistosity has been severely deformed. Quartz veins and stringers are common and either parallel or cut across the schistosity. Epidote is disseminated along fractures or concentrated as nodules around which the schistosity bends.

Petrography

The texture of the hornblende biotite schist is porphyroblastic to hypidioblastic granular. Crystals are anhedral to subhedral in form and range from 0.1 to 2 mm in size. Plagioclase, quartz and microcline commonly have undulatory extinction caused by strain.

Quartz (58 percent), biotite (20 percent), plagioclase feldspar (10 percent), hornblende (7 percent) and microcline (3 percent) are the essential minerals. Accessories are magnetite, epidote, sphene, apatite and zircon. Quartz crystals often have quartz overgrowths and sutured grain boundaries produced by recrystallization. Green or reddish-brown biotite crystals often have granular aggregates of magnetite concentrated along cleavage planes, and inclusions of sphene and zircon. Chlorite is the common alteration product of biotite. Plagioclase feldspar is andesine. Zoning is rare and is shadowy where present. Inclusions in the plagioclase crystals are mostly quartz, often arranged poikiloblastically with minor apatite and zircon. Alteration products are kaolin, sericite and epidote. Green hornblende crystals are often slightly embayed by feldspar and quartz. Inclusions of quartz are abundant, but zircon, sphene, epidote and magnetite are also present. Granular masses of magnetite are often concentrated along cleavage planes and the crystals are commonly altered to chlorite and biotite. Microcline appears to have crystallized between the primary detrital fragments. Alteration is not as pronounced in microcline as in plagioclase even though the same alteration products form from both. Magnetite is the most common accessory mineral and individual crystals are often surrounded by granular masses of sphene and occasionally epidote. Magnetite alters to hematite. Epidote often partially replaces biotite and hornblende.

The chlorite schist and andalusite schist are variations of the hornblende biotite schist. In the chlorite schist, light green chlorite crystals occur as finely crystalline scaly masses. Chlorite appears to be replacing both biotite and hornblende and locally forms pseudomorphs after biotite. Andalusite occurs as subhedral to euhedral porphyroblasts which are almost completely altered to muscovite, contain some graphite inclusions and are highly fractured with the fractures oriented parallel to the crystal boundaries. These crystals are up to 2 cm in length and 5 mm in width. Platy biotite crystals are commonly oriented parallel or subparallel to the surfaces of the porphyroblasts and appear to have been bent around the porphyroblasts. Also, these porphyroblasts locally cut across the schistosity. This evidence suggests that the porphyroblasts were formed after the schistosity, either as a result of static retrogressive metamorphism or, more likely, as a result of a later contact metamorphism associated with intrusion.

Amphibolite

Field Description

Isolated outcrops of amphibolite occur within the hornblende biotite schist. These rocks are coarsely crystalline, lack visible planar structures and are cut by numerous quartz stringers. Fresh specimens are greenish-black (5 G 2/1) and weather to dark greenish-gray (5 G 4/1).

Petrography

The amphibolites have a xenoblastic granular texture and are composed almost entirely of hornblende (73 percent) and actinolite (26 percent). Magnetite and zircon are common inclusions. Green hornblende crystals are anhedral in form and average 7 mm in diameter. Subhedral crystals of magnetite and rare zircon are the common inclusions. Alteration products are chlorite, calcite and muscovite. Actinolite mantles many of the hornblende crystals and also occurs as felty masses. Crystals are subhedral in form, light green in color and range from 0.25 to 4 mm in length. Magnetite and zircon are inclusions in actinolite. Calcite, muscovite and chlorite are the common alteration products. Hematite has altered from magnetite producing an iron-stained effect throughout the rock.

Conclusions

Regional metamorphism of greenschist grade has affected rocks in the Jackson Mountains southeast of the Pine Forest Mountains. Metamorphic rocks in the Pine Forest Mountains may have been formed during the same period of deformation (Willden, 1963). Superimposed on these regionally metamorphosed rocks in the thesis area are contact metamorphic features, such as the growth of andalusite porphyroblasts, induced by intrusion of the plutons.

The arkosic quartzite was probably derived from a quartz arenite containing some feldspar. The schists most likely were derived from shales or pelitic sediments rich in clays. Thus, the alternations of arkosic quartzites and schist probably mimic the original stratigraphic sequence and suggest that the quartz arenite and pelitic sediments were interbedded prior to metamorphism. Contacts between these alternating bands of rock are commonly sharp, but locally they are gradational. Schistosity in the schist and foliation in the quartzite are normally oriented parallel to the contacts between these two rock types.

Contacts between the metamorphic and plutonic rocks are sharp where visible. Inclusions of the country rock in the plutonic are usually elongate parallel to contacts. An angular unconformity marks the contact between the metamorphic and younger volcanic rocks.

Figure 2. Interbedded quartzite and schist.

PLUTONIC ROCKS

General Statement

Plutonic rocks are exposed in an area of approximately 11 square miles including most of the topographic highs within the thesis area. Five different plutons have been identified. Separate outcrop areas can often be combined into a single intrusive unit on the basis of mineralogy, texture, structure and proximity. The quartz diorites that crop out in the vicinity of Cold Spring and to the south of Black Mountain (Plate 1) belong to the same pluton, and two outcrop areas of leucogranodiorite, located in the vicinity of Thacker Canyon and Emigrant Pass (Plate 1), are also believed to be parts of the same pluton as are the hornblende gabbros that crop out in three different localities. For convenience, the quartz diorite that crops out on Black Mountain will be termed quartz diorite II and the quartz diorite that crops out in the vicinity of Cold Spring and to the south of Black Mountain will be termed quartz diorite I. The other plutonic bodies will be referred to as leucogranodiorite, hornblende diorite and hornblende gabbro.

Quartz diorite I has been intruded by hornblende gabbro west of Cold Spring. Apophyses and dikes of the gabbro intrude the quartz diorite and inclusions or xenoliths of quartz diorite showing varying degrees of assimilation occur within the gabbro. The contacts are

Figure 3. Looking northeast across Continental Lake from the Pueblo Mountains. Black Mountain is the prominent feature on the left side of the photo. Note mudcracks in foreground.

sharp and discordant to the foliation present in the quartz diorite. Quartz diorite I has also been intruded by the leucogranodiorite. Contacts exposed east of Cold Spring are marked by a breccia zone up to ten feet in width. This contact breccia contains angular fragments of both quartz diorite and leucogranodiorite set in a fine-grained matrix of brecciated quartz diorite. Inclusions of quartz diorite are present within the leucogranodiorite. However, no dikes or apophyses of the leucogranodiorite were noted intruding the quartz diorite. To the south of Black Mountain, quartz diorite I has been intruded by the hornblende diorite. The contact is sharp and inclusions of quartz diorite, with varying degrees of assimilation, are present within the hornblende diorite.

North of Emigrant Pass on the east side of the mountains, the hornblende gabbro has intruded the leucogranodiorite. The contacts are sharp where visible. Apophyses of gabbro cut the leucogranodiorite and xenoliths of leucogranodiorite were noted in the gabbro. Near the contacts, the gabbro becomes lighter in color and appears to have a higher than normal percentage of felsic minerals, probably as a result of assimilation of the leucogranodiorite country rock into the intruding melt. The hornblende diorite and the hornblende gabbro are in contact in this general vicinity, however, the contacts are covered and relative ages could not be determined. Apophyses and dikes of quartz diorite II intrude the hornblende diorite on Black

Mountain. The contact between these two units is sharp in some places and gradational in others. Xenoliths of hornblende diorite are often included in the quartz diorite. These inclusions show varying degrees of assimilation. Also, assimilation of the hornblende diorite by the quartz diorite magma during intrusion has caused the quartz diorite to become darker in color near the contacts.

Two sequences of intrusion are evident from examination of these contact relations. In both cases, quartz diorite I is the oldest. Near Cold Spring, this pluton was intruded first by the leucogranodiorite and then by the hornblende gabbro, which also intrudes the leucogranodiorite. In the vicinity of Black Mountain, quartz diorite I was intruded by the hornblende diorite that, in turn, was intruded by quartz diorite II. The relative age relationship between these two sequences cannot be determined as the contact between the hornblende gabbro and the hornblende diorite is covered.

A K-Ar age of 96 m.y. has been obtained on the youngest pluton in the Pine Forest Mountains near Duffer Peak (Smith, 1969). The plutons in the thesis area are somewhat older than the Duffer Peak pluton and are believed to have been intruded during Early Cretaceous time.

The plutonic units will be discussed in order of relative age where this can be determined; beginning with quartz diorite I. Where relative age cannot be determined, the sequences of units will be discussed in an arbitrary order beginning with the one exposed in the vicinity of Cold Spring and Emigrant Pass as illustrated in Table 1.

Table 1. Summary of relative ages of the plutonic rocks exposed in the thesis area. Two different sequences of intrusion have been determined from contact relationships.

COLD SPRING-EMIGRANT PASS	BLACK MOUNTAIN
Hornblende Gabbro	Quartz Diorite II
↓	↓
Leucogranodiorite	Hornblende Diorite
↓	↓
Quartz Diorite I	Quartz Diorite I

Quartz Diorite I

Field Description

Quartz diorite I crops out at three separated locations in an area of approximately four square miles. One outcrop area is located in the vicinity of Cold Spring where it extends across the entire mountain range. The other outcrop areas are located just to the south of Black Mountain, one on the west side of the mountain range and the other near the center of the range.

The quartz diorite weathers to rounded or sub-rounded fragments ranging in size from boulders more than ten feet in diameter to sand-size particles forming grus. Weathered surfaces are greenish-gray (5 GY 4/1) to brownish-gray (5 YR 4/1) and fresh surfaces are dark gray (N 3). Plagioclase phenocrysts are pinkish-gray (5 YR 8/1).

The pluton varies in grain size, texture and structure. The coarser grained variety of quartz diorite I is porphyritic and has a prominent foliation that is defined by the parallel alignment of platy biotite crystals, bladed hornblende crystals and plagioclase phenocrysts. In some cases, the phenocrysts appear to have been subjected to a "grinding action" which produced augen-like structures. The pluton becomes much finer grained near its outer margins, espeically along its extreme western edge and this may represent a chill zone. The porphyritic texture and foliation are absent in the finer grained variety of quartz diorite I. Two prominent joint sets are present in this unit; one parallel to the foliation, the other at right angles to it.

Leucocratic or aplite dikes, quartz veins and pegmatites intrude quartz diorite I. These range in width from one-half inch to ten feet. Evidence for forcible intrusion is seen where the foliation has been offset or pushed apart perpendicular to the contacts of the dikes.

Petrography

Quartz diorite I has a holocrystalline, hypidiomorphic, porphyritic to granular texture. Many of the crystals have undulatory extinction and some plagioclase and biotite crystals are bent and broken. Groundmass crystals are anhedral to subhedral in form and range in size from 0.1 to 2 mm.

The quartz diorite is composed mostly of plagioclase feldspar, quartz, orthoclase, augite, hornblende, and biotite (Table 2). Accessory minerals are zircon, magnetite and apatite. Plagioclase feldspar is calcic andesine. Subhedral phenocrysts range from 3 to 20 mm in maximum dimension. Inclusions are hornblende, biotite, magnetite, apatite and rarely sphene and zircon. Myrmekitic intergrowths are present where orthoclase and plagioclase are in contact. Kaolin, sericite, epidote and calcite are alteration products of plagioclase. Anhedral phenocrysts of orthoclase are up to 3 mm in maximum dimension. Crystals are devoid of inclusions except for occasional subhedral plagioclase grains. Kaolin and sericite are common alteration products. Orthoclase is characteristically less altered than plagioclase and occasionally rims plagioclase crystals. Quartz crystals are always interstitial.

Of the ferromagnesian minerals only clinopyroxene, probably augite (2V = 50-55 degrees), is colorless. Common inclusions in the augite are plagioclase, apatite, zircon and granular masses of magnetite concentrated along cleavage planes. Deuteric alteration of augite produces a mantle of hornblende around the augite crystals.

Table 2. Modal analyses of selected samples of the plutonic rocks exposed in the thesis area.

	Quartz Diorite I				Leucogranodiorite			Horn-blende Gabbro	Hornblende Diorite		Quartz Diorite II	
	GTB 152	GTB 171	GTB 172	GTB 227	GTB 14	GTB 137	GTB 140	GTB 181	GTB 220	GTB 240	GTB 206	GTB 239
Plagioclase	52.5	57.1	54.3	58.9	65.7	60.7	57.3	55.7	53.5	51.0	63.6	56.0
Orthoclase	3.0	3.3	4.3	5.7	-	-	-	-	10.6	13.9	-	-
Microcline	-	-	-	-	15.1	21.8	14.6	-	-	-	3.0	6.4
Quartz	11.3	13.1	10.3	12.4	16.3	14.8	19.2	1.0	7.2	9.3	11.3	10.5
Augite	1.2	9.1	2.6	-	-	-	-	-	0.4	4.1	-	-
Hornblende	13.9		14.8	7.9	0.6	-	-	34.1	13.8	8.2	1.8	9.2
Biotite	15.5	12.6	8.7	15.9	1.1	2.1	8.0	0.6	13.5	11.5	18.2	17.2
Others	2.6	5.8	5.0	4.2	1.3	0.6	0.9	8.6	1.0	2.0	2.1	1.1

Subhedral hornblende phenocrysts, up to 6 mm in maximum dimension, as well as crystals in the groundmass are pleochroic from light green to dark green and are often deeply embayed by quartz and feldspar. Hornblende often displays a poikilitic texture with plagioclase and quartz being the most common inclusions. Other inclusions are apatite, zircon, sphene and magnetite, which is often concentrated along cleavage planes. Horblende alters to biotite, epidote, chlorite and actinolite. Biotite is pleochroic from light green or brown to black. Epidote, apatite, magnetite and zircon are common inclusions and rutile needles form an interlocking network on basal sections of some crystals. Magnetite and sphene are often concentrated along cleavage planes. Some crystals have reaction rims of vermicular quartz due to late stage reaction with the melt. Chlorite, muscovite and actinolite are common alteration products. Magnetite, the most abundant accessory mineral, is often deeply embayed and commonly alters to hematite. Sphene and epidote often occur as granular masses rimming the magnetite crystals. Euhedral sphene crystals, up to 1 mm in length, alter to leucoxene.

Leucogranodiorite

Field Description

The leucogranodiorite crops out at two separate localities in an area of approximately two square miles. The outcrops located near Emigrant Pass form an elongate body that is from one-half to three-fourths mile wide and nearly two miles long. The outcrops near Thacker Canyon are a part of Mahogany Mountain located to the southeast.

The rock weathers as rounded to sub-rounded fragments ranging in size from boulders several feet in diameter to grus. Weathered surfaces vary from medium light gray (N 6) to very pale orange (10 YR 8/2) and fresh surfaces are light gray (N 7). Microcline phenocrysts are very pale orange (10 YR 8/2).

The texture and structure of the leucogranodiorite is variable. The central part of the pluton has abundant microcline phenocrysts set in a coarse-grained groundmass whereas in the outer margins the size and number of phenocrysts decreases and the groundmass becomes medium-grained. A poorly developed foliation defined by the alignment of biotite crystals parallels the contacts in the outer margins.

Petrography

The leucogranodiorite is porphyritic to subporphyritic, holocrystalline and hypidiomorphic in texture. Microcline, quartz and plagioclase have undulatory extinction. Groundmass crystals range from 0.1 to 4 mm in size and are subhedral to anhedral in form.

Essential minerals are plagioclase, microcline, quartz, biotite and occasionally hornblende (Table 2). Common accessory minerals are magnetite, zircon, apatite, epidote and sphene. Plagioclase feldspar is andesine that occurs in the groundmass and as subhedral phenocrysts up to 8 mm in length. It is poorly zoned and contains inclusions of quartz, apatite, biotite and occasionally sphene, epidote and zircon. Reaction rims of myrmekite occur where plagioclase and microcline are in contact. Plagioclase is altered to kaolin and sericite. Subhedral phenocrysts of microcline, up to 10 cm in length, are often deeply embayed by plagioclase and quartz. Inclusions are quartz and plagioclase and alteration products are kaolin and sericite. Occasionally quartz occurs as subhedral phenocrysts up to 8 mm in maximum dimension. Hornblende crystals are pleochroic from light to dark green and often have polysynthetic twins with (100) as the twin plane. The crystals are normally deeply embayed by quartz and feldspar and inclusions are magnetite, sphene, zircon, quartz and feldspar. Chlorite is the common alteration product of hornblende. Biotite is pleochroic from light green or brown to black and many of the larger crystals have been bent as a result of strain. Apatite, sphene, zircon and rarely quartz and plagioclase are inclusions and granular aggregates of magnetite are commonly concentrated along cleavage planes. Alteration products are chlorite and muscovite which are often intergrown with biotite.

Magnetite crystals alter to hematite and are often rimmed by granular masses of sphene. Sphene also occurs as euhedral crystals, up to 2 mm in maximum dimension, that alter to leucoxene.

Hornblende Gabbro

Field Description

Hornblende gabbro crops out at three separated locations in an area of one-third square mile. The main outcrop area is located between quartz diorite I and the metamorphosed country rock west of Cold Spring; other areas are located on the east side of the mountains south of Black Mountain.

Weathered fragments are sub-rounded to sub-angular and range from two inches to several feet in diameter. Weathered surfaces are medium dark gray (N 4) and fresh surfaces medium light gray (N 6). Hornblende phenocrysts are most abundant in the center of the bodies and decrease in size and abundance toward the outer margins. The groundmass also becomes finer-grained toward the margins.

Petrography

The hornblende gabbro has a porphyritic to subporphyritic, holocrystalline, hypidiomorphic texture. Groundmass crystals range from 0.25 to 4 mm in size and are subhedral to anhedral in form. Undulatory extinction occurs in quartz and plagioclase crystals.

Essential minerals are plagioclase and hornblende with minor amounts of biotite and quartz (Table 2). Epidote, magnetite, apatite and sphene are the common accessories. Plagioclase feldspar is labradorite. It is usually unzoned and contains inclusions of magnetite, apatite and rarely zircon. Alteration products are kaolin, sericite and epidote. Quartz crystals are always interstitial. Hornblende occurs as phenocrysts up to 15 cm in length and as groundmass crystals. It is pleochroic from light green to dark green and often deeply embayed by plagioclase. It often has a poikilitic texture with numerous inclusions of plagioclase or more rarely epidote, magnetite, apatite, sphene and zircon. Some of the larger crystals often have polysynthetic twins with (100) as the twin plane. Hornblende alters to muscovite, actinolite and chlorite and is often partially replaced by epidote. Biotite is pleochroic from light green to very dark green, contains a few inclusions of magnetite, sphene and zircon and alters to chlorite and muscovite. Magnetite occurs as granular masses concentrated along cleavage planes in hornblende and biotite, and commonly alters to hematite. Sphene occurs both as granular masses surrounding magnetite crystals and as euhedral crystals that alter to leucoxene.

Hornblende Diorite

Field Description

The hornblende diorite crops out in an area of approximately three square miles at two separated outcrop localities on Black Mountain. The most extensive of these localities includes the entire western half of Black Mountain and the other locality forms an elongate belt approximately one-fourth mile wide and one mile long extending south along the east side of the mountains from the center of Black Mountain.

The hornblende diorite weathers into sub-rounded to sub-angular fragments ranging from one inch to several feet in diameter. Weathered surfaces are medium dark gray (N 4) and fresh surfaces are medium gray (N 5). Grain size in the hornblende diorite varies from medium-grained in the central part of the pluton to fine-grained in a zone approximately 25 yards wide adjacent to the contacts which may represent a chill zone. Plagioclase phenocrysts are common in the coarser grained part of the pluton but are totally absent in the chill zone. A crudely developed foliation, defined by subparallel alignment of platy biotite crystals and bladed hornblende crystals, is localized in small areas within the pluton.

Aplite and lamphrophyre dikes have intruded the hornblende diorite in its outer margins. Aplite dikes range in width from several inches to ten feet, are up to one-tenth mile in length, have sharp contacts and contain inclusions of the diorite. Following intrusion of aplite, the lamprophyre dikes that range in width from several inches to three feet and are up to 50 feet in length intruded the hornblende diorite. Lamprophyre dikes crosscut aplite dikes, display sharp contacts with both the aplite and the diorite and are typically inclusionless. Presumably, both types of dikes intruded along joints or fractures in the hornblende diorite.

Along the contact with the metamorphosed country rock and the hornblende diorite on the south side of Black Mountain, a migmatite zone characterized by alternating bands of fine-grained diorite and biotite schist has developed. Contacts between the different phases of the migmatite are sharp with schistose bands varying from one inch to one foot and the diorite bands from several inches to four feet in width. The diorite has intruded the schist and is usually conformable with the well developed schistosity although in places it is disconformable. Inclusions of the schistose country rock with their longest dimensions parallel the contacts often occur within the plutonic rocks.

Petrography

The hornblende diorite has a porphyritic to granular, holocrystalline, hypidiomorphic texture. Quartz, orthoclase and plagioclase crystals often have undulatory extinction and large plagioclase and biotite crystals are often bent and broken as a result of strain. Crystals in the groundmass are anhedral to subhedral in form and range from 0.25 to 5 mm in size.

Essential minerals are plagioclase feldspar, orthoclase, quartz, clinopyroxene, hornblende and biotite (Table 2). Accessories are magnetite, apatite, zircon and sphene. Andesine crystals occur in both the groundmass and as subhedral phenocrysts that range in length from 1 to 2 cm. Zoning is rare and is poorly developed where it does occur. Subhedral inclusions are hornblende, biotite, apatite and magnetite. Alteration products are kaolin, sericite and rarely epidote. Reaction rims of myrmekite are present where plagioclase and orthoclase crystals are in contact. Orthoclase crystals contain inclusions of plagioclase, quartz, magnetite, hornblende and biotite and alter to kaolin and sericite. Quartz crystals are always interstitial. Clinopyroxene is invariably colorless augite (2V = 50-55 degrees). Magnetite and plagioclase are common inclusions with granular masses of magnetite commonly concentrated along cleavage planes. Augite alters to chlorite and some crystals have been partially replaced by epidote. Green hornblende crystals are deeply embayed and often have a poikilitic texture with abundant inclusions of quartz and feldspar. Magnetite is also a common inclusion, especially as granular masses concentrated along cleavage planes. Minor inclusions are apatite, sphene and zircon. Hornblende alters to chlorite and is often partially replaced by epidote. Biotite is pleochroic from light brown or light green to black. Magnetite is the most common inclusion and often occurs as a granular aggregate concentrated along cleavage planes. Other inclusions are apatite, zircon and sphene. Some crystals have reaction rims of vermicular quartz due to late stage reaction with the melt. Biotite commonly alters to chlorite. Individual magnetite crystals are anhedral to subhedral in form, are often deeply embayed and alter to hematite. Sphene occurs as granular masses surrounding individual magnetite crystals and as euhedral to subhedral crystals that alter to leucoxene.

Quartz Diorite II

Field Description

Quartz diorite II crops out on the eastern half of Black Mountain in an area of approximately two square miles. These rocks weather into sub-angular to sub-rounded fragments ranging in size from boulders several feet in diameter to sand-size particles that form grus. Weathered surfaces are medium gray (N 5), fresh surfaces are medium light gray (N 6) and phenocrysts are yellowish-gray (5 Y 8/1).

Quartz diorite II is medium-grained throughout its outcrop area with plagioclase phenocrysts common near the contacts that decrease in both size and abundance toward the central part of the pluton. A prominent foliation, defined by the parallel allignment of platy biotite crystals, bladed hornblende crystals and plagioclase phenocrysts occurs throughout the pluton.

Petrography

The texture of this rock type is porphyritic to granular, holocrystalline and hypidiomorphic. Many quartz, plagioclase and microcline crystals have undulatory extinction and most plagioclase phenocrysts are bent and broken as a result of strain. Crystals in the groundmass range in size from 0.1 to 5 mm and are subhedral to anhedral in form.

Essential minerals are plagioclase feldspar, microcline, quartz, hornblende and biotite (Table 2). Magnetite, apatite, sphene and zircon are common accessories. Plagioclase feldspar that occurs as subhedral phenocrysts up to 12 mm in maximum dimension as well as that in the groundmass is andesine. Normal zoning is not uncommon, but it is poorly developed and shadowy where it occurs. Inclusions are magnetite, apatite, hornblende and biotite. Reaction rims of myrmekite surround plagioclase where it is in contact with microcline. Kaolin and sericite are common alteration products.

Microcline crystals rarely contain inclusions, however, where present they are plagioclase, magnetite, hornblende and biotite. Microcline alters to kaolin and sericite to a lesser degree than does plagioclase. Quartz is always interstitial. Hornblende crystals are pleochroic from light green to dark green, are commonly deeply embayed and may have a poikilitic texture with inclusions of plagioclase and quartz. Other inclusions are sphene, zircon and magnetite which also occurs as a granular aggregate concentrated along cleavage planes. Hornblende alters to chlorite and is often replaced by epidote. Biotite is pleochroic from light green or light brown to very dark reddish-brown and contains inclusions of magnetite, sphene, zircon and apatite. Also, granular masses of magnetite and sphene may be concentrated along cleavage planes. Biotite is partially replaced by epidote and commonly alters to chlorite. Magnetite alters to hematite and is often mantled by granular sphene and epidote. Sphene commonly alters to leucoxene

Conclusions

The prominent foliation present in the quartz diorite plutons and less well developed in the leucogranodiorite and hornblende diorite plutons, probably formed as a result of flow. The minerals that define this foliation; mostly biotite, hornblende and plagioclase, had crystallized before complete solidification of the magma. These crystals were then aligned parallel to the flow direction of the magma as it intruded into its present position (Balk, 1937). As these crystals were being pushed into their present orientation, they were subjected to large amounts of strain which could have caused the marked undulatory extinction common to them and to other crystals in the plutonic rocks. This strain may also be responsible for the bent, broken and "ground up" nature of the larger crystals.

The presence of these subvertical flow lines in the plutons, marginal fissures intruded by aplite and occasionally pegmatite, and the development of domical foliation in the roof indicates upward flow of the magma. The wall rocks are highly folded in some areas indicating shortening which suggests that the plutons were forcefully intruded into the country rock (Buddington, 1959).

The plutons present in the thesis area were probably intruded in the Transitional Epizone-Mesozone. Epizonal features include (1) the presence of chill zones bordering the hornblende diorite and quartz diorite I, (2) intrusion of aplite dikes and pegmatites in the outer margins of some of the plutons and (3) contact metamorphism producing andalusite in the country rock. Mesozonal features common to the plutons are well developed in many cases. These features include (1) a well developed foliation that is subvertical in nature and is consistent with the proposed upward flow of magma during emplacement, (2) a schistose structure in the country rocks bordering the plutons that is steeply inclined and conformable with the contacts and (3) no well developed chill zones in the outer margins of the hornblende gabbro, leucogranodiorite and quartz diorite II intrusions (Buddington, 1959).

VOLCANIC ROCKS

General Statement

Volcanic rocks are located along the western side of the mountains in the thesis area and form an elongate belt from one-half to one and one-half miles wide and nearly three miles long. The rocks crop out in an area of approximately three and one-half square miles. The more resistant flows form a continuous series of low ridges that rarely exceed 25 feet in height. Interbedded with these are less resistant flows that are slope formers and volcaniclastic rocks that are valley formers. The total thickness of the volcanic rocks exposed in the thesis area is approximately 2600 feet.

The volcanic sequence has been divided into five units based on composition and stratigraphic continuity. The sequence of deposition and extrusion of these units is summarized in Table 3. Detailed macroscopic descriptions of these units are given in the measured sections of the Appendix.

Olivine Andesite

Field Description

The andesite unit is composed of a single flow that is exposed near the west end of Emigrant Pass in an area of approximately

Table 3. Summary of the volcanic rocks exposed in the thesis area in order of relative age.

Unit Name	Thickness (ft.)	Description
Basalt Dikes	--	Dark gray, aphanitic, columnar and platy jointing, blocky fracture.
Olivine Basalt	2323	Very dusky red to black; glomeroporphyritic and dense vesicular flows with minor interbedded air fall and ash flow tuffs.
Ignimbrite	77	Pale red, base poorly welded, grades upward into densely welded top; flattened pumice fragments and vesicles, sanidine and quartz phenocrysts, lithic fragments.
Rich Pebbly Volcanic Sandstone	118	Reddish brown to light pinkish-gray, thin bedded; composed mostly of broken and rounded glass shards with subordinate sub-rounded crystal and lithic fragments.
Olivine Andesite	103	Pale red, aphanitic, good to poor platy jointing, vesicular, vesicles filled with a yellowish-brown clay.
	Angular Unconformity	
Plutonic and Metamorphic Rocks	--	--

one-fourth square mile. The andesite flow lies on Triassic-Jurassic metasediments with profound angular unconformity. The rocks are highly weathered and iron-stained. Weathered surfaces are pale red (5 R 6/2) and fresh surfaces are light brownish-gray (5 YR 8/1). Platy and blocky fracture is so common that angular fragments rarely exceed six inches in diameter. Vesicles vary in size and abundance and are commonly filled with a yellowish-brown clay.

Petrography

The olivine andesite is composed of plagioclase feldspar (74 percent), augite (14 percent), olivine (9 percent) and others--mostly magnetite--(3 percent) arranged in a holocrystalline, subporphyritic, pilotaxitic texture. Andesine occurs as subhedral phenocrysts up to 2 mm in maximum dimension and as subhedral to anhedral groundmass crystals that average 0.1 mm in length. Magnetite occurs rarely as inclusions in the andesine which is slightly altered to kaolin. Augite is colorless to pale green, occurs as anhedral to subhedral crystals that range in size from 0.1 to 1 mm and may be deeply embayed by plagioclase. Polysynthetic twins with (100) as the twin plane are often present as well as euhedral to subhedral inclusions of magnetite. Augite alters to green chlorite. Colorless crystals of olivine are normally subhedral in form, range in size from 0.1 to 1 mm and have anhedral crystals of magnetite as inclusions. Olivine is commonly altered to iddingsite. Magnetite occurs as subhedral to anhedral crystals that are often deeply embayed, average approximately 0.1 mm in diameter and alter to hematite.

Rich Pebbly Volcanic Sandstone

Field Description

The volcanic sandstone unit overlies the olivine andesite at the west end of Emigrant Pass. To the north of Emigrant Pass and in the extreme southwestern part of the thesis area the volcanic sandstone is in contact with the older crystalline rocks along the angular unconformity that forms the contact between the olivine andesite and the metasediments at Emigrant Pass. These three outcrop localities have a combined area of approximately one-fourth square mile.

The volcanic sandstone beds range from one to 18 inches in thickness and vary in induration. This unit is so highly weathered that bedding contacts are often inferred from slight color changes in the soil zone. Fractures in the unit are commonly filled with calcite or zeolites. A reddish-brown baked zone, 2 to 3 feet thick, occurs at the top of the volcanic sandstone where it is overlain by basalt. Weathered surfaces are grayish-orange-pink (5 YR 7/2) or pinkish-gray (5 YR 8/1) and fresh surfaces are very pale orange (10 YR 8/2).

Petrography

The framework of the volcanic sandstone makes up approximately 60 percent of the rock and is composed of lithic fragments (16 percent), crystal fragments (12 percent) and glass shards (72 percent). Voids make up approximately 30 percent of the rock and clay the remaining 10 percent. No cement was recognized and therefore it is assumed that clay acts as the bonding agent. Basalt, andesite and pumice fragments range from 0.25 to 5mm in diameter, are sub-rounded to sub-angular and vary in degree of weathering. Crystal fragments are sub-angular quartz and feldspar, both plagioclase and potash, that average 1 mm in diameter. Glass shards appear to be highly fragmented with rounded to sub-rounded corners and average approximately 0.25 mm in diameter.

Ignimbrite

Field Description

The ignimbrite unit crops out at a number of isolated areas in the northwestern part of the thesis area where it lies unconformably over the hornblende diorite. In the extreme southwestern part of the

Figure 4. Looking northwest from Cold Spring toward the Pueblo Mountains. Note reddish-brown bake zone at top of volcanic sandstone in the center of the photo.

thesis area, the ignimbrite overlies the volcanic sandstone. The densely welded upper part of the ignimbrite unit is quite resistant and is a dominant ridge former, especially in the southwest. The unit occupies a total area of approximately one-eighth square mile.

The firmly welded tuff zone of the ignimbrite is underlain by a thin, up to ten feet thick, poorly welded zone. Collapsed pumice fragments and euhedral phenocrysts of sanidine and quartz are aligned subparallel to the bottom contact of the unit. The poorly welded zone grades upward into the densely welded zone which is characterized by well developed platy jointing and eutaxitic texture and is up to 65 feet thick. Fresh surfaces of the ignimbrite are pale red (10 R 6/2) and weathered surfaces are pale red (5 R 6/2).

Petrography

The ignimbrite is composed of glass shards (80 percent), sanidine (10 percent), rock fragments (5 percent), quartz (3 percent) and other constituents (2 percent). The texture is hypocrystalline, eutaxitic and porphyritic with phenocrysts set in a vitroclastic groundmass. Individual glass shards have been bent around phenocrysts and lithic fragments. The glass is reddish-brown in color and some of the glass shards have devitrified to a cryptocrystalline mass of cristobalite and feldspar. Euhedral to anhedral sanidine crystals are usually embayed by the groundmass.

Phenocrysts are up to 3 mm in length, commonly contain inclusions of magnetite and are slightly altered to kaolin. Quartz occurs as phenocrysts which are anhedral, deeply embayed and up to 2 mm in length. Rock fragments are volcanic in origin. Pumice fragments are usually flattened parallel to the top and bottom of the unit and may be up to six inches in length. The non-pyroclastic volcanic rock fragments are rounded to sub-rounded and rarely exceed 0.5 inch in diameter. Other constituents are plagioclase and magnetite. Magnetite commonly alters to hematite.

Olivine Basalt Unit

Field Description

The olivine basalt unit crops out in an area of approximately three square miles flanking the west side of the mountains and as isolated erosional remnants on the mountains. The basalt stratigraphically overlies the ignimbrite as indicated by extending outcrops along strike since the units are not in contact within the thesis area. The olivine basalt unit is 2323 feet thick and is composed of a series of basalt flows interbedded with minor ash flow and air fall tuffs. The basalts are dominantly of two types: a glomeroporphyritic basalt with plagioclase phenocrysts and a dense, slightly vesicular, aphanitic basalt. The glomeroporphyritic basalt is a slope-former whereas the denser basalt is a ridge-former.

Near the top of this unit, a distinctive bedded tuff member composed of air fall deposits crops out. This tuff is composed of angular glass shards, lithic fragments and crystal fragments. The more indurated beds are reddish-brown in color and the less indurated beds are grayish-pink. Bedding contacts appear to be gradational. Thin vitrophyres, up to ten feet thick, are probably remnants of much thicker ignimbrites that have been eroded away and are composed mostly of devitrified volcanic glass that has a perlitic texture.

Petrography

The glomeroporphyritic olivine basalt is composed of plagioclase feldspar (56 percent), augite (29 percent), olivine (7 percent) and magnetite and ilmenite (8 percent) arranged in a holocrystalline, intergranular and porphyritic texture. Labradorite phenocrysts are euhedral to subhedral in form, are lath-shaped, are up to 3 cm in length and contain inclusions of magnetite, ilmenite and olivine. Labradorite in the groundmass displays subhedral crystal outlines and range in size from 0.1 to 0.75 mm. Calcite and kaolin are the common alteration products of plagioclase. Pinkish-brown augite crystals are subhedral to anhedral in form, average approximately 0.5 mm in diameter and contain euhedral to subhedral inclusions of magnetite and ilmenite. The ilmenite inclusions and the pinkish-brown color are indicative of titaniferous augite. Subhedral olivine crystals average approximately 0.25 mm in diameter, do not display reaction rims and are commonly altered to nontronite and saponite. Magnetite and ilmenite occur not only as inclusions, but also as individual crystals in the rock that are subhedral in form and average 0.25 mm in diameter. Alteration of magnetite to hematite produces an iron-stained effect throughout the rock. Ilmenite is often altered to leucoxene.

The dense, slightly vesicular olivine basalts are composed of plagioclase feldspar (52 percent), olivine (22 percent), augite (18 percent) and magnetite and ilmenite (8 percent). The texture of these basalts is holocrystalline and ophitic to subophitic. Plagioclase feldspar is labradorite that occurs as subhedral laths which range from 0.25 to 2 mm in length. Labradorite contains inclusions of magnetite or ilmenite and apatite and alters to kaolin. Colorless, subhedral olivine crystals range in diameter from 0.25 to 1 mm, contain minute, subhedral magnetite inclusions and alter to saponite. Subhedral augite crystals range in size from 0.5 to 2.5 mm and are pale pinkish-brown. Common inclusions are anhedral to subhedral magnetite and possibly ilmenite crystals, small subhedral plagioclase laths and rarely olivine. Magnetite has the same physical characteristics as in the glomeroporphyritic olivine basalt.

Basalt Dikes

A number of basalt dikes cut the andesite, volcanic sandstone and basalt units. These dikes are up to 15 feet in width and have sharp contacts. The basalt is aphanitic, dark gray (N 3), has well developed columnar joints perpendicular to the contacts and platy jointing that forms parallel to the contacts. Where these two joint sets intersect, a blocky fracture is produced. Alteration of the country rocks along the dike contacts is uncommon, however, near the west end of Emigrant Pass where a dike intrudes the arkosic quartzite, the metamorphic rock becomes much redder in color probably as a result of oxidizing the iron present in the rock.

Stratigraphic Correlation and Age

The distinctive tuff member of the olivine basalt unit correlates lithologically with a similar member exposed in the Pueblo Mountains directly across Continental Lake Basin approximately one mile to the west (Burnam, 1969). Stratigraphically above the tuff member in the Pueblo Mountains is a thick rhyolite flow that is correlative with the Canyon Rhyolite Formation exposed in canyons around the borders of Virgin Valley located approximately 20 miles further west. The Virgin Valley Formation overlies the Canyon Rhyolite in Virgin Valley (Merriam, 1910).

The Virgin Valley beds have been dated paleontologically on vertebrate fossil remains; primarily mammalian fauna. The age of these beds is middle Miocene (Merriam, 1911). Since the volcanic sequence exposed in the thesis area underlies the Virgin Valley beds and overlies the plutonic and metamorphic rocks along an angular unconformity, the age of the volcanic rocks must be younger than the Cretaceous plutonic rocks, but older than the mid-Miocene Virgin Valley Formation.

QUATERNARY DEPOSITS

Quaternary alluvium is both fluvialtile and lacustrine. The fluvial deposits are composed of relatively coarse material and occur as alluvial fans at the mouths of the mountain canyons and as valley fill where no lakes exist. The lacustrine deposits consist of finer detritus deposited in the basins. Sediments that are presently being deposited in Continental Lake and that were previously deposited in Alvord Lake are good examples of lacustrine alluvium. Alluvial deposits that predate faulting are not exposed in the thesis area.

GEOMORPHOLOGY

Older Modified Features

Three large underfit valleys are located in the area near Cold Spring, at Emigrant Pass and just to the south of Black Mountain. These valleys were present before tilting and subsequent uplift of the mountain range which produced the present drainage pattern. Valley gradients, sloping gently toward the east, indicate former drainage in that direction as tilting was toward the west. The former gradients were much steeper than those now present. Since uplift, the valleys have been undergoing dissection. This process is not related to a lowering of base level but rather reflects uplift of the mountain range.

Continental Lake is probably a remnant of Lake Alvord which occupied the basin to the west of the thesis area during the Pleistocene Epoch (Russel, 1884). The former presence of Lake Alvord in the basin is suggested by the remnant of a lake terrace in the vicinity of the gravel pit just northwest of Black Mountain.

Present Day Features

Most of the smaller valleys present in the area are consequent valleys as their courses appear to be determined mainly by the initial slope of the mountains on which they have formed. The position and trend of small valleys west and north of Cold Spring are controlled by faults.

The stream pattern of the region is best described in terms of local "subareas." The pattern is radial on both Black Mountain and the high peak just south of Cold Spring. On the west side of the mountains between these two highs, the drainage pattern is dendritic and is a part of the centripetal drainage into Continental Lake. The pattern is also dendritic on the east side of the mountains between the two topographic highs. The streams here flow into Antelope Valley which drains to the north into Pueblo Valley.

Stream piracy has occurred at a few localities. The streams on the west side of the mountains are cutting into less resistant rocks than those on the east side, have steeper gradients and may be controlled by faulting. These streams have pirated some of the drainage from the larger valleys and this may account for the underfit nature of these valleys. Stream piracy, however, does not explain the present dissection of the valley alluvium in the eastern parts of the larger valleys.

One fault scarp and possibly a second are present within the thesis area. The most apparent of these scarps cuts across the entire mountain range in the southern part of the area. The ridges intersecting this scarp are all cut off along a definite line and springs, one of which is Cold Spring, are localized along this line.

Figure 5. Looking southeast from Cold Spring. Scarp of fault that cuts across the mountain range is visible on right side of the photo.

Another scarp, along the east side of the mountains may be fault controlled. The ridges intersecting this scarp are also cut off along a definite line, however, no springs are present.

From the evidence cited above certain interpretations can be made. The high area within the region existed before the faulting and subsequent uplift of the mountain range occurred. This uplift is responsible for the coalescing alluvial fans now present at the base of the mountains. Following the faulting and uplift, a large lake was present in Continental Lake Basin as indicated by terrace remnants.

The base level for the region is Alvord Lake, a remnant of the Pleistocene Lake Alvord, located approximately 50 miles to the north just east of Steens Mountain. Locally, Continental Lake is the base level for drainage from the west side of the thesis area and Pueblo Valley, which drains north into Alvord Lake, is the base level for the east side of the area.

The thesis area fits the youth or late youth stage in the arid erosion cycle (Davis, 1905). Evidence for this stage in the erosion cycle includes consequent drainage into an enclosed basin with few antecedant valleys, nearly maximum relief which is presently decreasing and active dissection of the highlands with accompanying aggradation of the enclosed basin causing a rise in the local base level.

STRUCTURAL GEOLOGY

Regional Structure

The Pine Forest Mountains lie along the northern border of the Basin and Range Province of the western United States. The mountain ranges in this area, especially the Kings River Range to the east and the Pueblo Mountains to the north as well as the Pine Forest Mountains themselves, appear to be rotated fault blocks. The displacement along the faults bounding the eastern face of these mountain ranges is west block up, east block down. This relative displacement would account for the consistant westward dip of the volcanic rocks from one range to another.

Uplift along the fault bounding the east flank of the Pine Forest Mountains is probably responsible for the 3,000 to 5,000 feet of relief which exists in the mountain range. The fault is probably a steeply dipping normal fault. The amount of throw along this fault can be determined from the offset of the volcanic rocks. A minimum throw of 3,000 feet along the fault has been calculated by Willden (1964). The age of the range-bounding fault is probably late Tertiary. Middle Tertiary volcanic rocks have been tilted toward the west as a result of movement along the fault whereas a Pleistocene lake terrace near Black Mountain is essentially horizontal.

Local Structure

Faults

In the southern part of the area, a large normal fault cuts across the entire mountain range. The trend of this fault is approximately N. 60 W. in the southeastern part of the thesis area changing to nearly east-west in the southern part. A north-facing fault scarp extends across the range. The position of Cold Spring and a brecciated quartz vein located approximately one-fourth mile east of the spring may be attributed to this fault. The quartz vein has been brecciated and recemented a number of times indicating more than one period of movement. If the emplacement of the quartz vein, which has an attitude of N. 70 W., 64 N., was controlled by the fault, then the attitude of the vein can be considered to be nearly the same as that of the fault at the point where the vein crops out. The amount of throw was at least 500 feet with the south block displaced upward relative to the north block. The mountains just south of the fault are about 500 feet higher than those just north.

Another large fault may lie along the eastern edge of the mountain range in the thesis area. Evidence for this fault consists of a scarp along the base of the mountains as recognized from truncated ridges or spurs. The fault appears to be similar in displacement to the large range-bounding fault located to the east; that is, west block up relative to the east block. A minimum throw of 450 to 500 feet may be estimated from the difference in elevation between the flat-topped ridges and the floor of the valley near the base of the mountains. The trend of the fault is approximately north-south, parallel to the larger range-bounding fault. Except for the difference in length and throw, these two faults appear to be quite similar. Possibly the smaller fault was produced by the same, or at least similar, applied stresses that caused movement along the larger fault.

Two smaller faults are present in the southwestern part of the thesis area. These are both located north of Cold Spring on the western side of the mountains. The trend of these two faults is approximately N. 60 E. but their dip is unknown. A minimum throw of 600 feet can be calculated for the northernmost fault with the north block displaced upward relative to the south block. This value is attained if the fault plane is assumed to be vertical and the major unconformity between the volcanic and metamorphic rocks dips more steeply than the slope of the valley wall on which it crops out. The other fault has a relative displacement of north side up, south side down. A minimum value of throw for this fault cannot be determined. Apparently some drag has occurred along this fault because the volcanic flows on the northwest side of the fault have been folded into a small asymmetrical anticline as shown on cross-section B-B' on

Plate 1.

Joints

Two prominent sets of joints are present in the plutonic rocks which are controlled by the foliation or planar flow structure of the rock. One set is parallel to the foliation and the other perpendicular to it. Where there are no planar structures the joint sets are randomly oriented even within a single rock unit. In the metamorphic rocks, joints are parallel to the schistosity and commonly have a random orientation in the quartzites where no planar structures have developed.

Folds

Two major episodes of deformation are recorded in the metamorphic rocks. These are (1) the formation of an initial foliation followed by (2) a later deformation of the foliation to produce folds. The folding is best developed near the contacts between the schist and plutonic rocks, especially in the topographic saddle located in the southeast one-fourth of sec. 7, T. 46 N., R. 30 E. The folding appears to be restricted to the schists as these are most commonly in contact with the plutons.

The first episode of deformation produced the prominent foliation and schistosity in the metamorphic rocks. Some folding may have accompanied this deformation, but it was not recognized in the field. This metamorphism may have been the result of either regionally applied stresses or it may have been induced by the plutons in their earlier stages of formation.

The second phase of deformation produced folding of the first phase foliation and schistosity. In this case the increase in temperature may have resulted from excess heat radiating from a plutonic body. The differential stress may have been applied by the forceful intrusion of the pluton resulting in subsequent shortening in the country rock as it was displaced and pushed aside. Near the contacts the folding is quite intense, but away from the contacts, the folding becomes progressively less intense.

In the saddle located in the southwestern one-fourth of sec. 7, T. 46 N., R. 30 E., there are three major folds, two synclines and an intervening anticline. These are fairly tight folds that occur in an area approximately one-half mile wide. The synclines are oversteepened toward the pluton whereas the anticline is oversteepened away from the pluton. The axial planes of these folds dip steeply toward the pluton and the axes of the folds appear to be horizontal. The folds can be classified geometrically as horizontal inclined folds (Badgley, 1965).

Minor folds occur on the limbs and in the hinge regions of the major folds. Some of these appear to be parasitic folds with the same geometric properties as the major folds, while others are highly irregular in form and orientation. The axes of the individual minor folds plunge either to the north or south or are horizontal. The axial planes of the more regular folds generally dip toward the east, parallel or nearly parallel to those of the major folds. The axial planes for the more irregular minor folds dip in either direction; however, their axial surface traces commonly trend nearly north-south.

ECONOMIC GEOLOGY

A number of prospect pits, adits and one mine are located within the thesis area. The prospect pits and adits are localized along the metamorphic-plutonic contacts where there is evidence of hydrothermal alteration. Also, prospect pits are found near quartz veins and pegmatites within the plutonic bodies. The mine is located in a large zone of altered metasedimentary and plutonic rock located just west of Cold Spring. Apparently, mineable quantities of scheelite were concentrated in this altered zone.

GEOLOGIC HISTORY

The Cordilleran Geosyncline, that extended from southeastern California to Alaska during the lower Paleozoic included the region now occupied by the Basin and Range Province (Osmond, 1960). At the end of Devonian time, the geosyncline was divided into two smaller geosynclines by the emergence of a geanticline or welt passing through western Nevada. By Permian time, this welt had been eroded and a second geanticline was emerging further to the east. This second large structure caused the development of two depositional troughs within the region (Nolan, 1943). The western trough extended through western Nevada and included the thesis area as shown in Figure 6.

A sequence of interbedded sandstones, shales and limestones were deposited in the western trough during Triassic and earliest Jurassic time. Deposition in the geosyncline ceased near the end of the Early Jurassic during a period of intense orogeny (Nolan, 1943). The sandstones and shales were regionally metamorphosed during this orogenic period. During Cretaceous time, intrusion of granitic rocks and subsequent contact metamorphic features were superimposed over regional metamorphic features near contacts between the plutons and the country rock in many areas including the thesis area.

A long period of erosion followed the period of intrusion and

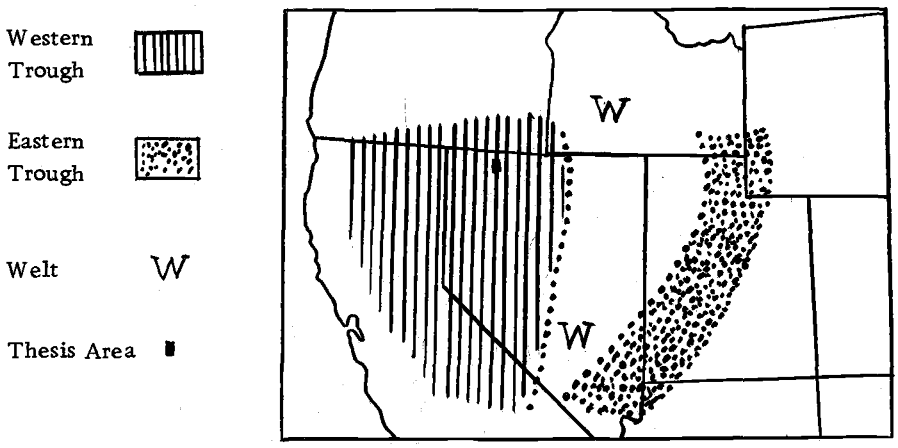

Figure 6. Generalized map showing location of the two depositional troughs and the intervening welt during Triassic and Early Jurassic time (Osmond, 1960).

metamorphism as the entire province appears to have been a highland area during Eocene and Oligocene time (Nolan, 1943). Evidence for this period of degradation in the thesis area is a profound angular unconformity between the plutonic and metamorphic rocks and the volcanic rocks. Whether or not this unconformity accounts for that entire span of time cannot be determined.

The record of Tertiary history in the thesis area begins with the extrusion of a relatively thick andesite flow. Following deposition of this flow, a period of pyroclastic volcanic activity must have occurred. The original pyroclastic rocks are not present, but are represented by a sequence of volcanic sandstones composed mostly of pyroclastic debris. Following deposition of the sandstones another ash flow unit was deposited. A thick sequence of basalt flows, with minor interbedded air fall and ash flow tuffs, was next deposited. Apparently these flows were extruded in rapid succession as little evidence for long periods of exposure of individual flows to the processes of degradation was noted. This period of active volcanism continued until middle Miocene time.

Block faulting movements began in late Eocene or early Oligocene time in the Basin and Range Province and have been continuous since that time (Nolan, 1943). No conclusive evidence for faulting before middle Miocene time is found in the thesis area. The relatively consistent dip of the rocks throughout the volcanic sequence is indicative of major post mid-Miocene faulting. Any previous major faulting would have produced more variance in the attitude of these rocks. Extensive block faulting must have ceased before the Pleistocene Lake Alvord occupied Pueblo Valley as remnants of a terrace associated with this lake are horizontal.

The beginning of block faulting in the province marked the beginning of deposition in the numerous closed fault basins. Deposition in the basins and erosion of the mountains began in middle Miocene time in the region including the thesis area and has been continuous since that time.

BIBLIOGRAPHY

Badgley, Peter C. 1965. Structural and tectonic principles. New York, Harper and Row. 519 p.

Balk, Robert. 1937. Structural behavior of igneous rocks. New York. 77 p. (Geological Society of America. Memoir 5)

Buddington, A. F. 1959. Granite emplacement with special reference to North America. Geological Society of America, Bulletin 70: 671-748.

Burnam, Rollins. 1969. Graduate student, Oregon State University, Department of Geology. Personal communication. Corvallis. March.

Davis, W. M. 1905. The geographical cycle in an arid climate. Journal of Geology 13: 381-407.

Grout, Frank F. 1932. Petrography and petrology. New York, McGraw-Hill. 522 p.

Hay, R. L. 1952. The terminology of fine-grained detrital volcanic rocks. Journal of Sedimentary Petrology 22: 119-120.

Merriam, John C. 1910. The Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Part I. Geologic history. Berkeley. p. 21-53. (University of California Publications. Department of Geology. Bulletin Vol. 6, no. 2)

__________ 1911. The Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada. Part II. Vertebrate faunas. Berkeley. p. 199-304. (University of California Publications. Department of Geology. Bulletin Vol. 6, no. 11)

Nolan, Thomas B. 1943. The Basin and Range province in Utah, Nevada and California. Washington, D. C. p. 141-196. (U. S. Geological Survey. Professional Paper 197-D)

Osmond, John C. 1960. Tectonic history of the Basin and Range province in Utah and Nevada. Mining Engineering 12: 251-265.

Ross, Clarence S. and Robert L. Smith. 1961. Ash-flow tuffs: Their origin, geological relations and identification. Washington, D. C. 81 p. (U. S. Geological Survey. Professional Paper 336)

Russel, I. C. 1884. A geological reconnaissance in southern Oregon. In: Fourth annual report of the U. S. Geological Survey. Washington, D. C. p. 435-464.

Smith, James G. 1969. Geologist, United States Geological Survey, Alaskan Branch. Personal communication. Menlo Park, California. May 5.

Turner, F. J. 1968. Metamorphic petrology: mineralogical and field aspects. San Francisco, McGraw-Hill. 403 p.

U. S. Weather Bureau. 1965. Climatic summary of the United States. Supplement for 1951 through 1960. Nevada. Washington, D. C. 42 p. (Climatography of the United States 86-22)

Willden, Ronald. 1963. Geology of the Jackson Mountains, Humboldt County, Nevada. Washington, D. C. 65 p. (U. S. Geological Survey. Bulletin 1141-D)

________________ 1964. Geology and mineral deposits of Humboldt County, Nevada. Reno. 154 p. (Nevada. Bureau of Mines. Bulletin 59)

Williams, Howel, Francis J. Turner and Charles M. Gilbert. 1954. Petrography. San Francisco, W. H. Freeman. 406 p.

APPENDIX

STRATIGRAPHIC SECTION and DETAILED UNIT DESCRIPTION

Volcanic Sequence
Western Part of Thesis Area

Traverse 3

Initial Point: SW1/4, SE1/4, SE1/4, section 36, T. 47 N., R. 34 E. at the top contact of the volcanic sandstone in this area.

Terminal Point: At top of the exposed volcanic section 3400 feet along bearing N. 77 W. from the initial point.

The traverse crosses a sequence of interbedded glomoroporphyritic basalt flows, dense slightly vesicular basalt flows, air fall tuffs and ash flow tuffs. Numerous offsets along the line of traverse were made so that the best exposures could be described.

OLIVINE BASALT (T_b)

Glomeroporphyritic Basalt: Vesicular, vesicles average approximately one-fourth inch in diameter. Phenocrysts of plagioclase feldspar are always present. The phenocrysts are lath shaped and range in length up to one and one-half inches. The phenocrysts commonly define a glomerophyritic texture. However, in some places (usually near the top and bottom) in the flow these crystals are aligned subparallel to the top bottom of the flow. Weathered surfaces are very dusky red (10 R 2/2) with grayish-pink (5 R 8/2) plagioclase phenocrysts. Fresh surfaces are grayish-red (5 R 4/2). The groundmass is aphanitic. This unit is a slope former.

Dense Basalt: Aphanitic in texture. Weathered surfaces are dark reddish-brown (10 R 3/4) and fresh surfaces are grayish-black (N 2). These units are commonly only slightly vesicular; however, the degree of vesicularity varies from flow to flow as well as within a single flow. Blocky fracture is common.

Air Fall Tuff: Composed dominantly of angular glass shards showing no preferred orientation. Lithic fragments are basalt and pumice, are angular in form and average 1 to 2 mm in diameter. Euhedral to subhedral quartz and feldspar crystals are present that average 1 to 2 mm in maximum dimension. The less indurated beds are grayish-orange-pink (10 R 8/2) on weathered surfaces and grayish-pink (5 R 8/2) on fresh surfaces. The more indurated beds are pale red (5 R 6/2) on weathered surfaces and pale reddish-brown (10 R 5/4) on fresh surfaces. The air fall tuff is crudely bedded with beds rarely thicker than two to three feet. The beds decrease in thickness toward the top of the unit and commonly have gradational contacts.

Ash Flow Tuff: Throughout this unit the ash flow tuffs have been highly eroded so that in most cases only the vitrophyre remains. The vitrophyre assumes a perlitic texture and is colored grayish black (N 2) on both fresh and weathered surfaces. Where exposed, the poorly welded bottom portion of the ash flow tuff can be seen underlying the vitrophyre.

Contact: The top of this unit is covered by alluvium. No contact is visible.

2323' - 2316': Dense basalt flow as in unit description. Top and bottom contacts covered.

2316' - 2303': Ash flow tuff as in unit description. Bottom contact is gradational. Bottom three feet poorly welded, grades upward into densely welded zone which displays good eutaxitic texture. Top contact is covered.

2303' - 2283': Air fall tuff as in unit description. Bottom contact covered. Top contact is gradational into a poorly welded zone of the overlying ash flow tuff.

2283' - 2247': Dense basalt flow as in unit description. Top becomes subscoriaceous. Contacts are covered.

2247' - 2237': Covered.

2237' - 2232': Dense basalt flow as in unit description. Contacts covered.

2232' - 2216': Covered.

2216' - 2198': Dense basalt flow as in unit description. Contacts covered.

2198' - 2196': Ash flow tuff as in unit description. Bottom one foot is poorly welded to non-welded, top one foot is densely welded, change is gradational. Contacts are covered.

2196' - 2096': Glomeroporphyritic basalt flow as in unit description. A series of thin flows rarely exceeding five feet in thickness occurs here. Contacts are covered.

2096' - 2093': Covered.

2093' - 2083': Vitrophyre as in unit description for ash flow tuff. Contacts are covered.

2083' - 1915': Covered.

1915' - 1898': Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts are black (N 1) and up to one inch in length. Contacts are covered.

1898' - 1891': Covered.

1981' - 1868': Dense basalt flow as in unit description. Contacts are covered.

1868' - 1864': Covered.

1864' - 1854': Vitrophyre as in ash flow tuff unit description. Contacts covered.

1854' - 1847': Covered.

1847' - 1844': Dense basalt flow as in unit description. Highly vesicular to subscoriaces, vesicles average 1/4 inch in diameter; some vesicles are filled with zeolites. Contacts are covered.

1844' - 1829':	Covered.
1829' - 1824':	Dense basalt flow as in unit description. Highly vesicular to subscoriaceous, vesicles average one-fourth inch in diameter.
1924' - 1788':	Covered.
1788' - 1766':	Dense basalt flow as in unit description. Non-vesicular near base, scoriaceous in top one to two feet. Contacts are covered.
1766' - 1756':	Covered.
1756' - 1743':	Dense basalt flow as in unit description. Vesicles, elongate parallel top and bottom of flow, average one inch long and one-fourth inch wide. Contacts are covered.
1743' - 1706':	Covered.
1706' - 1666':	Dense basalt flow as in unit description. Platy fracture formed parallel to the top and bottom of flow, plates one-half to one inch thick. Contacts are covered.
1666' - 1641':	Covered.
1641' - 1639':	Dense basalt flow as in unit description. Platy fracture, plates one-half to one inch thick. Contacts are covered.
1639' - 1634':	Covered.
1634' - 1627':	Dense basalt flow as in unit description. Contacts are covered.
1627' - 1622':	Covered.
1622' - 1572':	Dense basalt flow as in unit description. Bottom contact is sharp and occurs along the top of a bake zone. Vesicular zone, three feet thick at bottom, vesicles rarely larger than one-fourth inch in diameter. Grades upward into a massive, nonvesicular zone which extends to the top of the flow. Top contact is covered.
1572' - 1571':	Soil zone. Baked zone caused by heat from overlying basalt flow. Massive, weathers into angular fragments up to six inches in diameter. Color is moderate reddish-brown (10 R 4/6).
1571' - 1556':	Dense basalt flow as in unit description. Vesicles are small, average one-eighth inch in diameter and are commonly filled with zeolite. Top of flow is scoriaceous. Bottom contact is covered. Top contact is sharp with a soil zone formed on the top of the flow.
1556' - 1516':	Covered.

1516' - 1501':	Glomeroporphyritic basalt flow as in unit description. Contacts are covered. Vesicles are coated or filled with calcite or zeolite and are commonly less than one-half inch in diameter. Plagioclase phenocrysts are up to one and one-half inches in length.
1501' - 1461':	Covered.
1461' - 1459':	Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts average one-eighth inch in length. Contacts are covered.
1459' - 1452':	Covered.
1452' - 1449':	Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts average one-eighth inch in length. Contacts are covered.
1449' - 1434':	Covered.
1434' - 1432':	Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts average one-eighth inch in length. Top and bottom contacts covered.
1432' - 1423':	Covered.
1423' - 1411':	Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts average one-eighth inch in length. Contacts are covered.
1411' - 1403':	Covered.
1403' - 1395':	Glomeroporphyritic basalt flow as in unit description. Contacts are covered. Plagioclase phenocrysts average less than one-fourth inch in length.
1395' - 1382':	Covered.
1382' - 1369':	Glomeroporphyritic basalt flow as in unit description. Plagioclase phenocrysts average from one-fourth to one-half inch in length. Contacts are covered.
1369' - 1318':	Covered.
1318' - 1310':	Glomeroporphyritic basalt flow as in unit description. Contacts are covered.
1310' - 1180':	Covered.
1180' - 1168':	Dense basalt flow as in unit description. Entire flow is vesicular, average diameter of vesicles near bottom is one-fourth inch, size and number of vesicles increases upward, top of flow is subscoriaceous. Contacts are covered.
1168' - 1148':	Covered.

1148' - 1141':	Dense basalt flow as in unit description. Vesicular as in flow at 1180'. Contacts are covered.
1141' - 1126':	Covered.
1126' - 1099':	Dense basalt flow as in unit description. Vesicular as in flow at 1180'. Contacts are covered.
1099' - 979':	Covered.
979 - 969':	Dense basalt flow as in unit description. Some vesicles are filled with calcite. Contacts are covered.
969' - 909':	Covered.
909' - 869':	Dense basalt flow as in unit description. Bottom 10 feet quite vesicular, grades upward into a non-vesicular zone 15 feet thick, top 15 feet is scoriaceous. Contacts are covered.
869' - 809':	Covered.
809' - 788':	Dense basalt flow as in unit description. Non-vesicular. Contacts are covered.
788' - 729':	Covered.
729' - 679':	Dense basalt flow as in unit description. Contacts are covered.
679' - 633':	Covered.
633' - 626':	Dense basalt flow as in unit description. Angular fragments are further weathered into sub-angular to sub-rounded fragments less than one inch in diameter. Contacts are covered.
626' - 611':	Covered.
611' - 586':	Dense basalt flow as in unit description. Joints form parallel and perpendicular to the top and bottom of the flow. Top three feet of the flow is highly vesicular, vesicles average one inch in diameter, some are filled with calcite. Contacts are covered.
586' - 546':	Covered.
546' - 533':	Dense basalt flow as in unit description. Contacts are covered.
533' - 502':	Covered.
502' - 472':	Dense basalt flow as in unit description. One foot thick zone near top and bottom of flow displays a granular type of weathering with fragments being sub-angular to sub-rounded and less than one inch in diameter. The zone weathers to black (N 1) color.

472' - 422':	Covered.
422' - 397':	Dense basalt flow as in unit description. Contacts are covered.
397' - 312':	Covered.
312' - 303':	Dense basalt flow as in unit description. Contacts are covered.
303' - 152':	Covered.
152' - 117':	Dense basalt flow as in unit description. Contacts are covered. Flow becomes vesicular near top. Vesicles average one-fourth inch in diameter. Two joint sets, one parallel and one perpendicular to top and bottom, produce angular fragments up to eight inches in diameter.
117' - 64':	Covered.
64' - 52':	Glomeroporphyritic basalt flow as in unit description. Highly vesicular near top with vesicles up to one inch in diameter. Contacts are covered.
52' - 7':	Covered.
7' - 0':	Dense basalt flow as in unit description. Lower two feet of this flow are vesicular and grade upward into non-vesicular basalt. Top contact covered.

Total thickness: Olivine Basalt = 2323 feet.

Contact: Olivine Basalt, Volcanic Sandstone; contact is covered.

Traverse 2

Initial Point: At base of ash flow tuff on the north side of Vicksburg Canyon near the mouth of the canyon.

Terminal Point: At top of ash flow tuff, 90 feet west of the initial point, parallel the trace of the dip of the unit.

Vicksburg Canyon is located approximately one-half mile south of the southern boundary of the thesis area on the west side of the mountains.

IGNIMBRITE (T_i)

The unit decreases in thickness to the north until it "pinches out." Attitudes are constant.

Ash Flow Tuff: This unit is composed of two distinct zones; a lower, poorly welded zone and an upper densely welded zone. The poorly welded zone is characterized by collapsed pumice fragments alligned nearly parallel the top and bottom of the unit and by euhedral to subhedral phenocrysts of sanidine and quartz that are oriented in a similar fashion. The poorly welded zone grades upward into the densely welded zone of the ignimbrite. The densely welded zone is characterized by having a well developed eutaxitic texture and platy jointing oriented parallel the top and bottom of the unit. Phenocrysts of quartz and sanidine are similarly oriented. Weathered surfaces are colored pale red (5 R 6/2) and fresh surfaces are colored pale red (10 R 6/2).

Contact: The top of this unit is covered by alluvium. No contact is visible.

77' - 75':	Densely welded tuff as in unit description. Top contact is covered.
75' - 20':	Densely welded tuff as in unit description. Most densely welded part of the unit; excellent eutaxitic texture, vesicles and pumice fragments are extremely flattened and elongated; jointing is poorly developed except near the top and bottom of this part of the unit.
20' - 17':	Densely welded tuff as in unit description.
17' - 7':	Densely welded tuff as in unit description. Platy jointing well developed, plates up to 12 inches in width. Vesicles up to two inches long and one inch wide are present. Good eutaxitic texture in top five feet.
7' - 6':	Zone of gradation from poorly welded tuff to densely welded tuff. Crude jointing developed, parallel to top and bottom of unit. Joints may be caused by the parallel allignment of flattened pumice fragments.
6' - 1':	Poorly welded zone as in unit description.
1' - 0':	Poorly welded zone as in unit description. Some angular fragments of the volcanic sandstone are inclusions, fragments are randomly oriented.

Total Thickness: Ignimbrite = 77 feet.

Contact: Ignimbrite, Volcanic Sandstone; contact is sharp. The ignimbrite unit is conformable with the underlying volcanic sandstone.

Traverse 1

Initial Point: At bottom conta ct of andesite flow in a dry wash located at the intersection of bearings N. 65 W. from Hill 5361-T and S. 50 W. from Hill 5423-T just west of Emigrant Pass.

Terminal Point: 600 feet along bearing N. 74 W. from the initial point at the upper contacts of the volcanic sandstone.

PEBBLY VOLCANIC SANDSTONE (T_{vs})

The attitude of this unit is constant; however, the thickness varies along the strike.

Volcanic Sandstone: Bedded deposit with beds ranging in thickness from one to 18 inches. The beds are two different colors on weathered surfaces; grayish-orange-pink (5 YR 7/2) and pinkish-gray (5 YR 8/1). Fresh surfaces are colored very pale orange (10 YR 8/2). The rocks are poorly indurated except for some very thin well indurated beds that are interbedded with the thicker beds. These thin beds are one to two inches in thickness and are used to determine the attitude of the unit. Fractures present in the unit are filled with calcite and zeolite. No sedimentary structures are visible as the unit is highly weathered and most of the beds are only poorly exposed. The rock is composed mostly of broken, sub-angular glass shards. Sub-angular to sub-rounded basalt, andesite, and pumice pebbles are present as well as sub-angular quartz and feldspar crystals. The cement is clay.

Contact: Olivine Basalt, Volcanic Sandstone; contact is covered.

118' - 115':	Volcanic sandstone as in unit description. Bake zone is present here; color is dark reddish brown (10 R 3/4).
115' - 55':	Covered.
55' - 24':	Volcanic sandstone as in unit description. Bedding is determined by color changes in the soil zone; beds range in thickness from four to 18 inches.
24' - 0':	Covered.

Total Thickness: Pebbly Volcanic Sandstone = 118 feet.

Contact: Pebbly Volcanic Sandstone, Olivine Andesite; contact is covered.

OLIVINE ANDESITE (T_a)

The attitude and thickness of this unit is highly variable as a result of extrusion on an extremely dissected erosion surface.

Andesite Flow: Highly weathered and iron-stained. Weathered surfaces are colored pale red (5 R 6/2) and fresh surfaces are light brownish-gray (5 YR 6/1). Platy and blocky fracture is common with angular fragments rarely exceeding six inches in diameter. Platy jointing is also well developed. The joints are formed parallel the bottom contact of the flow and are therefore highly variable in attitude. Vesicles vary in size and abundance throughout the flow and are commonly filled with a yellowish-brown clay.

103' - 90':	Zone of extreme vesicularity; vesicles remain quite small and average approximately one-tenth of an inch in diameter; vesicles compose up to 50 percent of the rock.
90' - 59':	Andesite as in unit description.
59' - 47':	Andesite as in unit description. Massive zone, vesicles are uncommon.
47' - 35':	Andesite as in unit description. Zone of very well developed platy joints, thickness of plates varies from one-fourth to two inches.
35' - 0':	Andesite as in unit description.

Total Thickness: Olivine Andesite = 103 feet.

Contact: Olivine Andesite, Arkosic Quartzite; contact is sharp along an old erosion surface with at least 100 feet of relief. The unconformity is angular in nature.