PETROGRAPHIC AND PETROFABRIC STUDY
OF THE METAMORPHIC ROCKS NORTH OF
CARMON CITY, ORMSBY COUNTY, NEVADA

A THESIS

SUBMITTED TO THE FACULTY OF THE UNIVERSITY OF NEVADA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

BY

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PETROGRAPHIC AND PETROFABRIC STUDY
OF THE METAMORPHIC ROCKS NORTH OF
CARSON CITY, ORMSBY COUNTY, NEVADA

By Christe P. Zones

ABSTRACT

The metamorphic rocks of the report area are predominantly pyroclastic rocks in the southern part of the area and altered shales and limestones interbedded with pyroclastic rocks in the northern part. They were intruded by granitic rocks during the Nevadan orogeny. The age of the metamorphic rocks can not be determined but they may be Triassic.

The rocks were subjected to low rank regional metamorphism, followed by medium to high rank contact metamorphism. During the dynamic metamorphism the rocks were folded about a northwest axis and a fabric was imprinted on them. Recrystallization of the mineral components during contact metamorphism took place along directions of easy growth, governed by the anisotropism of the earlier metamorphic fabric. The rocks show a strong lineation, which parallels the northwest-trending fold axis, and a well developed foliation.

The fabric was probably imposed on the rocks predominantly by slip along the foliation plane but there is evidence in the pattern of preferred orientation of quartz that rotation of slip planes or mineral grains about the a and b fabric axes was also operative.

Following the metamorphism, the area may have been folded or warped about a northeast trending axis and cut by step faults whose strikes paralleled the trend of the fold axis. As an alternative possibility, differential tilting of adjacent fault blocks may have simulated folding.
INTRODUCTION

Location and Extent of Area

The metamorphic rocks discussed in this report are immediately north of Carson City, Ormsby County, Nevada, and about 10 miles east of the California-Nevada boundary. (See location map, figure 1).

The metamorphic rocks are exposed mainly in three areas, the largest a square mile in area and each of the others a quarter of a square mile. In addition, there are several smaller areas of a few acres or less. Granitic rocks and unconsolidated alluvium separate the outcrop areas.

The three main outcrop areas are designated the Washoe Hills area, the Lakeview Hill area, and the Lone Mountain area. The Washoe Hills area, the largest of the three, extends from the southern flank of the Virginia Range south to the Carson Hot Springs; the Lakeview Hill area includes an isolated hill immediately south of the Lakeview town site; the Lone Mountain area extends from the Carson Hot Springs south to the northeast limits of Carson City.

Purpose and Scope of the Investigation

The purpose of the investigation was to study the petrography and to determine the megascopic and microscopic fabric of the metamorphic rocks north of Carson City, Nevada. The non-metamorphic rocks also were mapped but were not studied in detail.
Figure 1.— Map of Nevada, showing location of report area.
Field mapping was done on aerial photographs on a scale of about 1:20,000. In addition to mapping lithologic units, a detailed study was made of the linear and planar features of the rocks and for this purpose approximately 700 determinations were made of the attitudes of the schistosity, lineation, and joints.

Specimens collected in the field were examined in the laboratory with a binocular microscope and 20 selected specimens were studied in thin section.

The orientation in space of certain crystallographic directions of quartz, biotite, and hornblende was measured in selected specimens for the purpose of determining the preferred orientation of the mineral grains. On the basis of these data and the data of the megascopic fabric an attempt is made to deduce the kinematics of the metamorphism.

Previous Investigations

The only previous study of the mapped area was made by J.A. Reid (1911). Reid's primary objective was a study of the geomorphic history of the region and consequently his treatment of the lithology was brief.

The metamorphic rocks in the Virginia City area, northeast of the Carson City area, have been described briefly by Gianella (1936), Calkins (1941), and Thompson (1956).

Acknowledgments

Thanks are due to Professor D. B. Slemons, who directed the investigation, and to Professor E. R. Larson, both of the
University of Nevada, and to Mr. Robert Rose, Nevada Bureau of Mines, for guidance and advice during the course of the investigation and for helpful criticism during the writing of the manuscript.

Thanks are due also to Dr. V. E. Sheid, Dean of the Mackay School of Mines, for financial assistance toward the preparation of most of the thin sections used in the study.
THE REGIONAL SETTING

The mapped area, which is immediately east of the Sierra Nevada, is geographically a part of the Basin Range physiographic province, but the metamorphism and pre-Tertiary structural history of the mapped area are allied with the history of the Sierra Nevada. For that reason the discussion of the regional setting centers on a discussion of the Sierra Nevada.

The bedrock complex of the Sierra Nevada is divisible into an older group that includes sedimentary, volcanic, and intrusive rocks of pre-Nevadan-orogeny age, and a younger group that consists of acid to basic igneous rocks that were intruded into the first group during the Nevadan orogeny.

Rocks of the older group are of Paleozoic, Triassic, and Jurassic age. The Paleozoic rocks are included in the Calaveras formation, which is at least Carboniferous in part but may be in part Devonian and Triassic. Originally, the Calaveras consisted largely of shales, sandstones, cherts, limestones, and fine pyroclastic rocks but metamorphism has altered them to greenschists and phyllites, with subordinate amounts of quartzite, limestone, and chert. These rocks were folded and sheared during an orogeny at the end of the Paleozoic or the beginning of the Triassic.

The Paleozoic rocks are overlain unconformably by Triassic and Jurassic rocks. Taliaferro (1942) describes an eastern belt of Triassic and Jurassic rocks and a western belt of Jurassic rocks. The Calaveras formation and the
amphibolite facies. The contact aureoles are mostly narrow and are generally in the amphibolite or pyroxenite facies.

Metamorphic rocks of Paleozoic and Mesozoic age are exposed locally in Nevada and California in the Basin Range province. They consist of volcanic and sedimentary rocks that were folded and faulted during the Nevadan orogeny and were then intruded by granitic plutons. Regional metamorphic effects are difficult to isolate from contact effects but are of low grade and are certainly no higher than that of the greenschist or possibly the albite-epidote-amphibolite facies. In the vicinity of the mapped area regional metamorphism has been of low rank. About 5 miles southeast of the mapped area Mesozoic limestones and shales have been little affected by dynamic metamorphism. The limestones have been recrystallized and the shales have changed to slates. Similarly, metamorphic rocks that crop out on Peavine Mountain about 30 miles north of Carson City show only slight changes resulting from dynamic metamorphism (Godwin, 1953).
granitic rocks of the Sierra Nevada batholith lie between the two belts. The eastern belt is made up of discontinuous areas of metamorphosed sedimentary and volcanic rocks.

The western belt includes the Amador group and the Mariposa formation. The great bulk of the Amador consists of volcanic and clastic rocks, but cherts and limestones are common. Normally, the Amador grades upward into the Mariposa, which consists primarily of black slate and graywacke with associated greenstone and local beds of conglomerate, sericite schist, and limestone.

All the above rocks were folded, thrust faulted, and then intruded by numerous plutons during the Nevadan orogeny, which began in the late Jurassic and continued into the early Cretaceous. The maximum deformation was concentrated along the western slope of the Sierra Nevada in the zone of the western belt of the Jurassic deposits, where overturned folds and great thrusts were widespread.

The eastern belt of Jurassic and Triassic rocks, near the present crest of the Sierra Nevada, is not as greatly deformed. Broad, open folds are more common although isoclinal folds are also present. In both the eastern and western belts the structural trends are approximately northwest.

Regional metamorphism in the northern and central Sierra Nevada has been of relatively low grade. With a few local exceptions, mainly in contact aureoles, the metamorphic rocks are in the greenschist or albite-epidote-
GENERAL FEATURES OF THE REPORT AREA

The metamorphic rocks in the report are of diverse lithologic types. Both sedimentary and igneous antecedent types are represented. In the southern part of the area the metamorphic rocks are largely of volcanic origin and include pyroclastic rocks and possibly flows; in the northern part, pyroclastic rocks are interbedded with shales and limestones. However, it is not always possible to identify the antecedent rock type owing to the relatively high degree of metamorphism that they have undergone.

No fossils have been found in the metamorphic rocks of the report area and therefore they can not be dated with certainty. Metamorphic rocks immediately to the north of the mapped area, in the Virginia City quadrangle, have been tentatively dated as Triassic by Gianella (1936, p. 37-38) on the basis of their similarity to fossiliferous rocks about 10 miles to the east, but he states that they may also be Paleozoic. These rocks are probably of the same age as those of the report area. However, there is also the possibility that the metamorphic rocks of the report area are of Jurassic age, for they are somewhat similar, lithologically, to rocks of the Peavine Mountain area that have been tentatively dated as Jurassic on the basis of fossil flora (Godwin, 1958).

The rocks of the mapped area were altered during the Nevadan orogeny, first by a weak regional metamorphism, then by moderate-to high-rank contact metamorphism caused
by the intrusion of granitic rocks. Only a cursory examination was made of the granitic rocks, but they appear to be similar to those of the Virginia City quadrangle, which have been described by Thompson (1956, p. 43-49) as follows:

"Although the granitic rocks range in composition and texture, by far the most abundant type is granodiorite containing about twice as much plagioclase as orthoclase. Gradational changes in total amount of hornblende and biotite and also in the relative proportions of these two minerals are the most obvious, but quartz and feldspar also range considerably in amount. These changes are not always marked by sharp contacts, · · ·"

In the general vicinity of the mapped area several thousand feet of Cenozoic volcanic rocks are exposed in the mountain ranges, but only one small patch is exposed in the report area.

During the latter part part of the Cenozoic, normal faulting on a large scale took place and gave rise to the present relief. A series of these faults trends generally northeast through the northern part of the report area.
DESCRIPTIONS OF THE METAMORPHIC ROCKS

Meta-Tuffs (Ma) and Meta-Volcanic Breccias (Mb)

Field Characteristics. -- The dominant rock type in the Lone Mountain area is a weakly schistose volcanic breccia that outcrops in all but the extreme southern part of the area. It is a gray to greenish-gray rock that weathers dark gray to brown. The volcanic rock fragments range in diameter from a fraction of an inch to two feet and are embedded in an aphanitic matrix. Most of the fragments, which exhibit a strong dimensional orientation, are flat lenses whose dimensions are approximately in the ratio 2:3:6. The two longest dimensions are parallel to the plane of schistosity; the longest is parallel to the direction of lineation.

The other rock type in the area is a massive, well-jointed rock that forms prominent outcrops in the southern part of Lone Mountain. It consists of metamorphosed crystal tuffs, of dacitic or andesitic composition. Outcrops of this type are gray to greenish-gray and weather dark gray to brown so that at a distance this unit somewhat resembles the coarser volcanic breccia.

The tuffs consist essentially of large plagioclase phenocrysts, 1 to 3 mm. in diameter, in a dark gray aphanitic groundmass. Locally, the rocks exhibit a strong lineation that is due to parallelism of numerous elongated inclusions of basic rocks and clusters of mafic minerals. Schistosity is poorly developed or non-existent. Where xenoliths
and clusters of mafic mineral are abundant and are slightly flattened; they exhibit a planar orientation that defines a rather poor schistosity. A vague color banding, which probably represents original bedding, locally parallels the schistosity. The rocks show no obvious tendency toward fissility.

Many of the joints at the south end of Lone Mountain are filled with epidote, quartz, and black tourmaline. In most instances the joint fillings are only a fraction of an inch thick but a few are more than an inch thick.

In the same area there are numerous dikes, a few inches to a few feet thick, composed of a black devitrified glass enclosing numerous fragments of the host rock. 

Petrography (specimens 1655, 1658, 1662, and 1666).—Thin sections of the breccia from the north and central parts of Lone Mountain consist of lithic fragments, fragmental plagioclase, embayed quartz, a small amount of orthoclase, poeciloblastic actinolite or hornblende, and epidote-clinozoisite, in a fine-grained matrix of quartz, albite, epidote, and greenish-brown biotite. Accessory minerals are zircon, sphene, magnetite, hematite, tourmaline, apatite, and scapolite. Thin streaks of biotite, sphene, magnetite, and epidote have crystallized in the planes of schistosity. The quartz and feldspar phenocrysts and the zircon and possibly a few of the other accessory minerals are relics. The feldspars have largely altered to aggregates of fine-grained quartz, micas, and albite.
Cataclastic effects, although generally weak, are seen in the granulation of the edges of the feldspars and quartz and in the crushing and recrystallization of quartz into granular aggregates. The relict quartz grains that have survived granulation show undulatory extinction as a result of having been strained.

The dacitic or andesitic tuff is composed of relict plagioclase phenocrysts that average 1 to 2 mm. in length and make up 50% to 70% of the rock. The plagioclase is oligoclase-andesine that has altered partly to sericite. The only other relict phenocrysts are quartz, which forms 5% to 10% of the rock, and an occasional orthoclase anhedron. Clusters of biotite anhedra, larger than those of the matrix, and grains of magnetite, occur sparingly and are probably the products of the destruction of the original amphiboles. There are a few porphyroblasts of poeciloblastic actinolite or hornblende and some anhedral epidote. The matrix consists of greenish-brown biotite, quartz, and untwinned albite. Other minerals are magnetite, which forms as much as 5% of the rock, zircon, in streaks, and clusters of small grains of sphene, apatite, and tourmaline. (See figure 2a).

The quartz and feldspar phenocrysts are corroded and embayed and both have been somewhat granulated along their edges.

The granulation of the feldspars and quartz in both the volcanic breccias and the tuffs imparts to these
Figure 2.— (a) Meta-tuff, made up mostly of plagioclase and quartz phenocrysts. X 25.
(b) Sheared schist; augen consist largely of chlorite and muscovite. Some augen composed of quartz or feldspar. X 25.
rocks a distinctly cataclastic fabric. Most of the constituents of the matrix, however, have been recrystallized and a crude schistosity has developed. These rocks therefore have characteristics of both cataclasites and schists and appear to be intermediate between the two.

The breccias and tuffs contain albite, epidote, and amphibole, the latter as either hornblende or actinolite. (It is not possible to distinguish between the two optically). Such a mineral assemblage is compatible with either the albite-epidote-amphibolite facies or with the biotite-chlorite subfacies of the greenschist facies. However, the presence of garnet in veinlets in at least two outcrops suggests that the rocks of these two units are in the higher facies (the albite-epidote-amphibolite facies).

**Biotite-Muscovite and Muscovite-Chlorite Schists (Mc)**

**Field Characteristics.**— The rocks of this group occur in the southern part of the Washoe Hills area. They consist of massive to fissile dark gray schists and phyllites and pale green, or gray to dark green, chloritic schists. The characteristic spotted appearance of the chloritic rocks is due to the presence of clusters of chlorite.

Phenocrysts and lenticles of quartz and feldspar and a few rock fragments are visible in most of the schists of this group.

**Petrography** (specimens 1657, 1667, and 1669).— The massive, dark gray schists consist of relict plagioclase and quartz
in a fine-grained matrix that consists largely of biotite, muscovite, quartz, and albite with lesser amounts of chlorite and calcite. The micas have a good planar orientation. Larger grains of biotite, associated with magnetite, form thin, discontinuous, crinkled layers that define imperfect planes of fissility.

The phenocrysts are largely fragmented and corroded grains of plagioclase in the oligoclase-andesine range. They are relatively fresh, although the more calcic zones have been altered to calcite and sericite. Quartz relics occur as embayed fragments that show undulatory extinction and as partly crushed grains. Clusters of biotite indicate the former presence of mafic minerals. In addition, there are large grains of anhedral calcite and some scapolite that replaces plagioclase. There is a small amount of hornblende or actinolite in specimen 1667, but none in specimens 1657 and 1669.

Zircon, apatite, and magnetite are accessory minerals.

Inequant phenocrysts and rock fragments lie with their least dimensions perpendicular to the plane of foliation and exhibit a strong dimensional orientation.

The mineral assemblages indicate that the degree of metamorphism is equivalent to that of the greenschist facies, and possibly, at least locally, to that of the albite-epidote-amphibolite facies.

The mineralogy of this group suggests that the antecedent rocks were limy tuffs.
Scapolite-Augite-Quartz-Albite Rock (Md)

Field Characteristics.— This unit is best exposed in the area immediately north of the Carson Hot Springs and may also be seen in small exposures elsewhere in the Washoe Hills. It is dense, massive, very fine-grained and shows no tendency toward fissility. On a fresh surface the rock is white to light gray, with irregular green streaks, but weathers dark brown. A characteristic feature is the presence of flat, elongated hollow spaces as much as a foot long, which probably indicate former limestone lenses that have been removed by solution. The rock is associated with calcite and lime minerals in a small outcrop in the west-central part of the Washoe Hills area where it is interbedded with bands of massive grossularite, coarsely crystalline tremolite, and calcite.

Petrography (specimens 1661 and 1664).— A fine-grained mosaic of scapolite, augite, hornblende or tremolite, quartz, calcite, and a few tuffaceous fragments make up the bulk of the rock. Of these minerals, scapolite and augite are the most common and comprise more than half the aggregate. Calcite occurs in occasional large grains and as veinlets. Residual quartz and plagioclase up to \( \frac{1}{2} \) mm. in diameter and a few grains of potash feldspar are scattered through the rock. The quartz and plagioclase have been broken and crushed by shearing and the quartz grains have been elongated parallel to the foliation.
All the quartz phenocrysts exhibit undulatory extinction as a result of strain.

The plagioclase is zoned and the more calcic zones of many of the crystals have been replaced by calcite. Much of the plagioclase has also been partly replaced by a strongly birefringent scapolite. The very high birefringence of this scapolite suggests that it is near the calcium end member, meionite, in composition. However, many of the smaller grains of scapolite in the matrix have a lower birefringence, indicating that a more sodic scapolite is also present. Lime scapolite may form in calcic rocks during metamorphism without the introduction of outside material, but on the other hand, the presence of a more sodic scapolite may be attributed to metasomatism and implies that chlorine, and in calcic rocks, sodium, has been added, (Turner and Verhoogen, 1951, p.492). It is probable, therefore, that at least the scapolite with the lower birefringence is of metasomatic origin.

The original rock was probably a tuffaceous limestone which has been subjected to metamorphism in the high-grade part of the albite-epidote-amphibolite facies.

Chiastolite-Biotite-Graphite Slate (Me)

Field Characteristics.—This rock outcrops in the central part of the area. It is dark gray and locally weathers to a dark brown. The rock parts readily along well-developed planes of fissility that are parallel to the regional trend
of the foliation. None of the constituent minerals are visible to the unaided eye except for porphyroblasts of chiastolite and possibly cordierite in the slates of the central part of the area.

**Petrography (specimen 1651).**— A specimen from the central part of the area contains numerous chiastolite porphyroblasts in a very fine-grained matrix that consists of equal parts of biotite, quartz, and graphite. Tourmaline in small rods is abundant and forms about 5% of the matrix. The tourmaline is evenly distributed and the rods are aligned parallel to the trend of the lineation. A dimensional orientation is shown also by the biotite and quartz, which are elongated in the direction of the lineation. Apatite is a minor accessory mineral.

Chiastolite occurs in well developed porphyroblasts that enclose numerous carbonaceous particles arranged in hourglass patterns. The porphyroblasts tend to lie in the plane of fissility and show a slight tendency to a parallel alignment that defines a weak megascopic lineation. Several of the porphyroblasts have been fractured perpendicular to their length and the fractures have been filled with quartz. Quartz in grains larger than those of the matrix has crystallized in pressure shadows behind the chiastolite. Fine mica flakes rim many of the chiastolites.

Although chiastolite is regarded as an anti-stress mineral it is clear that stress was an important factor in the metamorphism of the slate. Evidence for this is
dimensional orientation of the mineral constituents and the formation of pressure shadows parallel to the linea-
tion. Although the chiastolite probably crystallized during a period of relatively high temperature and low stress, the dimensional orientation and the development of pressure shadows may have been influenced by an iso-
tropism imposed on the rock by an earlier period of stress.

Tourmaline crystals that are evenly distributed through the matrix rather than in isolated aggregates are a good indication that the boron necessary to the formation of the tourmaline was present originally in the sediment and was not derived from magmatic solutions or gases. Gold-
schmidt and Peters (1932) have shown that marine muds may contain enough boron to yield tourmaline during dynamic metamorphism of their derivatives. It appears probable, therefore, that the schists of unit Me were originally pelitic marine sediments.
Slates, Phyllites, and Fine-Grained Schists (Mf)

Field Characteristics.-- These rocks occur in three areas in the central and northeastern part of the Washoe Hills area. Exposures are rare and this unit was mapped largely on the basis of float.

The rocks range in color from dark gray to light green. A good fissility that is characteristic of the finer-grained rocks passes into a crinkled schistosity in those of somewhat coarser grain. Very fine segregation bands can be seen in the phyllites. Relict crystals and a few large rock fragments sheared into augen are visible. A few small, pink garnets are present in one specimen.

Petrography (specimen 1654).-- A thin section of a schistose rock of this group shows evidence of much shearing. Approximately a third of the rock consists of augen, each of which is made up either of a cluster of very fine-grained chlorite and muscovite, and small amounts of quartz and magnetite, or the augen may consist of a single relict plagioclase crystal that has been sheared. Muscovite and biotite wrap around the augen, giving rise to a crinkled schistosity. (See figure 2b).

The matrix consists largely of fine-grained biotite—which shows a well-developed planar orientation parallel to the schistosity—and quartz, with lesser amounts of feldspar. Magnetite and zircon are accessories.

The rocks of this unit probably are derived from fine-grained tuffaceous sediments.
The grade of metamorphism is low; the mineral assemblage of the single specimen studied in thin section is compatible with the greenschist facies. However, the presence of garnet in a hand specimen from the northwestern one of the three areas of this unit indicates that the grade of metamorphism is higher there.

Quartz-Albite-Biotite Schist (Mg)

Field Characteristics.— The schist occurs as prominent outcrops near the northern part of the area and is the best exposed metamorphic-rock unit in the Washoe Hills. On a fresh surface, the schist is light tan to gray, weathering to a gray-brown color. It is massive to schistose and has a tendency to split along planes of schistosity, particularly in horizons where the schistosity is well developed. The schistosity is imparted by fine flakes of biotite, which are more numerous in some horizons than others. Biotite, where it occurs in streaks is also responsible for a well defined lineation. A few rock fragments have been sheared out into augen that are elongated in the direction of the lineation.

Petrography (specimens 1653 and 1671).— From a fourth to half of the rock is composed of a fine mosaic of quartz and untwinned albite. Subparallel flakes of biotite and chlorite define the foliation. (See figure 3a).

Numerous phenocrysts of plagioclase and quartz, about 1 mm. in diameter, are present and show clearly the effects of cataclastic deformation. Most of the quartz phenocrysts
Figure 3.-- (a) Quartz-albite-biotite schist. Large grains are quartz and highly altered feldspar. Biotite in clusters. X 25.
(b) Amphibolite, containing augite and hornblende in apparent equilibrium. Sphene is abundant. X 25.
are crushed and elongated parallel to the lineation. A few larger grains that have survived crushing are embayed, indicating a volcanic origin, and show undulatory extinction.

Plagioclase phenocrysts occur as corroded and embayed fragments and large rounded grains. They are extremely cloudy and twinning is vague. In addition to plagioclase and quartz phenocrysts, there are also a few clusters of biotite derived from the original mafic minerals. Magnetite, zircon, and apatite are accessory minerals.

The presence of embayed quartz suggests a volcanic origin for the rocks of this unit, which originally may have been composed of pyroclastic rocks of acidic composition.

The grade of metamorphism is low, corresponding to that of the greenschist facies.

Hornblende-Plagioclase and Hornblende-Augite-Plagioclase Amphibolites (Hh)

Field Characteristics.—Rocks of this unit are exposed in the Lakeview Hill area and in the northern part of the Washoe Hills area. In the Lakeview Hill area the metamorphic rocks have been intruded by granitic rocks of the Carson Range. Bodies of granitic rocks that may be cupolas, and granitic and pegmatitic dikes intrude the metamorphic rocks as much as several hundred yards from their visible contact with the main intrusion. But, despite their proximity to the igneous intrusives, the metamorphic rocks
by and large have retained their foliated character and do not have the texture that is characteristic of hornfelses. Locally, they are quite fissile, but the massive varieties are more common, and weather to a dark gray to brown color. The latter show a well developed color banding. In one outcrop alternating cream-colored, green, gray, and brown bands, each about 1 mm. thick can be traced for several feet. Such fine banding is uncommon, however; normally the bands average from an inch to several inches in thickness. The cream-colored bands contain a large amount of feldspar and quartz, while the green and gray bands derive their color from that of the amphiboles they contain. Garnet is a major constituent of the brown bands.

It is not known how much of the banding is the result of segregation of minerals by metamorphic processes and how much is due to original differences in composition of a sedimentary rock. The coarser bands, up to one foot in width, are assumed to represent original differences in chemical composition for it is doubtful that diffusion in the solid state can produce segregation bands of so great a thickness (Harker, 1932, p.18-21). On the other hand, segregation could have been a factor in the formation of the finer bands.

A striking feature of these amphibolites is that they show a strong lineation and foliation, which is not necessarily a plane of fissility. The lineation is due to the parallel
alignment of the amphiboles, whereas, the foliation is
due largely to the statistical orientation of the amphiboles
into a position such that one face of the prism lies in
the plane of foliation. (This was determined by plotting
the orientation of the cleavage planes of amphibole, and
will be discussed in a later section). The foliation is
further accentuated by the strong dimensional orientation
of the plagioclases, which tend to be flattened in the
plane of foliation. They also show a strong tendency to
elongation parallel to the amphibole rods.

The rocks of this unit exposed in the Washoe Hills
area are somewhat similar in appearance to the rocks of
the Lakeview Hill area and may be an eastward extension
of them. In general appearance they are gray, tan, and
green, banded rocks, in which the individual bands range
in width from a fraction of an inch to several feet.
Boudinage is common and ordinarily has formed in horizons
that consist almost entirely of garnet and epidote.

The amphibolites in which biotite is an important
constituent have a tendency to part along schistosity
planes. Amphibolites in which biotite is lacking or is
present in minor amounts show only a crude tendency to
part parallel to the foliation.

Petrography (specimens 1652, 1656, 1659, 1663, and 1668).--
Most of the specimens contain plagioclase and hornblende
as essential constituents and may be classed as amphibolites.
Normally, the rocks are banded, so that hornblende-rich
bands alternate with bands composed almost entirely of plagioclase. Quartz also occurs in bands in one specimen in which it is an important constituent. Sphene, apatite, and magnetite in varying amounts are the accessory minerals.

Specimen 1656 is typical of the amphibolite in the southern part of the Lakeview Hill area. In outcrop the rock is greenish-gray, fine-grained and somewhat fissile. Biotite plates up to 1 mm. in diameter occur in the planes of fissility but no biotite was observed in thin section. The mineral constituents exhibit a strong dimensional orientation and parallel prisms of hornblende define the lineation. Laths of plagioclase and flattened grains of quartz lie with their least dimension perpendicular to the plane of schistosity. Twinned plagioclase (andesine-labradorite) is the most common mineral and forms about 50% of the total volume of the rock. Next in abundance are epidote-clinozoisite and hornblende, which together make up about 30% of the rock. The other minerals, in order of decreasing abundance, are magnetite, quartz, augite, potash feldspar, and sphene. The augite occurs as minute grains distributed through the matrix and appears to be in equilibrium with the hornblende.

Most of the plagioclase is clear but a few larger grains are clouded with numerous reddish-brown inclusions of an unidentified mineral. Many of these cloudy feldspars are zoned and these are considered to be relics. That these relics have undergone cataclastic deformation is
evident from the fact that some of them have been broken, pulled apart, and subsequently recemented by quartz.

The rocks in the northern and central part of the Lakeview Hill area are generally less fissile than those described above. They are well-banded parallel to original bedding planes. Mineralogically they are somewhat similar to the rocks in the southern part of the area in that they contain essentially the same minerals, but they are dissimilar in that they are composed almost entirely of equal amounts of hornblende and oligoclase. Quartz and epidote-clinozoisite are only minor constituents, and clear, untwinned cordierite is also present.

Specimen 1668, from the northern part of the area, contains numerous bands a few millimeters in thickness. Some bands are nearly all quartz; others are composed largely of hornblende, while plagioclase predominates in other bands. Augite, epidote-clinozoisite, orthoclase, and cordierite are minor constituents. The mineral grains show a strong dimensional orientation.

Specimen 1665, a finely-banded rock which differs from the others in that it contains no amphibole, was collected from an outcrop in the central part of the Lakeview Hill area between two cupolas that are about 150 feet apart. This rock consists of about 50% andesine, 20% quartz, and lesser amounts of epidote-clinozoisite, augite, cordierite, garnet (probably grossularite), vesuvianite, and minor accessories. Cataclastic deformation has crushed
and drawn out the garnet into elongated masses, and the spaces between the fragments have been filled with quartz and epidote.

It is difficult to determine from what type of rocks the amphibolites were derived, for they may be formed from such rocks as basic to semi-basic igneous rocks, impure calcareous or dolomitic sediments, or from relatively pure limestones into which silica, magnesia, and iron have been intruded. Williams, Turner, and Gilbert (1955, p. 241-243) give several criteria that are useful in establishing the nature of the original rock. They state that ultra-basic igneous rocks yield amphibolites that lack plagioclase and contain amphiboles that are high in magnesia. Amphibolites derived from basic igneous rocks contain about equal amounts of plagioclase and amphibole, and quartz and biotite are minor constituents unless the amphibolite was derived from a basic tuff. Almandine and epidote also may be present. Mixed calcareous sediments that have been metamorphosed to amphibolites contain relatively less plagioclase and more quartz and biotite than the amphibolites derived from igneous rocks. The presence of diopside and the lack of almandine garnet is also characteristic of the "sedimentary" amphibolites.

It is clear that the finely bedded amphibolites were derived from sedimentary or pyroclastic rocks but their original character is obscure. Zones that now consist almost entirely of garnet and epidote probably represent
original limestone horizons. Specimen 1663, consisting almost entirely of equal amounts of hornblende and plagioclase, may have been a basic tuff. Whether the other specimens described above represent metamorphosed tuffs or impure calcareous sediments or both is not known.

The rocks of this unit in the Washoe Hills area are somewhat similar to those exposed at Lakeview Hill. The plagioclase in specimen 1652 is highly calcic and has a composition of about An35. Very few of the plagioclase grains are twinned. The plagioclase occurs in bands that are composed almost entirely of that mineral, with minor amounts of quartz and sphene. Alternating with these bands are bands in which the mafic minerals hornblende and augite predominate. The latter minerals appear to be in equilibrium with each other. A few bands consist largely of quartz. (See figure 3b). In addition to the above minerals, a small amount of epidote, zoisite, orthoclase, and zircon are present.

Another specimen (no. 1672) from the same locality is similar to specimen 1652 but is very fine grained and contains biotite as an important constituent. The plagioclase, which is less calcic, is in the oligoclase-andesine range. Garnet is not present in either of the above specimens but is quite prevalent in garnet-epidote bands in most of the rocks of this unit.

The sedimentary or pyroclastic origin of these rocks is obvious from their bedded character and they have been
derived either from impure calcareous sediments or pyroclastic rocks.

Rocks of this unit have been subjected to a relatively high grade of metamorphism. Their mineralogy generally is compatible with that of the amphibolite facies, but locally, the lack of hornblende and the presence of grossularite and vesuvianite may reflect a higher grade of metamorphism, equivalent to that of pyroxene-hornfels facies.

Discussion of the Metamorphism

The lowest grade of metamorphism exhibited by the rocks of the report area is equivalent to that of the green-schist facies, the highest is equivalent to at least the amphibolite facies and locally may be as high as that of the pyroxene-hornfels facies. Those rocks nearest the visible contact with the granitic rocks have undergone the most intense metamorphism. Their mineral assemblages, and particularly the presence of the anti-stress minerals cordierite and chiastolite, are characteristic of contact aureoles. Even the rocks of lowest rank may have been affected by contact metamorphism, for many of the metamorphic rocks of the central and southern part of the Washoe Hills area have the spotted texture that often is present in fine-grained rocks in the outer limits of contact aureoles (Harker, p. 15 and 43-49). Furthermore, these rocks of low metamorphic rank are more intensely metamorphosed than the slightly altered rocks immediately
east of the report area. For these reasons, it is thought that contact metamorphism has affected all the pre-intrusive rocks of the report area.

The strong dimensional orientation of lenses of minerals and rock fragments was probably affected by earlier dynamic metamorphism which made the rocks strongly anisotropic. This previously imposed anisotropism appears to have governed the orientation of the minerals formed during the subsequent contact metamorphism.
THE MEGASCOPIC FABRIC

Terminology

Following are definitions of terms used in later sections of the report. They are largely taken from Turner (1948, p.177-198).

a. -- This is the direction of tectonic transport and coincides with the direction of slip in the deformation by laminar slip, or with the direction of maximum elongation in deformation by flattening. In the mapped area, a has a northeast bearing and normally plunges less that 45 degrees. It lies in the plane of foliation.

b. -- This is normal to a and is also in the plane of foliation in the mapped area. It is an axis of rotation and coincides with the axis of slip or flexural folding. Usually, b is tentatively chosen as the most prominent lineation. In the mapped area, b corresponds to the only visible lineation, which has an average plunge of 40 to 50 degrees to the southeast.

c. -- The c-axis is normal to both a and b. In the report area it plunges 40 to 50 degrees to the northwest.

ab-plane. -- The ab-plane corresponds to the foliation plane in the mapped area.

ac-plane. -- This is the deformation plane, in which movement occurs.
**s-plane, or s-surface.**—This is a non-genetic term describing any surface of actual or potential yielding during deformation. It may also refer to pre-metamorphic structures, such as bedding, if it makes the rock anisotropic. An s-plane may be designated as an s-plane of slip, or s-plane of flattening, etc., if its origin is known. If the origin is not known, then s-planes may be designated numerically, such as $S_1$, $S_2$, $S_3$, etc., and preferably in the order of their formation. In the area covered by this report, the foliation plane is $S_1$.

**B.**—"B" is an axis of internal or external rotation, or the axis of intersection of simultaneously active slip planes. In the report area $b$ equals $B$. 


Foliation

The only megascopic plane that can be identified readily in the field is the plane of foliation. Normally, it is well developed but locally it is inconspicuous and its attitude is difficult to determine, particularly in the coarse-grained volcanic breccias and crystal tuffs at Lone Mountain. Foliation in the breccias is defined by the dimensional orientation of flattened lenses of rock fragments and clusters of mineral grains; in the crystal tuffs it is defined in many outcrops only by a faintly discernible color-banding. All the other rock types exhibit a clearly-defined foliation plane and the micaceous rocks, in particular, are well foliated and tend to be fissile.

In most of the exposures the foliation plane is a relatively smooth surface with only minor crinkling. There are exceptions, however, and many of the highly micaceous rocks show a well developed crinkling on a minute scale.

The foliation is a bedding-plane foliation. Wherever beds of different lithology are present in the same outcrop the bedding plane is always parallel to the schistosity. This relationship holds also in the few folds that have been observed, where the bedding schistosity is folded. No development of undoubted axial plane foliation was noted anywhere in the area.

Foliation in the Carson City area is defined by:

1. -- Preferred dimensional orientation of platy minerals,
such as micas or graphite, and of prismatic minerals, such as hornblende.

2.-- Preferred dimensional orientation of flat lenses of rock fragments or mineral clusters.

3.-- Alternating layers of different composition that show either as color bands, or as changes in texture, or both.

The attitude of the foliation planes is shown on the map in plate 1. In general, the foliation strikes northeast and dips to the southeast. The dips average about 20 to 30 degrees in the northern part of the area but become progressively steeper toward the south and are nearly vertical at the southern end of Lone Mountain. Locally, the beds have been strongly warped in the vicinity of Cenozoic faults, but dip steeply north.

The poles to the foliation planes are plotted on a stereographic projection in figure 4a. They show a considerable scatter but in a fabric diagram of the poles (figure 4b) there is a strong, elongated statistical maximum aligned on a great circle, which is represented in the diagram by the arc $\Pi$. There is a less pronounced alignment of the poles along a second great circle, labeled $\Pi'$. The normal to each arc is labeled $\beta$ and $\beta'$ respectively. In addition, the average trend of the lineation in the whole area is indicated by "b".

The tendency for the poles to spread along two great circles can be interpreted to indicate folding about two axes—the nearly east-trending $\beta$ axis and the northeast-
Figure 4.--- (a) 81 poles of foliation planes measured in the whole area.
(b) poles of foliation planes contoured for density; 2-5-10-15-20% per 1% area.
b = average position of lineation.
Arrow points to true north.
trending $\beta'$ axis. Folding about the $\beta$ axis is manifested in the field by the southward steepening of the dip of the foliation plane. Folding about the $\beta'$ axis is not obvious in the field except in the central part of the Washoe Hills area and in the Lakeview Hill area, where parts of a few folds that are at least a few feet or yards in amplitude can be observed.

**Lineation**

Lineation is defined by Cloos (1946, p. 1) as

"...a descriptive and nongenetic term for any kind of linear structure within or on a rock. It includes striae on slickensides, fold axes, flow lines, stretching, elongate pebbles or ooids, wrinkles, streaks, intersection of planes, linear parallelism of mineral or components, or any other kind of linear structure of megascopic, microscopic, or regional dimensions."

Lineation, conspicuous in most exposures in the mapped area, is in the plane of foliation and its bearing is normally within about 30 degrees of the direction of dip of the foliation plane.

The lineation in the Carson City area is of several types:

1. Lineation defined by parallelism of flattened, and elongated lenses of rock fragments or pre-metamorphic mineral clusters.---The lenses range in length from a fraction of an inch to 2 feet. The intermediate and longest axes of the lenses are in the plane of foliation and the longest axis is parallel to the lineation. The lengths of the axes are in the approximate ratio 2:3:6. This is the most
conspicuous type of lineation in the volcanic breccias at Lone Mountain. Elsewhere, outcrops of an altered limy tuff (unit Md) in the vicinity of the Carson Hot Springs contain numerous lens-shaped voids up to a foot long that probably indicate dissolved limestone lenses.

2. Parallel orientation of inequant mineral.— The parallelism of inequant minerals, particularly amphibole, imparts a fine lineation to many of the rocks. Also included in this group is lineation due to rods of quartz that are elongated parallel to the other linear features. The rods, which rarely exceed an inch in length, occur largely in the southern half of the Washoe Hills area.

3. Streaks of tabular minerals.— Streaks of biotite or chlorite define a strong lineation in the rocks of unit Mg. Streaks of mica also define a vague megascopic lineation in many other fine-grained schists of the area.

4. Crinkling.— Lineation defined by crinkling of the foliation plane is not as readily apparent as the other types of lineation, owing to the small amplitude of the crinkles, but it is nevertheless present on a megascopic scale in many of the schists. The crinkles are either small folds or long ridges and grooves whose parallelism defines the lineation.

5. Boudinage.— Boudinage is present in the northern part of the Washoe Hills area and in the Lakeview Hill area. In the Washoe Hills area the boudinage is of two mineralogically different types. One type is in a schistose
rock that appears to have been originally a limy tuff or a sediment that contained many lime-rich layers. The limy layers, which have been altered largely to garnet and epidote, form the boudins. These occur either as flat lenses, separated from adjacent boudins, or as continuous masses that pinch and swell. The individual boudins range in size from an inch to more than a foot in length. The second type of boudinage in the Washoe Hills area occurs in a fine-grained amphibolite. The boudins, which are about the same size as those of the first type, consist of granitic material that appears to have been intruded into the country rock as sills and in one outcrop, as a dike cutting across the foliation.

Boudinage occurs also in the metamorphic rocks exposed in the Lakeview Hill area. Normally, garnet and epidote form the boudins, but in one outcrop granitic material that appears to have been injected parallel to the bedding forms well developed boudinage. (See figure 5). The mineral components of the granitic material display a strong dimensional orientation that parallels the orientation of the components of the host rock, but there is no apparent dimensional orientation of the minerals in the constricted portions of the boudinage. These constrictions consist largely of quartz that crystallized in zones of minimum stress.

A common feature of the boudinage in the mapped area is the elongation of the individual boudins parallel to
Figure 5.-- Granitic boudinage.
the trend of the other linear features.

In general boudins form where competent beds are interbedded with incompetent beds. During deformation the competent beds break into segments and the broken edges are rounded off. The gaps between segments are filled either by flowage of material from the incompetent beds or by recrystallized material that originated in the competent bed. The competent beds that formed boudins in the report area consist of granitic material or of garnet and epidote that probably represent former limestone bands. The incompetent beds are fine-grained schists or amphibolites that were derived from fine-grained sediments or pyroclastics.

DeSitter (1956, p. 37) believes that boudins are always parallel to the fold axes but Cloos (1946, pp. 16-17) shows that they may also be oriented with their length perpendicular to the fold axes. In the Carson City area the boudins are elongated parallel to the general trend of all the other types of lineation, which, as will be demonstrated later, parallels an axis of cylindroidal folding.

Granitic intrusions that bear a superficial resemblance to boudinage are exposed in a prospect at the north end of the Washoe Hills area, near the contact. The granitic material pinches and swells like boudinage but appears to have been forcibly injected into the host rock along curved fissures and foliation planes, for contacts with the host rock are approximately parallel on opposite sides of the intrusion.
(6) Mullions.-- Fold mullions, or bedding mullions (described by Wilson, 1953) are well developed locally in hornblende-biotite schists of map unit Mn. The mullions are small, tight folds of about $\frac{1}{2}$ inch to 4 inches in amplitude and have lengths as great as ten times the amplitude. Each mullion lies with its axial plane parallel to the foliation of the enclosing rock and with its axis parallel to the other linear features.

The composition of the mullions is the same as that of the country rock but the mullions are physically separated from the country rock and can be easily pried out with a pick or pulled out by hand.

In detail, the fold mullions are small, mica-coated, similar folds in which the beds are thinned on the limbs and thickened on the crests. (See figure 6). The folded beds in the mullions are in sharp discordance with the unfolded beds of the enclosing country rock. There is continuity neither between the bedding in the country rock and that in the mullions nor in the bedding of adjacent fold mullions. As illustrated in figure 6, the fold mullions and abruptly against each other.

Fold mullions are of obscure origin but their presence is significant because they are thought always to be parallel to the fold axis of the general structure. (DeSitter, 1956, p.89).

A second type of mullion structure, cleavage mullion, was observed near the crest of a fold in the Lakeview Hill
Figure 6.-- Fold mullions.
area. The cleavage mullions are formed by the intersection of foliation planes with fractures that parallel the length of the fold. In cross section some of the mullions are rounded off, apparently as a result of breaking along curved fractures. A few fold mullions are also present and lie with their axis parallel to the axis of the fold.

Fold axes.—Other than crinkles and fold mullions, the only other folds that could be observed directly in the field are small shear folds and several larger folds. The shear folds which are associated with the fold mullions in the northern part of the Washoe Hills area are several inches in amplitude. The shear folds are thicker on the crests and troughs than on the limbs. The folds could be observed only in two dimensions and their exact attitude could not be determined, but their axial planes appear to be parallel to the schistosity of the host rock. Their origin is attributed to shearing stress in a layered material along shear surfaces that are not localized parallel to the layering but rather cut across it. (Fairbairn, 1954, p. 173).

The larger folds, exposed in the central part of the Washoe Hills and in the Lakeview Hill areas, have amplitudes of a few feet to possibly a few tens of feet. They are broad, open folds in which foliation is parallel to the bedding and follows the configuration of the folds. Owing to the nature of the outcrops, the attitude of the fold axes is difficult to determine in many cases, but where it
can be determined, the axis parallel the general trend of the other types of lineation in the immediate area.

\[ \beta \] -diagrams

The most common type of fold in nature is the cylindroidal fold, which may be described geometrically as the locus of a line moving about a parallel line fixed in space. (McIntyre, 1957). It is not necessary that the moving line remain at a constant distance from the fixed line, and consequently, a cross section of a cylindroidal fold perpendicular to the fold axis may have almost any conceivable shape.

An important consequence of the geometrical properties of a cylindroidal fold is that the fold can be recognized and the trend of its axis determined by means of a stereographic net. The method is as follows (see Weiss, 1954): each foliation plane is plotted as a great circle on the lower hemisphere of a stereographic projection. Ideally, all the great circles that represent foliation planes will intersect at a point if the folding is cylindroidal, but in actual practice all the great circles do not intersect at a single point. Therefore, every intersection is plotted as a point on another net and the points are contoured for density as in a normal fabric diagram. The maximum represents \( \beta \), the fold axis.

An alternative to the \( \beta \)-diagram is the \( \beta \)-diagram, which is constructed by plotting the normal to each foli-
iation plane as a point on a stereographic net. If the area is homogeneous and has undergone cylindroidal folding the poles of the foliation planes will cluster along a great-circle arc. As the area approaches homogeneity and the folding approaches true cylindricity the poles of the foliation planes lie very close to the great circle. (Thus, both $\beta$ and $\Pi$ diagrams can be used to test for cylindricity and homogeneity of folding). The axis of folding, or $\beta$, is perpendicular to the plane represented by the great circle $\Pi$. This relationship between $\beta$ and $\Pi$ diagrams is shown in figure 7.

The map area was divided into 7 subareas and a $\beta$-diagram constructed for each one. The $\beta$-diagrams are shown in figure 8. Lineation, $b$, is also indicated in each diagram. Three of the diagrams, those in subareas 4, 5, and 6 each have two maxima, $\beta$ and $\beta'$. $\beta'$ strikes northwest and approximately corresponds in position to the lineation, $b$. $\beta$ strikes northeast and plunges from 0 to 25 degrees east. Subareas 1, 2, and 7 show only a $\beta'$ maximum whose position corresponds with the lineation, $b$. Subarea 3, on the other hand, has no $\beta$ maximum, but has only a $\beta$ maximum. The $\beta$ and $\beta'$ maxima for all the subareas are shown in a synoptic diagram in figure 9. In this diagram the $\beta'$ and $b$ maxima show a fairly high degree of scatter, while the $\beta$ maxima are in a smaller cluster. Coincidence of $\beta'$ with $b$ makes it clear that the folding about $\beta'$ and the origin of the lineation are genetically related. On the other hand
Figure 7.-- Relationship between $\Pi$ and $\beta$. Pole of foliation plane is $\Pi$. Poles fall on great circle 90 degrees from fold axis, $\beta$. $\beta$ is also defined by the intersections of the trace of the foliation planes.
Figure 6.--- $\beta$-maxima. $\beta$ and $\beta'$ shown as solid circle.
Lineation shown as cross.
Scale of map is 1:450,000.
Figure 9.— Synoptic $\beta$-axis diagram prepared from 7 subareas. $\beta$- and $\beta'$-axes shown as solid circles. Average attitude of lineation in each subarea shown as cross. Numbers refer to subareas of figure 8. Arrow points to true north.
there is no evidence, either in hand specimens or in out-
crop, that any of the metamorphic features are related to
folding about $\beta$. It is tentatively concluded, therefore,
that $\beta$ and $\beta'$ were not formed contemporaneously. The close
grouping of the $\beta$ maxima as compared to the scattering
of the $\beta'$ and $b$ maxima in the synoptic diagram in-
dicates that folding about $\beta$ followed folding about $\beta'$
and caused the scattering of the $\beta'$ and $b$ maxima.

Unrolling the Fabric

In order to determine the nature of the deformations
that were responsible for flexure of the beds about the
axes $\beta$ and $\beta'$ the megafabric was first unrolled into the
position it would assume had the lineations been rectilinear
throughout the area. By this process of unrolling, the
effect of flexure as a result of the latest deformation
can be removed. In general, this technique can reveal the
effects of several consecutive deformations, provided the
fabric is unrolled about successively older axes of fold-
ing. (Knopf and Ingerson, 1938, p.116).

In the area under discussion it is assumed that the
closely grouped $\beta$ maxima indicate that flexure about $\beta$
ocurred after flexure about $\beta'$, and that the scattering
of $\beta'$ and the related lineation, $b$, is due to the flexure
about $\beta$. The close grouping of the $\beta$ maxima further
indicates that there has been no subsequent flexure about
another axis of different orientation following flexure
about $\beta$. It is therefore possible first to unroll the fabric about the $\beta$ axis. This is done by the following method: The attitudes of the lineation and the pole to the foliation plane at each outcrop are plotted on a stereographic net. Then the points representing the lineation are rotated to a new and arbitrary position that corresponds to the average trend of the lineations throughout the mapped area, thereby restoring the rectilinearity that was presumably destroyed by the deformation about $\beta$. The next step in unrolling the fabric is to make a corresponding rotation, in the same direction and of the same magnitude, for the pole of each foliation plane as has been made for the lineation in the same outcrop. Figure 10 shows the poles to the foliation planes after rotation, whereas figure 14a shows their position before rotation. After rotation the poles of the foliation planes fall very closely along a great-circle arc, $\Pi$, that represents the trace of a plane whose pole parallels the trend of the lineation. This pattern indicates that the rocks were folded about an axis trending parallel to the trend of the lineation. Moreover, the excellent alignment of the poles along the great circle—90 percent of the poles plot within 5 degrees of the great circle—indicates that the configuration of the folds approached true cylindricity very closely. The outcrop pattern as mapped does not indicate tight folding, but this does not preclude the possibility that folds are merely small, open folds on a major, more tightly folded structure similar
Figure 10.— Poles to 52 foliation planes after unrolling. 
($b = \text{lineation}$).
to the nearly isoclinal folds east and west of the area.

The mutual parallelism of $\beta'$ and $b$ indicates that there is a genetic relationship between the folding about $\beta'$ and the formation of the lineation, but whether or not the two were formed contemporaneously is open to question. The lineation is determined not only by preferred dimensional orientation of minerals and lenses, but also by a crystallographic orientation of the mineral grains. This implies that the minerals and lenses developed under conditions of stress. However, they belong typically to contact metamorphic assemblages and include such anti-stress minerals as cordierite and andalusite, suggesting that the minerals developed under conditions of little or no stress. This seeming anomaly can be explained by assuming that the rocks were subjected first to stresses that folded them and made them strongly anisotropic, and then were invaded by the granitic magma and underwent contact metamorphism. The contact metamorphic minerals grew along directions of easy growth governed by the previously imposed anisotropism. In this manner, the orientation of the minerals can be indirectly determined by the deforming forces that were acting on the rocks before the period of contact metamorphism.

The folding about the $\beta$ axis may be due to one of the following:

(1)-- It may represent a shifting of the axis of folding during the period of regional metamorphism. It is doubtful, however, that folding about the $\beta$ axis could have
occurred during the metamorphism, for the axis is unsymmetrically oriented to the elements of the metamorphic fabric.

(2) -- It may have occurred during a period of compressive stresses at some time after the metamorphism and was unrelated to it. However, there is no evidence for a period of compressive stresses on a regional scale after the Nevadan orogeny, and this explanation must be considered as being only remotely possible.

(3) -- The folding may be a simple arching of the beds due to the forcible upward movement of the granitic magma.

(4) -- The mapped area is cut by Cenozoic step faults which strike approximately parallel to the bearing of the $\beta$ axis. Differential tilting of blocks bounded by the faults, and possibly warping of beds as a result of drag along the faults, may simulate folding. The differential tilting and drag warping, even if not entirely responsible for the rotation of the beds about the $\beta$ axis, has probably contributed to that rotation to some extent. The strike of the faults may parallel the trend of an older fold or arch, or faulting may have occurred contemporaneously with arching of the beds.

Joints

Joints differ from other $s$-surfaces in that their development generally is not accompanied by relative movement of opposing surfaces, and in that joints are the result of rupture, which does not influence the preferred
orientation of the mineral constituents.

Joints are late-metamorphic or post-metamorphic structures, for it is inconceivable that open joints formed during the more active stages of metamorphism would survive plastic deformation. Nevertheless, they are related either directly or indirectly to the forces that deformed the rocks (Turner, 1948, p. 182). The relationship may be an indirect one in the sense that their orientation is governed by the anisotropic fabric. They may form, for example, during cooling and shrinking of the metamorphic body. In this case the stresses that result in rupture are a direct result of shrinkage of the rock mass and the rupturing takes place along directions of easiest fracturing, governed by the anisotropism of the fabric. However, the relationship more probably is a direct one. After metamorphism the rocks are left in a state of elastic strain, which is relieved by fracturing during a subsequent stage of unloading. The elastic strain is directly related to the stresses involved in the metamorphic deformation.

Figure 11 shows equal area projections of the poles of joints in the seven subareas. A composite diagram is shown for subareas 2, 3, and 4, and one for subareas 6 and 7. The general pattern exhibited by the poles is a broad, discontinuous girdle, whose axis nearly corresponds to the pole of the average position of the foliation planes in the subarea. There are at least three strong maxima and several weaker ones in each girdle.
Figure 11.— Poles of joints in subareas; contours 2, 4, 6, 8% per 1% area. Average attitude of lineation shown by cross.
In most parts of the mapped area, the best developed joint set is represented by maximum 1 in the diagrams and in many outcrops this is the only joint set present. The individual joints of this set are open, smooth-walled, and occasionally are filled with quartz. They normally are spaced at least a foot apart. These joints are nearly, but not quite, perpendicular to the trend of the lineation, which is shown in each diagram by a cross, and the set is therefore an ac set. ac joints, or cross joints, which are very common in folded metamorphic rocks, are almost invariably subnormal to the lineation and to the fold axes and form as a result of elongation in a direction parallel to the trend of the fold axes. (See Fairbairn, 1954, p. 156, and Turner, 1943, p. 182). The direction of tectonic transport, a, is parallel to the surface of the ac joints.

The ac joints form an important element in the symmetry of the fabric. They are nearly perpendicular to both the foliation plane, or ab plane, and the b-lineation, and constitute the only plane of symmetry in the fabric. The only other element of symmetry is an axis parallel to the trend of the lineation. By definition then, the megascopic symmetry of the fabric is monoclinic.

Joint set 2, which is as well developed as the ac joints of set 1, is closely associated with the ac joint set in the Washoe Hills area and in the area near the Carson Hot Springs, where joints of this set are more common than those of set 1. There is some reason to be-
lieve that set 2 is also an ac set. Although the ac joints in individual exposures may vary in dip by 20 or 30 degrees, so that the joints may have any orientation in the area of maxima 1 and 2, it was noted that there is a tendency for the ac joints to be oriented more closely to one of the two maxima in different outcrops and even in adjacent outcrops. There is some suggestion that this preference is related to the rock type, for there appears to be a tendency for the orientation of ac joints in the more fissile rocks, such as the biotite and chlorite schists immediately north of the Carson Hot Springs, to conform more closely to the position of maximum 2. However, this relationship can not be proved statistically with the available data.

Joint sets 3 and 4 are well developed in the northern part of the mapped area, locally almost to the exclusion of all other joint sets, and cause the rocks to break into rhombs. In many outcrops these joints are very numerous, being spaced less than an inch apart, while in other outcrops the spacing may be several feet. The two sets are symmetrically disposed in reference to the lineation, which bisects their angle of intersection. This bisected angle is the acute angle in the fissile schists, but is the obtuse angle in the more massive rocks, particularly in the northwestern part of the Washoe Hills area.

Longitudinal, or (h01) joints (set 5) are developed as tight, irregularly-surfaced joints subparallel to bc.
They are present throughout the area but are best developed in the southern part of Lone Mountain. The joint pattern in the latter area also differs from that elsewhere in that there is a strong development of joints (set 6) subparallel to the plane of foliation.
Sander recognized two types of tectonites. These are summarized by Turner (pp. 199-200) as follows:

**S-tectonites** are fabrics that are dominated by one visible set of \( s \) planes, giving rise to a planar schistosity. Linear parallelism of elements is either inconspicuous or absent. There has been no external rotation and girdle patterns in the fabric diagrams are absent. The dominant movements are slip movements in the plane of flattening.

**B-tectonites** are those in which there is a strong linear parallelism of elements parallel to the \( b \) (\( B \)) fabric axis. The \( b \) (\( B \)) axis is an axis of external rotation and there may be obvious rotation about that axis of crystals, layers, and \( s \)-surfaces, with the development of \( ac \) girdles in the fabric diagrams. This type of **B-tectonite** has been called an **R-tectonite** to distinguish it from the second type of **B-tectonite** in which there is no evidence of external rotation. In the latter tectonite the \( B \) axis is defined conspicuously by intersecting \( (h\overline{0}l) \) planes, which may give rise to planes of schistosity.

There is no clearly defined boundary between **B-tectonites** and **S-tectonites** and many fabrics are transitional between the two. For example, an **R-tectonite** may have incompletely developed girdles as a result of having undergone only slight rotation or a **B-tectonite** with intersecting \( (h\overline{0}l) \) planes may show only a weak lineation. Both of
these fabrics would be transitional.

For this study fabric diagrams were prepared showing the orientation of 0001 of quartz, poles of (001) of mica, and poles of (110) of hornblende. The locations of the specimens used for the fabric study are shown in figure 12.

Preferred Orientation of Hornblende

The preferred orientation of hornblende was determined in only one specimen, an amphibolite from the northern part of the Washoe Hills area. The specimen (specimen 1652) is made up of alternating quartz-rich and hornblende-rich bands which have been folded about the b(=B) axis. The orientation of the poles to the prism faces (110) of 100 grains of hornblende determined in an ac section yielded an incomplete girdle with a strong maximum at c. (See figure 13a). The maximum at c indicates that the hornblende lies with a prism face parallel to the ab, or foliation, plane; the lesser maxima at II and III represent the pole to the second prism face. A strong tendency for the hornblende to orient itself with its length parallel to b(=B) is indicated by the well developed girdle.

It is doubtful that the hornblende, which is in a contact metamorphic assemblage, received its strong dimensional orientation in direct response to stress. It is more probable that it grew along directions of easy growth determined by the anisotropism resulting from a previous
Figure 12.-- Locations of specimens by number.
Scale of map is 1:48,000.
Figure 13. -- Hornblende and mica orientation diagrams.
(a) 100 poles to (110) of hornblende in specimen 1652; 1-2-3-4-5% per 1% of area.
(b) 125 poles to 001 of mica in specimen 1657; 2-3-4-5-10% per 1% of area.
(c) 100 poles to (001) of mica in specimen 1671; 1-2-3-4-5% per 1% of area.
(d) 100 poles to (001) of mica in specimen 1655; 1-2-3-4-5% per 1% of area.
deformation. The hornblende grew with one prism face parallel to the foliation plane, $ab$, and emphasized that plane. The strong linear orientation exhibited by the hornblende emphasizes the older $b(=B)$ axis.

Preferred Orientation of the Micas

Orientation diagrams for mica were prepared from three specimens: specimen 1655 from Lone Mountain; specimen 1657 from the area immediately north of the Carson Hot Springs; and specimen 1671 from the northern part of the mapped area. Specimen 1655 consists largely of relict phenocrysts of quartz and feldspar up to 3 mm in diameter. Most of the matrix consists of small plates of undistorted biotite. There is no obvious crinkling of the fabric. Specimens 1657 and 1671 are somewhat similar to 1655 but contain fewer phenocrysts. The matrix contains numerous plates of biotite and muscovite or sericite. Crinkled plates of biotite, larger than those of the matrix, occur with magnetite in specimen 1657 and define the foliation. This is the only one of the three specimens in which folding is clearly seen in thin section.

There is evidence of some crushing of the larger grains of feldspar and quartz in all three specimens, and particularly in specimen 1671. The orientation of the latter specimen is such that thin, hair-like cracks can be seen in the large grains of quartz and feldspar, indicating extension perpendicular to the cracks.
Figure 13b, c, and d shows the preferred orientations of the poles of \((001)\). The poles were plotted either by determining the orientation of the cleavage and plotting normal to it, or, if the orientation of any of the grains was such that the cleavage was not visible, the \([001]\) crystallographic axis was determined optically and its orientation plotted, even though \([001]\) and the normal to \((001)\) do not quite coincide.

Each of the fabric diagrams shows a conspicuous partial girdle about the \(b(=B)\) axis. Each girdle contains a strong maximum near the \(c\) fabric axis and a second strong maximum 20 to 30 degrees from \(c\). Each of these maxima defines an \(s\)-surface. In addition to the partial \(ac\) girdle there is also a development of a group of maxima that define an \(s\)-surface with \((hk0)\) orientation.

The interpretation of mica orientation is reviewed by Turner (1943, pp. 271 to 274). There are three general patterns of preferred orientation for micas and each pattern has more than one possible interpretation. The most common pattern is one in which the micas lie parallel or sub-parallel to the \(ab\) plane. This type of orientation is characterized by a single strong \((001)\) maximum coinciding with the \(c\) fabric axis. The second most common pattern is a girdle with one or more maxima. The third pattern is an uncommon one in which \((001)\) has a preferred orientation at right angles to the principle set of \(s\)-planes.

The first pattern is not present in any of the diagrams.
The second pattern is the most conspicuous one. In this pattern, the maxima in the girdles are disposed unsymmetrically in relation to \( \mathbf{c} \). This type of pattern is thought by Sander to be due to a combination of: (1)--translation gliding upon (001) with \( \mathbf{a} \) as glide line, and (2)--rotation of the micas as rigid plates, in a matrix undergoing affine plastic deformation, until (001) becomes oriented parallel to the \( \mathbf{AB} \) plane of the strain ellipsoid, provided the ellipsoid, is elongated parallel to \( \mathbf{B} \). Deformation takes place along one set of \( \sigma \)-planes (ab) but there are two stable orientations which (001) of mica would tend to assume. These are the slip plane (ab) and the \( \mathbf{AB} \) plane of the strain ellipsoid. The movement picture involved in this orientation is shown in the inset in figure 13b. The mica plates that were used to construct the fabric diagrams show no evidence of having been deformed and it appears that they grew after the deforming forces had ceased or had become too weak to affect directly the orientation of the micas. The micas may have grown along previously formed actual or incipient shear planes that may be correlated with the \( \mathbf{AB} \) plane of the strain ellipsoid and the \( \text{ab} \) plane of the fabric.

A possible explanation for the additional maxima that define an (hk0) plane is that the mica is the result of mimetic crystallization along a plane of easy growth. The plane may be a plane of potential rupture, which corresponds to an (hk0) joint, or possibly, in the case of specimen 1671, to a plane of easy growth subparallel to the axial plane.
of the major folding about the \( b(=B) \) axis.

No fabric diagram has been made of the older generation of biotite in specimen 1657. The flakes, which are bent, indicate some degree of rotation, apparently about the \( b(=B) \) fabric axis.

**Preferred Orientation of Quartz**

Orientation diagrams for the crystallographic c-axis of quartz were made for five specimens: 1658 from Lone Mountain; 1657 and 1667 from the vicinity of the Carson Hot Springs; and 1671 and 1652 from the northern part of the Washoe Hills area. (See map, figure 12). Specimens 1657 and 1671 are described in the section on preferred orientation of biotite. Specimen 1652 is a banded amphibolite with quartz-rich bands, \( 1/4 \) to \( 3 \) mm. thick. The amphibolite has undergone external rotation and the bands have been folded along an axis parallel to \( b(=B) \). The quartz and feldspar grains are somewhat flattened in the plane of foliation. Specimen 1667 is a fine-grained meta-tuff consisting largely of hornblende, epidote, quartz, and feldspar. Embayed relict phenocrysts of quartz show pressure shadows of recrystallized quartz. Specimen 1658 is also a meta-tuff but consists largely of fragmented relict plagioclase crystals 1 to 2 mm. in diameter. Quartz phenocrysts, which make up about 5 percent of the rock, have recrystallized along the edges and are partly bordered by fine grains of quartz.
Quartz grains in all the specimens show undulatory extinction to some degree. For each of these grains, a single, average determination of [0001] was made if the orientation of [0001] did not vary greatly over the whole grain. If it varied by more than a few degrees a determination of [0001] was made in different parts of the grain. Either method yields an accurate picture of the quartz orientation (Weiss, 1954, p.62).

All the thin sections were not cut parallel to ac or bc. Several were cut at random orientations. The lineation, b, and the trace of S_p (the foliation plane) are therefore shown in each diagram.

There is no blind spot in an orientation diagram of quartz. The [0001] directions can be determined regardless of the orientation of the quartz grains. However, to avoid unintentionally introducing a blind spot due to overselection of grains with a higher interference color and an underselection of grains that are at or near extinction because [0001] is parallel to the tube of the microscope, the selection of grains was made under plane polarized light.

The orientation diagrams for [0001] of quartz are shown in figures 14 and 15. These show several different patterns of preferred orientation which agree closely with the standard patterns illustrated in figure 16 (from Fairbairn, 1954, p.10). The types of orientation diagrams present in the report area and their interpretation are discussed below (1)-- In specimens 1671 and 1658 (figures 14a and 14b) the
Figure 14. -- Quartz orientation diagrams.
(a) 80 (all available) 0001 of large quartz in specimen 1671; 1-2-3-4-5; per 1% of area.
(b) 90 0001 of large quartz in specimen 1658; 1-2-3-4-5 per 1% of area.
Figure 15.— Quartz orientation diagrams.

(a) 150 [0001] of quartz in specimen 1667; 1-2-3-4-5% per 1% of area.
(b) 251 [0001] of quartz in specimen 1657; 2-4-6-8-10% per 1% of area.
(c) 175 [0001] of quartz in specimen 1652; 2-4-6-8-10% per 1% of area.
Figure 16.— Schematic diagram of quartz axes showing twelve types of lattice orientation found in tectonites. Three views of each type are shown, each perpendicular to one of the fabric axes a, b, c. The Roman numerals refer to various characteristic maxima. (From Fairbairn, 1954, p.10).
crystallographic axes are spread along two intersecting partial girdles. One girdle is around the b fabric axis; the other is around a. This pattern corresponds to type "j" in figure 16. There are at least two possible explanations for the occurrence of the mutually perpendicular girdles (Turner, 1948, p. 222). The girdles may be the result of superposition of two independent deformations, or secondly, they may be due to the development of a crossed strain with slip on (h0l) and (0kl) surfaces, and rotation about b (= B) and a (= B'). The girdles are related symmetrically to the megascopic fabric. They are perpendicular to the plane of foliation and intersect in c. One girdle is in a plane parallel to the megascopic lineation; the other is perpendicular to it. This close relationship between the megascopic and the microscopic fabrics suggests a close genetic relationship between all the fabric elements, and unless the relationship is fortuitous it tends to discount the possibility that the fabric is due to two superimposed deformations. Therefore, the crossed girdles may be interpreted as being due to rotation about a during deformation around the b axis. Elongation in b in this case may be accompanied by rotation about a of mineral grains or of (0kl) slip planes. This type of pattern is characteristic of B1B' tectonites.

(2) -- A quartz orientation diagram for specimen 1667 (figure 15a) shows two incomplete (0kl) girdles intersecting at right angles to each other (type "g" in figure 16). The maxima near the periphery of the diagram correspond to
maximum III. These maxima are due to the concentration of [0001] in two directions inclined at about 45 degrees to b and c in the bc plane. In addition to maximum III there is a group of strong maxima at a which correspond approximately to maximum I of type 'a' in figure 16. Maxima I and III often occur together (Fairbairn, 1945, p.12). This type of orientation is common in many granulites and is open to several possible interpretations. These are summarized by Turner (1948, p.266) and Fairbairn (1954, pp.10-12, and 166). In cases where the girdles are weak and the maxima strong the tectonite may be an S-tectonite rather than a B-tectonite. Deformation then may have been accomplished by slip on the ab, or foliation, plane. Schmidt believes that Maximum I is due to alignment of quartz c-axes parallel to the slip direction. Maximum III is due to the (1011) face lying in the ab plane, with [r:m] parallel to a. Sander, however, believes that Maximum III is due to the alignment of the quartz c-axes in the slip direction on intersecting (0kl) planes. A crossed strain develops in the later stages of deformation and a becomes a B-axis of intersecting planes.

The type of deformation which Sander, Schmidt, and others (see Fairbairn, 1954, p.123) visualize for oblique girdles is essentially a flattening type deformation in which forward movement along a is restricted by compression perpendicular to the ab plane.

(3) A quartz orientation diagram for specimen 1657 (figure
15b) shows a non-peripheral, or cleft girdle, around b (B). This corresponds to type "1" in figure 16. There is also a strong tendency for [0001] to concentrate subparallel to the a fabric axis and approximately in the position of maximum I of type "a" in figure 16. The cleft girdle may be due to gliding on rhombohedral or pyramidal planes parallel to (h0l) slip planes and rotation around b(=B). (See Turner, 1943, p.266).

(4) Quartz in specimen 1652 (figure 15c) has essentially the same type of orientation as that of specimen 1657, discussed above, but with the addition of maxima that approximate maximum IV of type "1" in figure 16. Maximum IV, which is characteristically present in orientation patterns that show a cleft girdle, may be present in any one, or all, of the positions indicated in figure 16 (Fairbairn, 1949, p.13). This maximum may appear when one plane of slip (ab) predominates and is due possibly to the orientation of the glide plane (1011) parallel to ab and the glide line r:z parallel to a.

This specimen also shows maxima that may possibly be correlated with maximum III. If that is the case, then the quartz orientation pattern exhibited by the specimen is transitional between the cleft girdle of specimen 1657 (figure 15b) and the inclined girdle of specimen 1667 (figure 15a).
Resume of the Microscopic Fabric

The hornblende and mica fabric diagrams show incomplete girdles about $b(=B)$. All the diagrams show a strong maximum perpendicular to the plane of foliation, but in addition, there are other maxima that define a statistical $s$-plane other than the foliation plane. These $s$-planes are ($h0l$) planes intersecting in $b(=B)$. The strongest of these $s$ planes ($S_2$ in the diagrams) is 20 to 30 degrees from $S_1$, the plane of foliation. A fabric of this type may developed by slip along the $ab$ plane without external rotation, and indeed, there is little evidence of external rotation in the outcrops from which the specimens used in constructing the mica diagrams were collected. However, an older generation of biotite occurring in a few widely spaced planes of schistosity in specimen 1657 is somewhat crinkled.

Of the five quartz orientation diagrams, the pattern in two (specimens 1667 and 1652, figures 15a and 15c) could be interpreted as being due to slip predominantly along the foliation plane, $ab$. The pattern of specimen 1657 (figure 15b) may be due to gliding on ($h0l$) planes and rotation about $b(=B)$. The other two diagrams (specimens 1671 and 1658, figures 14a and 14b) indicating that a crossed strain involving rotation about $b$ and $a$ was operative. Large quartz grains were used in constructing the latter fabric diagrams. As these larger grains are not as readily affected by metamorphism as the smaller grains the patterns
may be relict from an earlier metamorphism.

From the above data it can be concluded that slip parallel to a along the ab plane was an important factor in the development of the metamorphic fabric. Rotation, either of slip plane or of mineral grains, was important locally or at an earlier stage in the metamorphism.

It is probable that the fabric developed before contact metamorphism affected the rocks. If so, then the minerals recrystallized during metamorphism along directions of easy growth that were developed before the contact metamorphism. Their orientation in such a case would reflect the anisotropism imposed on the rocks by the stresses that were operative before the intrusion of the granitic rocks.
SUMMARY AND CONCLUSIONS

1. -- The metamorphic rocks consisted originally of sedimentary and volcanic rocks that were subjected to low rank regional metamorphism. During this period the rocks were folded about a northwest axis.

2. -- These rocks were then subjected to contact metamorphism of medium to high rank when they were intruded by granitic rocks during the Nevada orogeny.

3. -- During the contact metamorphism the minerals that recrystallized probably did so along directions of easy growth determined by the earlier dynamic metamorphism. As an alternative possibility, minerals such as quartz, which is affected readily by stress, may have developed their orientation as a result of weak directional stresses that may have been operative for some time after the period of contact metamorphism.

4. -- The orientation of the biotite and of the quartz of several specimens can be interpreted as being due to slip, predominantly along ab. The orientation of quartz in other specimens, however, must be attributed to rotation about b=A or to a crossed strain resulting in rotation of (h01) surfaces or mineral grains about both b and a axes.

5. -- After the imprinting of the metamorphic fabric, the rocks were arched or folded about a northeast axis and broken by northeast-trending step faults. Folding about the northeast-trending axis may only be apparent, however, as faulting and differential tilting of the fault blocks may simulate folding.
BIBLIOGRAPHY

Calkins, F. C., 19^1h, Outline of the geology of the Com- 
Rept., 35 p.


De Sitter, L. U., 1956, Structural geology: New York, 
McGraw-Hill Book Co.

Fairbairn, H. W., 1954, Structural petrology of deformed 
rocks: Cambridge, Mass., Addison-Wesley Publishing 
Company, Inc.

Gianella, V. P., 1936, Geology of the Silver City district 
and the southern portion of the Comstock lode, Nevada: 
Univ. of Nevada, unpublished thesis.

Godwin, L. H., 1930, Geology of the west side of Peavine 
Mountain, Washoe County, Nevada: Univ. of Nevada, 
unpublished thesis.

Goldschmidt, V. M. and Peters, C., 1932, Zur Geochemie des 
p. 403-407, 528-545.

Co., Inc.

Knopf, E. B. and Ingerson, E., 1938, Structural petrology: 
Geol. Soc. Amer. Mem. 6.

Lindgren, W., 1897, Geol. Atlas of the U.S., Truckee Folio, 
California: Folio 39.

McIntyre, D. B. and Christie, J. M., Nature of the faulting 
5, p. 545-562.

Reid, J. A., 1911, The geomorphogy of the Sierra Nevada 
northeast of Lake Tahoe: Calif. Univ. Publs., Dept. 

Taliaferro, N. L., 1942, Geologic history and correlation 
of the Jurassic of southwestern Oregon and California: 

Thompson, G. A., 1956, Geology of the Virginia City quad- 


