GEOLGY OF THE SOUTHERN PART OF THE SAND SPRINGS
RANGE, CHURCHILL COUNTY, NEVADA

By

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Figure 1. View of the east face of the southern part of the Sand Springs Range.

Figure 2. Southeastern contact between granitic rocks (light colored) and metamorphic rocks (dark bluish gray). Looking west.
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ABSTRACT

The southern part of the Sand Springs Range in Churchill County, Nevada, is underlain chiefly by metamorphosed Mesozoic (Triassic?) rocks of both sedimentary and volcanic origin and the southernmost portion of a late Cretaceous granitic pluton consisting of quartz monzonite and granodiorite. Petrographic study of the metamorphic rocks indicates two distinct types of metamorphism. During the Nevadan Orogeny in Middle Jurassic to Middle-Early Cretaceous time, the area was subjected to low-grade dynamothermal metamorphism. Later heat from the younger granitic pluton resulted in static thermal metamorphism of the rocks near the contact. In the 1,500 to 2,000 foot wide contact aureole the rocks are of hornblende hornfels to possible pyroxene hornfels facies. The anorthite content of plagioclase in the metamorphic rocks rises gradually toward the contact and greenish biotite changes to red biotite at the outer limit of the aureole.
INTRODUCTION

Location and Accessibility

The Sand Springs Range, a north-trending mountain range approximately 20 miles in length and 5 miles in width, is in Churchill County, Nevada, about 28 miles southeast of Fallon (Fig. 3). The range is separated from the Stillwater Range located to the north by a low pass crossed by Highway 50. To the south the range broadens and blends with adjacent ranges including the Cocoon Mountain to the west and the Fairview Peak-Slate Mountain ranges to the east. The Sand Springs Range is bordered on the east by Fairview Valley and on the northwest by Fourmile Flat. The area under investigation comprises approximately 25 square miles in the southern part of the Sand Springs Range (Fig. 3).

A paved road linking Nevada Scheelite Camp with Highway 50 runs along the east side of the Sand Springs Range. A dirt road, in places requiring a 4-wheel drive vehicle, passes along the west side of the range and connects Rawhide with Highway 50 (Fig. 3). From this dirt road it is possible to reach the range front by Jeep.

Scope and Method of Investigation

The purpose of this study has been to map the southern part of the Sand Springs Range to attempt a lithologic and structural
Figure 3. Location of the southern part of the Sand Springs Range.
division of the metamorphic rocks and to study the nature of the metamorphism.

Ten weeks during the summer of 1965 were spent in the field. The area was mapped on a scale of 1:31680 using the topographic base prepared by Mark Hurd Aerial Surveys, Inc., for the Nevada Bureau of Mines. In addition, aerial photographs of the same scale were used and data transferred to the base map.

Thirty-five specimens were collected from various rock types during general mapping. Later, 42 additional specimens were collected from the metamorphic rocks along three traverses (A, B, C in Plate 1). These traverses are oriented perpendicular to the contact of the "Sand Springs Range Pluton" with the metamorphic rocks. The contact is everywhere concordant with the foliation and bedding of the metamorphic rocks that are parallel, and the distance recorded for each specimen was, therefore, measured perpendicular to structural and compositional changes. Specimens were collected at 50-foot intervals for the first 500 feet and then at 500-foot intervals to a total distance of 2,000 feet from the contact. The dip of the foliation changes along these lines, and the stratigraphic distances between specimens are not known.

Thin sections were made from these specimens by Mr. J. Bartlett Murphy of the Mackay School of Mines. Thirty sections were stained for potassium feldspar by the author following the method described by Bailey and Stevens (1960). In addition, 6 thin sections of the granitic rock were lent by Professor M. J. Hibbard for study. Approximate modal analyses for mineral composition were done by visual
microscopic inspection. The a-normal method was used to determine plagioclase compositions, and the 4-axis universal stage was utilized for checking optic axial angles.

Previous Investigations

The Sand Springs Range was mapped on a reconnaissance scale by the personnel of the Nevada Bureau of Mines (1962). Because of the special purpose of their work, they restricted themselves primarily to the granitic body in the central part of the range and did not subdivide the various metamorphic rocks to the south.

Donald C. Ross (1961) made reconnaissance studies immediately south of the area in Mineral County. A Stanford University field geology class made a geologic map of the Sand Springs Range in 1946, 1947, and 1951, but no published map or report of that work is available. Ben M. Page (1965) published the geologic map of the Stillwater Range farther to the north.

Acknowledgments

Professor M. J. Hibbard of the Mackay School of Mines originally suggested this study. His help and guidance, both in the field and during the study of the thin sections, and many helpful discussions during the writing of the report are gratefully acknowledged. Professor D. B. Slemmons of the Mackay School of Mines and Dr. John Schilling of the Nevada Bureau of Mines spent one day in the field, for which the author is grateful. It was through Professor Slemmons that the
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Thanks are due to Mr. J. Bartlett Murphy of the Mackay School of Mines for making the thin sections.

Special thanks are due to Mr. and Mrs. Ed Wyher of the Frenchman Station; their kind hospitality made the field work much more interesting than usual.

A scholarship from the United States Agency for International Development financed all expenses for the author's course of study in the Mackay School of Mines, University of Nevada, and is duly acknowledged.
GEOLOGIC SETTING

The Sand Springs Range is in the western part of the Basin and Range province. This region was a part of the Cordilleran eugeosyncline which occupied the western margin of the continent and thus received a dominant amount of volcanic material all through its history. The volcanic rocks and volcanic-derived sedimentary rocks occur in every stratigraphic system from Upper Cambrian to Cretaceous (Eardly, 1962). During the Mesozoic era the region south of the Sand Springs Range in Hawthorne and Tonopah quadrangles sank more rapidly than adjoining areas, and a total of about 30,000 feet of sediments accumulated (Muller and Ferguson, 1936). These sediments, though largely marine clastics, chert, and limestone, are predominantly volcanic material in the lower and upper part of the section.

The Nevadan Orogeny of Late Jurassic time affected all previously deposited rocks in the region. As a result they were folded, thrusted, metamorphosed, and then intruded by large masses of granitic magma.

Tertiary volcanic rocks underlie a major part of the surrounding mountain ranges. Basin and Range block faulting in Tertiary time is largely responsible for the present physiographic characteristics. Late Tertiary sediments deposited in Lake Lahontan occur in the surrounding region. Recent earthquake activities in the region demonstrate continued tectonic activity.
GRANITIC ROCKS

Introduction

The central part of the Sand Springs Range is a granitic body, here termed the "Sand Springs Range Pluton." The pluton underlies the northernmost part of the mapped area. The granitic body is composed chiefly of porphyritic quartz monzonite and locally nonporphyritic granodiorite. Numerous aplite-pegmatite dikes intrude the granitic body and rarely the metamorphic unit. Many andesite and rhyolite dikes also intrude the granitic and metamorphic units and the aplite-pegmatite dikes.

The Pluton

The rock types in the Sand Springs Range pluton range from quartz monzonite to granodiorite. They were mapped together as a single unit (N. B. M., 1962). The quartz monzonite is largely porphyritic and is exposed over much of the area; the granodiorite variety is equigranular and predominates in the west central part of the pluton. Along the western escarpment of the range there is a mixed zone of both types. Average concentration of the phenocrysts of alkali feldspar is about 35 per cent, with local lower and higher variations. At numerous places in the quartz monzonite the phenocrysts are clustered and the rock could be classified as granite. The outcrops are typically
rounded, but in detail the surfaces are rough and the phenocrysts stand out in relief.

**Porphyritic Quartz Monzonite:**--The quartz monzonite is characterized by essentially nonaligned alkali feldspar phenocrysts in a medium- to coarse-grained groundmass of hypidiomorphic granular texture. The phenocrysts are up to 2 inches in length and on an average make up about 35 per cent of the rock. The groundmass consists of 35 to 40 per cent plagioclase, 20 to 25 per cent quartz, 5 to 10 per cent biotite, 3 to 5 per cent alkali feldspar, locally up to 1 per cent hornblende, and less than 1 per cent sphene, zircon, apatite, magnetite, and rutile.

The phenocrysts of alkali feldspar are megascopically well formed. In thin sections they are weakly perthitic and the average 2V measured in 4 thin sections is 66°. Carlsbad twinning is well developed, but cross-hatched microcline twinning is rare and very faint. The phenocrysts enclose small crystals of plagioclase, biotite, and sphene. Most of these enclosed plagioclase crystals are oriented with respect to the structure of the alkali feldspar host (Fig. 4). The alkali feldspar in the groundmass is anhedral and some grains have well-developed microcline twinning.

Plagioclase occurs in the groundmass and as inclusions in the alkali feldspar phenocrysts. The groundmass crystals are larger (up to 2.7 mm in long dimensions) and are mainly well-formed to subhedral, but some of the crystals have myrmekitic margins. The
included crystals are subhedral to subhedral. The plagioclase, whether as inclusions or in the groundmass, is normally crossed from calcic cores to sodic rims, and also variolitically zoning with a normal trend to locally present. The composition of the groundmass plagioclase as determined by a neutron method follows the 'low temperature' curves of Tobi (1958).

The composition of the groundmass plagioclase cores to alkali feldspar and alkali feldspar and plagioclase inclusions.

Most of the crystals are fine-grained and interstitial, while others are medium-grained. The groundmass is a transgranular, medium-grained, hedenbergite-transgairicite. The rock is hypidiomorphic granular and consists of 60 to 80 per cent plagioclase, 10 to 20 per cent quartz, 5 to 10 per cent hornblende, 5 to 10 per cent alkali feldspar, 0 to 1 per cent biotite, and a total of less than 1 per cent

Figure 4. Photomicrograph of a phenocryst of alkali feldspar in porphyritic quartz monzonite with oriented plagioclase inclusions.
included crystals are euhedral to subhedral. The plagioclase, whether as inclusions or in the groundmass, is normally zoned from calcic cores to sodic rims, and also oscillatory zoning with a normal trend is locally present. The composition of the groundmass plagioclase, as determined by a-normal method following the "low temperature" curves of Tobi (1963), varies from An$_{30}$ in the cores to An$_{13}$ in the rims. The composition of the included plagioclase varies from An$_{34}$ in the cores to An$_{16}$ in the rims. Partial sericitization of both groundmass and included plagioclase is common.

Quartz is anhedral. Some of the quartz grains are evenly distributed while others are grouped together in the groundmass. Most of the grains have wavy extinction. The biotite is pleochroic from greenish to pale brown and is mostly subhedral, but rare euhedral crystals are present. Near shear zones chlorite partly takes the place of biotite. The hornblende is subhedral and has $Z = \text{dark green}$, $Y = \text{light green}$, $X = \text{very pale green}$, and some crystals have biotite rims. The accessories are scattered throughout the rock; some are interstitial while others are included in essential and varietal minerals.

Granodiorite:--The granodiorite is a directionless, equigranular, medium-grained hornblende granodiorite. The rock is hypidiomorphic granular and consists of 60 to 80 per cent plagioclase, 5 to 10 per cent quartz, 5 to 10 per cent hornblende, 5 to 10 per cent alkali feldspar, 0 to 5 per cent biotite, and a total of less than 1 per cent
sphene, apatite, zircon tourmaline, and magnetite. In the plagioclase crystals normal zoning from calcic cores to sodic rims is common, and rarely oscillatory zoning with a normal trend is present. The composition of the plagioclase varies from An_{35} in the core to An_{12} in the rims.

**Contacts and Minor Structures:** The contact of the pluton with the metamorphic rocks is sharp and everywhere concordant with the foliation of these rocks. In certain areas along the contact partly discordant apophyses extend into the metamorphic rocks. Inclusions of metamorphic rocks up to 12 inches long are present in the granitic rocks only near the contact. Schlieren banding and related structures occur but are very uncommon.

**Origin:** It is accepted by most petrologists that well-developed oscillatory zoning and patchy zoning of plagioclase are indications of a magmatic origin of the rock (Vance, 1962). The significance of zonally arranged oriented plagioclase crystals has been discussed in detail by Hibbard (1965). The presence of these textures in the granitic rocks of the Sand Springs Range is clear indication that they are of truly magmatic origin.

**Age:** The quartz monzonite has both sharp and gradational contacts with the granodiorite. According to the Nevada Bureau of Mines (1962), potassium-argon age determinations on biotite from the quartz monzonite and granodiorite gave ages of 79.6 (± 2.0) and 76.0
(± 2.0) million years respectively. These factors strongly suggest that the two varieties probably are two phases of the same intrusive, emplaced at about the same time.

The Dike Rocks

Aplite-Pegmatite Dikes:—Numerous aplite-pegmatite dikes, ranging from less than 1 inch to more than 20 feet in width, intrude the granitic body. Aplite and pegmatitic material commonly occur in the same dike, and both usually have sharp contacts with the wall rock. In most cases the aplite forms the outer part; the pegmatite occurs as lenses, stringers, and continuous layers in the inner part. Some dikes grade into quartz veins along their strike. The aplite-pegmatite dikes commonly are more resistant to weathering than the enclosing rocks, and form bold wall-like outcrops.

The aplite consists of 30 to 40 per cent quartz, 20 to 30 per cent plagioclase (An10 to 15), 20 to 30 per cent alkali feldspar, 1 to 5 per cent muscovite, and less than 1 per cent biotite, epidote, chlorite, magnetite, and rutile.

The pegmatite consists of coarse pink alkali feldspar, white sodic plagioclase, gray quartz, and locally abundant coarse biotite flakes and some rutile and sphene.

The aplite-pegmatite dikes intrude the granitic body and the metamorphic rocks and in turn are intruded by the andesite and rhyolite dikes. The aplite-pegmatite dikes probably were formed during the
same period as the granitic body, reflecting late stage differentiation product. The porphyritic variety of rhyolite contains up to 30 per cent phenocrysts of quartz, feldspar, and albite in a groundmass of the same minerals plus 2 per cent biotite (N. B. M., 1962).

**Andesite Dikes:** A few andesite dikes intrude the granitic body, metamorphic rocks, and the aplite-pegmatite dikes. They are up to 25 feet wide and are dark green to black in color. Individual dikes are straight, long, and relatively even in width, and some are resistant to weathering.

The composition is hornblende-andesite containing 30 to 40 per cent plagioclase (An$_{35}$ to 40), 50 to 55 per cent hornblende, 2 to 5 per cent magnetite, 0 to 5 per cent biotite, 0 to 3 per cent quartz, and less than 1 per cent apatite. Propylitization is common in these rocks; the propylitic minerals include chlorite, epidote, calcite, and quartz.

In most cases the andesite dikes are cut by rhyolite dikes, but the reverse relation was seen in one place. Commonly faults that offset the andesite dike are cut without offset by the rhyolite dikes.

**Rhyolite Dikes:** Light-colored rhyolite dikes occur in the granitic body, metamorphic rocks, aplite-pegmatite dikes, and the andesite dikes. The dikes are white to buff, but commonly are stained brown or reddish brown. The dikes of this group range from rhyolite to dacite in composition, and are porphyritic, phaneritic, and/or aphanitic (N. B. M., 1962).

The aphanitic rhyolite is allotriomorphic-granular with poikilitic and cuneiform intergrowths of quartz and alkali feldspar;
METAMORPHIC ROCKS

Introduction

A northwest-trending belt of metamorphic rocks extends across the mapped area. The upper part of the unit is composed of a recrystallized calcite dolomite. The stratigraphy of the lower part of this unit is complex. Within an exposed thickness of approximately 5,000 feet, the rocks are so varied and heterogeneously distributed that their subdivision into mappable units is very difficult. The various rock types, in layers of tens of feet or less, do not continue along the strike. Usually, the lithologic changes are very rapid and the contacts between two different rock types are commonly gradational.

In the field the metamorphic rocks were divided into 4 groups for the purpose of mapping. They are the crystalline calcite dolomite, the predominantly metavolcanic rocks, the predominantly metasedimentary rocks, and amphibolite (Plate 1).

Structurally the calcite dolomite group forms the upper part of the succession. The predominantly metavolcanic unit forms a middle unit, and the predominantly metasedimentary unit forms the lower part. The amphibolites occur in the eastern part of the area and transect both the metavolcanic and metasedimentary units.

Heterogeneity of all these rocks poses a problem in describing them in detail. For the sake of clarity in presentation they are grouped petrographically according to mineral assemblages (but these are not necessarily rock assemblages) and related textures that probably correspond to premetamorphic rock types (Table 1).
grouped petrographically according to mineral assemblages (but these are not necessarily stable assemblages) and relict textures that probably correspond to premetamorphic rock types (Table 1).

Most of the metamorphic rocks are foliated; this structure is parallel to bedding which is now expressed by the compositional variation of the original rock type.

Correlation and Age

The age of these rocks is uncertain. No fossils were found within the mapped area. Ross (1961) described lithologically similar rocks in the vicinity of Rawhide, immediately south of the area under investigation, and correlates them with the "Excelsior Formation" of the upper plate of the Gillis thrust in the Gillis Range. Silberling and Roberts (1962) separated the "Excelsior Formation" in the upper plate of the Gillis thrust and included it in the Gillis Sequence. On the basis of lithologic similarity, the metamorphic rocks in the mapped area are tentatively assigned to the Gillis Sequence. The age of the Gillis Sequence is Middle to Upper Triassic (Silberling and Roberts, 1962).

Description of the Metamorphic Rocks

Calcitic Dolomite:—The main calcitic dolomite unit is a light-gray to blue-gray, fine- to medium-grained rock. It is thickly bedded and contains thin (2 to 4 inches) chert layers. Faulting and coverings of volcanic rock and alluvium prevent estimation of the
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<td>1. Dolomite-Calcite (with Tremolite)</td>
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</tr>
<tr>
<td>2. Quartz-Muscovite-Albite-Chlorite-Biotite</td>
<td>Shale or Silty Shale</td>
</tr>
<tr>
<td>3. Quartz-Plagioclase-Andalusite-Muscovite-Biotite</td>
<td>Shale or Silty Shale</td>
</tr>
<tr>
<td>4. Quartz-Muscovite-Andalusite-Albite-Biotite-Chloritoid-Garnet</td>
<td>Shale or Silty Shale</td>
</tr>
<tr>
<td>5. Quartz-Biotite-Muscovite</td>
<td>Siltstone or Fine-grained Sandstone</td>
</tr>
<tr>
<td>6. Quartz-Biotite-Plagioclase-Hornblende</td>
<td>Tuffaceous Sandstone or Dolomitic and Argillaceous Sandstone</td>
</tr>
<tr>
<td>7. Quartz-Plagioclase-Biotite-Muscovite-Chlorite-Calcite</td>
<td>Felsic Volcanic Rock</td>
</tr>
<tr>
<td>8. Quartz-Plagioclase-Biotite-Hornblende</td>
<td>Felsic to Intermediate Volcanic Rock</td>
</tr>
<tr>
<td>10. Actinolite-Hornblende-Pyroxene-Plagioclase-Quartz</td>
<td>Mafic Volcanic Rock or Volcanic-derived Sedimentary Rock</td>
</tr>
<tr>
<td>11. Quartz-Plagioclase-Biotite-Muscovite-Calcite</td>
<td>Clastic Volcanic Sedimentary Rock</td>
</tr>
</tbody>
</table>
total thickness. Limonitic stains in fault contacts and thin veins of quartz and calcite are common.

In addition, calcitic dolomite occurs as thin layers and lenses within the predominantly metasedimentary unit. Wherever possible these carbonate lenses were mapped separately (Plate 1).

Two specimens, one from the main calcitic dolomite unit and one from near the contact at locality B (Plate 1), were analyzed by Differential Thermal Analysis method. Assuming all MgCO₃ present is in dolomite, the results show that 80 to 85 per cent of the carbonate present is dolomite and the rest, 15 to 20 per cent, is calcite. The rock can properly be named as calcitic dolomite (Pettijohn, 1957, p. 417).

In the main calcitic unit the rock consists of a mosaic of dolomite and calcite with minor amounts of quartz and sericite and rare epidote. In specimens from near the contact, tremolite is present, developed in radial, brush-like aggregates.

Quartz-Muscovite-Albite-Chlorite-Biotite Phyllitic Schist:—

This rock type is common in the predominantly metasedimentary unit. The rock is dark gray to blue-gray, very fine grained and foliated. Silty to sandy variations are present, but such types retain the blue-gray color and fissility.

The mineral percentages vary considerably from specimen to specimen, but the over-all mineral assemblage remains essentially constant. The rock consists of 50 to 60 per cent muscovite, 25 to
50 per cent quartz, 5 to 8 per cent albite, 0 to 10 per cent biotite, 4 to 8 per cent chlorite, 2 to 10 per cent graphite, 1 to 4 per cent iron oxide, and trace amounts of epidote, tourmaline, and calcite.

Muscovite is the major constituent of the rock and occurs in minute flakes (sericite) parallel to the foliation. Quartz and plagioclase occur in very fine, somewhat elongate grains, lying in the foliation. Plagioclase is untwinned and unzoned, and the anorthite content varies from 6 to 8 per cent.

Biotite percentage in these rocks decreases away from the contact of the Sand Springs Range pluton. Nearer to the contact it is pleochroic from red to yellow and occurs both as minute flakes parallel to the foliation and also as larger flakes up to 0.5 mm lying across the foliation. Away from the contact it is pleochroic from green to pale yellow and lies only parallel to the foliation. Epidote lies across the foliation and is anhedral. Small grains of calcite occur in some of the specimens.

The foliation is strong and is related to the orientation and distribution of muscovite, chlorite, and graphite, and in all cases it is parallel to the original bedding.

Quartz-Plagioclase-Andalusite-Muscovite-Biotite Schist:--This schist is the most common rock type in the predominantly metasedimentary unit. The rock is dark gray, with well-developed schistosity, and contains porphyroblasts of andalusite which characterize the rock as a spotted schist.
The percentages of individual minerals vary considerably in specimens from different layers and lenses, but the over-all mineral assemblage remains essentially constant. The main variations are in the muscovite/biotite ratio; wherever the biotite percentage increases the muscovite percentage decreases and vice versa. The percentage of andalusite is highly variable as is the anorthite content of the plagioclase.

The rock consists of 15 to 30 per cent andalusite (mostly chiastolite), 5 to 25 per cent biotite, 5 to 35 per cent muscovite, 20 to 30 per cent quartz, 10 to 25 per cent plagioclase, and from trace amounts to 3 per cent each of chlorite, epidote, and tourmaline (Fig. 5). Only one specimen has traces of alkali feldspar.

Andalusite (chiastolite) occurs as porphyroblasts up to 3 mm in cross section and up to 7 mm in length. Many crystals are unaltered; others are partly or completely replaced by sericite, biotite, and/or quartz. Both pleochroic and nonpleochroic varieties are present.

Biotite, pleochroic from straw yellow to red-brown, is ubiquitous. Most of the flakes are less than 0.1 mm in length and lie parallel to the schistosity. An average of about 10 per cent of the biotite is in larger flakes up to 0.5 mm in length lying across the foliation and also rarely replacing the porphyroblasts of andalusite.

Muscovite occurs (1) as minute flakes (sericite) parallel to the foliation, (2) as sericite aggregates replacing the andalusite porphyroblasts, and (3) in larger flakes of up to 0.7 mm in length.
Figure 5. Photomicrograph of quartz-plagioclase-andalusite-
muscovite-biotite schist.

Figure 6. Photomicrograph showing how the micas defining
foliation are "deflected" around the andalusite
porphyroblasts.
lying across the foliation. Percentages of muscovite in this rock type decrease near the contact of the pluton.

The size of the quartz grains ranges from 0.02 to 0.2 mm and varies according to the distance from the contact of the pluton. Nearer the contact they occur in mosaic of the larger grains, but away from the contact the grains are smaller and are partly stretched along the foliation. Quartz-rich layers of up to 0.5 mm in thickness and microscopic quartz veins are common.

Plagioclase occurs in the groundmass with quartz. The crystals are untwinned and unzoned. At the contact the specimens have anorthite content of up to 40 per cent, and away from the contact this gradually decreases to 8 per cent. Most of the plagioclase has a clouded appearance distinct from the turbidity shown by feldspar affected by weathering or hydrothermal alteration.

Epidote (pistacite) occurs in most of the specimens. Chlorite occurs both in small flakes parallel to the schistosity and also as larger crystals lying across the foliation with included S. The chlorite is slightly pleochroic from colorless to yellowish green and has anomalous blue birefringence. Small grains of tourmaline up to 0.2 mm in length are present in all the specimens.

The foliation of the rock parallels the original bedding. This foliation is "interrupted" by the growth of the andalusite porphyroblasts in that the micas defining the foliation are "deflected" around those crystals (Fig. 6).
Quartz-Muscovite-Andalusite-Albite-Biotite-Chloritoid-Garnet Schist:--This is a minor rock type exposed in the northwestern part of the area. Rocks containing this mineral assemblage were encountered along the traverse in locality A (Plate 1). This is a dark gray, fine-grained schist with andalusite porphyroblasts.

The rock consists of 40 to 50 per cent muscovite, 25 per cent quartz, 20 per cent albite, 5 per cent biotite, 10 per cent andalusite (mostly occurring as pseudomorphs), 2 per cent chloritoid, 5 per cent opaque minerals (mainly graphite), and a total of less than 2 per cent epidote, tourmaline, and garnet.

Highly altered porphyroblasts of andalusite up to 4 mm in cross section and 1.5 cm in length characterize the rock as a spotted schist. They are mostly altered to sericite, but uncommonly biotite and quartz are also found in the altered aggregates. In some cases the dark cross inherited from the chiastolite is still present.

Muscovite occurs as small flakes parallel to the foliation, commonly concentrated in layers up to 1 mm thick. It also occurs as aggregates replacing the porphyroblasts of andalusite. Biotite occurs in two ways: a very minor amount of it in small flakes parallel to foliation, and the remainder occurs as large flakes of up to 0.7 mm in length in randomly oriented aggregates. It is pleochroic from green to light yellow. Quartz occurs as small anhedral grains of 0.02 to 0.08 mm, and mostly the grains are elongated along the foliation. Plagioclase is unzoned and untwinned and has a grain size similar to that of quartz. The composition is An₉. 
Chloritoid occurs in large flakes of up to 0.9 mm in length lying across the foliation with included S. Polysynthetic twinning is very common. It is pleochroic from green to colorless and has an anomalous birefringence. Clear rounded crystals of garnet occur rarely. The crystals are fractured and are pale brown. Epidote (pistacite) in small anhedral crystals is distributed evenly. Small grains of tourmaline up to 0.2 mm in length are present in all specimens.

The rock is foliated and this foliation is "disrupted" by the growth of andalusite porphyroblasts. Most of the biotite and all the chloritoid and tourmaline crystals lie across the foliation.

**Quartz-Biotite-Muscovite Schistose Quartzite:**—The quartzose rocks are light gray and somewhat foliated. In outcrop the foliation is not apparent, but a close inspection reveals a foliation parallel to the bedding. This is a prominent rock type in the metasedimentary unit.

The rock is composed of 80 to 85 per cent quartz, 8 to 15 per cent biotite, 5 to 10 per cent muscovite, and trace amounts of plagioclase, tourmaline, and chlorite. Rarely zircon and calcite also occur.

Quartz occurs in semipolygonal mosaics; individual grains vary in size from 0.01 to 0.2 mm. Microlaminations, about a millimeter thick, are composed of pure quartz alternating with the mica-rich layers. Microscopic quartz veins are common with their thickness ranging from 0.2 to a few millimeters with grains up to 1.2 mm. The veins are both parallel and across the foliation.
Muscovite occurs (1) as minute flakes (sericite) that are oriented to form the foliation, and (2) in larger flakes of up to 1.7 mm in length lying across the foliation. The larger flakes have a sieve texture with inclusions of quartz. The amount of muscovite decreases toward the contact of the pluton.

Biotite is pleochroic from red to light yellow and the grain size ranges from 0.2 to 0.8 mm. The percentage of biotite decreases away from the contact of the pluton. At some places it lies parallel to the schistosity, particularly when muscovite is at a minimum, but generally it is aggregated into layers parallel to the schistosity within which the flakes are not well oriented.

Plagioclase occurrence is similar to quartz. The crystals are untwinned and unzoned, and the anorthite content varies from 4 to 12 per cent in different specimens.

Quartz-Biotite-Plagioclase-Hornblende Rock:—This is a very minor rock type and was encountered along the traverse at locality B. The rock is a fine-grained, light-colored quartzose rock with a minor amount of hornblende.

The rocks consist of 75 to 80 per cent quartz, 8 to 12 per cent biotite, 3 to 5 per cent hornblende, plagioclase (per cent ?), and trace amounts of chlorite, calcite, and sphene.

Quartz occurs in a mosaic of fine grains ranging in size from 0.02 to 0.1 mm. Plagioclase is untwinned, and the fineness of the grains and commonly diffused nature of the grain boundaries make it
extremely difficult to identify, so that its quantity and composition
could not be determined. Red-brown biotite is ubiquitous, occurring
in flakes ranging from 0.03 to 0.1 mm in length; the crystals are
subparallel to the foliation. Hornblende occurs in grains of 0.05 to
0.1 mm, but rare porphyroblasts are also present. It is strongly
pleochroic with Z = dark green (i.e., hornblende) but also Z = yellow
green probably representing an actinolitic hornblende. Both biotite
and hornblende are locally partly altered to chlorite.

The rock has a very fine-grained granoblastic texture with a
faint foliation related to biotite and hornblende.

Quartz-Plagioclase-Biotite-Muscovite-Chlorite-Calcite

Metavolcanic Rock: -- This is a minor rock type within the metavolcanic
unit. The rock is light gray, massive, and occurs in beds up to 30
feet thick. The rock has a relict porphyritic texture with phenocrysts
of plagioclase and quartz in a fine-grained matrix.

The rock consists of 40 to 45 per cent plagioclase, 30 to 35
per cent quartz, 10 to 15 per cent biotite, 3 to 5 per cent muscovite,
and up to 3 per cent of each of calcite and chlorite. Trace amounts of
sphene and apatite are also present.

Relict phenocrysts of plagioclase occur as ragged crystals.
They are much replaced by sericite and a brownish isotropic mineral.
Not uncommonly only the relict outline of the phenocrysts is present.
The grains are elongate, as much as 1 mm long; anorthite contents is
about 8 to 10 per cent, and the crystals are unzoned but twinning is
common. The groundmass plagioclase is very minute, subhedral, and untwinned.

Quartz occurs in a very fine-grained semipolygonal mosaic in the groundmass and also as clear, large crystals of up to 2 mm in diameter. They contain numerous inclusions of opaque minerals. These large crystals are probably relict phenocrysts, completely recrystallized and coalesced into even larger grains (Fig. 7).

The biotite is red and a major part of it is distributed evenly, but some aggregates are also present. Muscovite occurs in larger flakes than biotite and the crystals are mostly clustered. Calcite is associated with plagioclase; in rare cases calcite occurs within the plagioclase parallel to the twin plane of the host. Chlorite occurs in the groundmass and also rarely as larger flakes.

Quartz-Plagioclase-Biotite-Hornblende Metavolcanic Rock:--This is a common rock type in the predominantly metavolcanic unit. The rock has a granoblastic texture and contains relics of plagioclase phenocrysts.

The rock contains 40 to 45 per cent plagioclase (largely seri­citized), 30 to 35 per cent quartz, 10 to 15 per cent biotite, 3 to 5 per cent hornblende, and up to 2 per cent calcite, chlorite, and epidote. Opaque minerals, apatite, and sphene are constant accessories.

The relict phenocrysts of plagioclase are considerably seri­citized and not uncommonly only the relict outline of the phenocrysts remains. The grains are elongate and the maximum length is 1.5 mm. Twinning is common, and the crystals are not zoned. Anorthite content
Figure 7. Photomicrograph showing the relict phenocrysts of quartz and plagioclase in a groundmass of biotite, muscovite, calcite, and chlorite.
varies widely ranging from $\text{An}_7$ to $\text{An}_{26}$ in different specimens. The groundmass plagioclase is fine grained, diameters averaging about 0.03 mm. They contain inclusions of opaque minerals. Biotite occurs as small flakes, generally evenly distributed but some aggregates are present. The color of the biotite changes from green far away from the granitic pluton to red nearer the contact, but nowhere do both types occur together. Muscovite occurs as sericite and rarely as crystals larger than biotite. Hornblende is well formed with $Z = \text{Z/\lambda}$ varying from dark green to yellow green, the latter perhaps representing an actinolitic hornblende. Alteration of hornblende to chlorite is not uncommon. Epidote is scarce, but calcite is present in all specimens.

**Actinolite-Hornblende-Plagioclase-Biotite-Quartz-Chlorite-Garnet Amphibolite:** The amphibolites were mapped as a separate unit in the eastern part of the area (Plate 1), but there are also amphibolite layers in the predominantly metavolcanic unit. These are greenish black, very fine-grained foliated rocks.

The rock is mainly composed of actinolite and plagioclase. It consists of 65 to 70 per cent actinolite, 20 to 25 per cent plagioclase, 5 to 10 per cent biotite, up to 5 per cent quartz, and trace amounts of chlorite, garnet, epidote, apatite, sphene, opaques, and calcite.

Acicular amphibole is the most widespread metamorphic mineral and is probably actinolitic hornblende in almost all cases, though $Z/\lambda$ is as high as $18^\circ$ in some specimens. The color in $Z$ is evenly pale
green to blue green. The alignment of the actinolite is fair to very weak. Nearer the contact randomly oriented hornblende is common. They are pleochroic from Z = green to pale yellow green.

Plagioclase crystals occur in the groundmass and are generally untwinned and unzoned but rare twinned crystals are also found. In one specimen twinned crystals of up to 0.5 mm are present which may be relict phenocrysts. Composition of the plagioclase varies widely depending on the distance from the contact of the pluton. The anorthite content is An₉ out of the aureole and progressively increases up to An₃₃ at the contact.

Greenish biotite changes to red biotite as the contact is approached. Fine-grained garnet occurs rarely, and chlorite is present in every specimen. Quartz occurs in fine grains in the groundmass.

**Actinolite-Hornblende-Pyroxene-Plagioclase-Quartz Metavolcanic Rocks:** The pyroxene-bearing rocks are divisible into two types, both occurring within 300 feet from the contact.

The first type consists of 65 to 70 per cent actinolitic-hornblende, with 30 to 35 per cent plagioclase and minor amounts of quartz, biotite, and diopsidic hedenbergite and rare sphenes and apatite. These rocks are weakly foliated with part of the actinolite oriented. Diopsidic hedenbergite in grains from 0.1 to 0.4 mm in size are evenly distributed. Anorthite content of the plagioclase varies from An₂₉ to An₃₉ in different specimens.
The second type consists of 30 to 35 per cent actinolitic-hornblende, 30 to 35 per cent quartz, 20 to 25 per cent plagioclase, 10 to 15 per cent biotite, 2 to 3 per cent diopsidic hedenbergite, and trace amounts of calcite and opaque minerals. They have a granoblastic texture, the other minerals being randomly distributed in a mosaic of quartz and plagioclase. Composition of the plagioclase ranges from An$_{26}$ to An$_{35}$.

Quartz-Plagioclase-Biotite-Muscovite-Calcite Metatuff:—These are light to dark gray, and blue-gray subschistose rocks. They occur throughout the metavolcanic unit in layers of up to 30 feet and constitute approximately 30 per cent of that unit. Primary structural features were not found, and secondary structural characters include a moderate schistosity related to orientation of muscovite (sericite) and chlorite flakes.

The rock is chiefly made up of angular to subangular large grains of quartz and plagioclase in a fine-grained matrix of sericite, chlorite, and calcite. Biotite occurs in about half the specimens.

Quartz occurs as large grains up to 2 mm in diameter. The crystals are generally clear and perhaps most of them have recrystallized. Percentage of quartz ranges from 40 to 60 in different specimens.

Plagioclase occurs as large original grains and in some cases embayed tabular porphyroblasts of up to 2 mm long. Minute inclusions of isotropic minerals and sericite give a faint brownish color to the grains. Anorthite content varies from 6 to 10 per cent in different specimens. The mineral constitutes about 25 to 35 per cent of the rock.
Biotite occurs in about half the specimens examined. It is in flakes of up to 0.3 mm long distributed evenly but without orientation. Chlorite occurs as pale green fibrous shreds and as minute crystalloblasts oriented to give a faint schistosity. It constitutes up to 30 per cent in some specimens. Calcite occurs both as idioblastic grains and also in the groundmass and makes up to 10 per cent of the rock. Minute rods and needles of pale green actinolite were observed in some of the specimens where they constitute up to 2 per cent of the rock.

The remainder of the rock is an aphanitic pseudoisotropic mass of unidentifiable nature. This matrix is probably a chlorite-albite-actinolite intergrowth.

Probable Premetamorphic Rock Types

The probable original rock types corresponding to the metamorphic assemblages just described are shown in Table 1. The carbonate rocks are the result of metamorphism of calcitic dolomite. The rocks rich in Al-bearing minerals, i.e., the assemblages (1) quartz-muscovite-albite-chlorite-biotite, (2) quartz-plagioclase-andalusite-muscovite-biotite, and (3) quartz-muscovite-andalusite-albite-chloritoid-garnet, are metapelitic rocks (shales) and probably had essentially one source and were deposited under similar conditions. The special chemical conditions of the chloritoid-bearing schists will be discussed later. The original nature of the clays and the carbonates cannot be determined because all the fine-grained rocks have progressed at least to the stage of phyllites; however, the abundance of fine-grained chlorite
and muscovite suggests that the original clays were mixtures of iron-bearing montmorillonite and kaolin (or illite) or mafic volcanic glass and kaolin (Compton, 1960).

Before metamorphism the quartzitic rocks (quartz-biotite-muscovite assemblage) probably were coarse siltstones and fine-grained sandstones mainly of a quartz wacke type. The quartzitic rock with hornblende in it may be interpreted as tuffaceous sediment or slightly dolomitic quartzose sediments (Woodland, 1965).

On the basis of relict texture and present mineral composition, the assemblages quartz-plagioclase-biotite-muscovite-chlorite-calcite, quartz-plagioclase-biotite-hornblende, actinolite-hornblende-plagioclase-biotite-chlorite-garnet, and actinolite-hornblende-pyroxene-plagioclase-quartz are interpreted as metamorphosed volcanic rocks. The assemblage quartz-plagioclase-biotite-muscovite-chlorite-calcite is representative of a felsic volcanic rock, probably rhyodacite, dacite, or rhyolite. The assemblage quartz-plagioclase-biotite-hornblende is suggestive of an intermediate to felsic volcanic rock. The actinolite and hornblende-bearing rocks are metamorphosed mafic volcanic rocks which originally were probably basalts or hornblende andesites.

Whether all the metavolcanic rocks are flows or shallow intrusives could not be established.

The metatuffs seem to have originated from first cycle volcanic sediments. The angularity of the grains and the over-all texture are indicative of a nearby source.
METAMORPHISM

General Statement

The metamorphic rocks of the southern part of the Sand Springs Range are the result of a complex metamorphic history. There is evidence for two distinct types of metamorphism. The texture and mineralogical composition indicate that the rocks first underwent regional dynamothermal metamorphism and later static thermal metamorphism related to the emplacement of the Sand Springs Range pluton, followed by some retrograde alteration. The rocks of pelitic origin record these two events particularly well as these rocks have well-developed schistosity, interpreted as dynamothermal in origin, in which porphyroblasts of andalusite have grown in response to the thermal metamorphism alone.

The dynamothermal metamorphism cannot be dated even approximately in the area under investigation, but stratigraphic evidence from the nearby areas in Nevada indicates only that it might have started in the Late Jurassic (Ferguson and Muller, 1943) and that it was completed by Middle-Early Cretaceous (Wilden, 1958). As mentioned earlier, the age of the granitic rocks is between 74 and 81 million years, which is very late Cretaceous. Whether the two types of metamorphism are the result of different phases of one orogenic event or are polycyclic is difficult to establish.
Regional Dynamothermal Metamorphism

The metamorphic minerals that formed or recrystallized during this period of metamorphism are quartz, biotite, albite, muscovite, chlorite, epidote, actinolitic-hornblende, calcite, and dolomite.

The survival of certain volcanic textures and structures, and the mineral assemblages, indicate low-grade metamorphism. The conditions of the quartz-albite-epidote-biotite subfacies of the greenschist facies (according to the classification of Fyfe, Turner, and Verhoogen, 1958) are indicated by the mineral assemblages of the metapelitic and metabasaltic rocks. However, the occurrence of plagioclase as calcic as An$_{25}$ and the scarcity of chlorite in some of the specimens outside the contact aureole suggest that the conditions of this subfacies have been exceeded, and that of quartz-albite-epidote-almandine subfacies of the greenschist facies and even the beginning of almandine-amphibole facies might have been reached at least locally. Coexistence of an intermediate plagioclase with epidote is not unusual though it may indicate high load pressure, perhaps augmented by stress (Turner and Verhoogen, 1960, p. 546).

The mineral assemblages developed at the boundary between greenschist and amphibole facies are hardly affected by a variation of pressure and are realized at temperatures of 540° C. to 560° C. with pressures ($P_{H_2O}$ = total pressure) of 2,000 to 8,000 bars (Winkler, 1965, p. 25). From the available mineralogical data it is suggested that the physical conditions of dynamothermal metamorphism in the Sand
Springs Range area reached nearly the same levels of temperature and pressure as suggested above.

Contact Metamorphism

There is clearly a change of mineral parageneses between the regional metamorphic terrane and the contact aureole of the Sand Springs Range pluton. In the rocks of metapelitic origin the key minerals are andalusite, biotite, chloritoid, and plagioclase, and in the rocks of mafic volcanic origin the key minerals are plagioclase, epidote, and hornblende.

In addition to these index minerals, the appearance of red biotite and the clouding of plagioclase feldspars are suggestive and have been used by some workers to delimit contact aureoles. Reddish biotite as an indicator of contact metamorphism was first mentioned by Gilluly (1936), but it was not generally accepted. Engel and Engel (1953) made a detailed chemical study of the reddish biotite and the greenish biotite, and their conclusion is that a mutual reaction of granitic components with greenish biotites was instrumental in the evolution of the reddish biotites. Their observations are consistent with the present data, because reddish biotite was not found outside the aureole in the rocks of the mapped area.

In some rocks the plagioclase feldspars have a clouded appearance which is distinct from the turbidity shown by plagioclase affected by weathering or hydrothermal alteration. The clouding of plagioclase has been attributed to thermal metamorphism (Poldervaart
and Gilkey, 1954), and clouded plagioclase commonly was observed in rocks within the aureole of the area under investigation.

The width of the aureole is variable, ranging from 1,500 to 2,000 feet. The outer limit of the contact is marked by the appearance of andalusite and red biotite in the metapelitic rocks and the appearance of porphyroblastic biotite and hornblende in the metavolcanic rocks.

There are not enough critical index minerals to subdivide the contact aureole into an outer and an inner zone. Considering only the metapelitic rocks it is possible, if we assume red biotite with albite without andalusite to delimit an outer zone and andalusite, red biotite, and plagioclase (An > 10) to indicate an inner zone (Figs. 8a and 8b).

**Evolution of the Critical Mineral Assemblages during the Contact Metamorphism:**

(1) Andalusite-Biotite Rocks:—Andalusite rocks without cordierite are the most important assemblage in the metapelitic rocks of the contact aureole. Many specimens of this paragenesis have ovoid aggregates of red biotite (in part with muscovite and chlorite) that once might have been cordierite. None of these rocks, however, contain any trace of cordierite, and in view of the fact that unaltered andalusite and biotite are common, it appears that the assemblage andalusite-biotite-muscovite was widely stable, whether cordierite was once present or not. No alkali feldspar was found in these rocks though plagioclase as calcic as andesine is present.

The general reaction giving rise to andalusite and biotite will be:
Figure 8a. Diagrammatic sketch map, showing the subdivision of the contact aureole into an outer and an inner zone.
Figure 8b. Variation of anorthite in plagioclase with respect to distance from the contact of the Sand Springs Range Pluton.

P = Metapelitic Rocks, M = Metamorphosed mafic volcanic rocks, F = Metamorphosed felsic to intermediate volcanic rocks.
Judging from the abundance of andalusite and biotite with no cordierite, it seems possible that if there were any cordierite formed, it reacted with muscovite to form biotite and presumably some potential alkali feldspar has gone into the plagioclase and the following reaction might have taken place:

\[
\text{muscovite + chlorite} \rightarrow \text{andalusite + biotite + quartz + H}_2\text{O}
\]

(2) Andalusite-Biotite-Chloritoid-Garnet Rocks:—This is a very minor rock type in the area under investigation, but according to Professor Slemmons (personal communication), chloritoid rocks are not uncommon in this part of Nevada. Chloritoid forms in rocks of a restricted chemical composition; this mineral is produced in rocks with an abundance of alumina, and a sufficiency of iron oxide, but relatively poor in magnesia, lime, and potash (Halferdahl, 1961). In such environment this mineral forms at an early stage of metamorphism and persists through a wide range of temperatures. The idea of chloritoid as only a stress mineral (Harker, 1932) has been discarded by later workers. In the Sand Springs Range aureole, the occurrence of chloritoid porphyroblasts lying across the foliation and its association with andalusite support the view that chloritoid can develop by contact metamorphism if the chemical conditions are satisfied. The assemblage chloritoid-biotite is uncommon in low-grade rocks; even in higher grade rocks where biotite is present with chloritoid, biotite is probably formed by reactions which do not involve chloritoid, such as:

\[
\text{cordierite + muscovite} \rightarrow \text{biotite + andalusite + quartz}
\]
muscovite + chlorite → biotite + andalusite (or cordierite) + H₂O

(Halferdahl, 1961)

Almandine garnet will form in a similar manner if the reacting chlorite is not too high in iron by the reactions:

iron chlorite + quartz → almandine

chlorite + muscovite + quartz → almandine + biotite + andalusite + H₂O

(Halferdahl, 1961)

It is suggested that the assemblage chloritoid-biotite-garnet in the Sand Springs Range area has formed in the above manner.

(3) Tremolite-Dolomite-Calcite:—It has been observed that tremolite occurs in the calcitic dolomite lenses within the aureole. According to Winkler (1965), the conditions for the development of this assemblage from an impure calcitic dolomite are that the pore fluids must be relatively poor in water and have a high CO₂ pressure. Under these conditions this assemblage will develop by the reaction:

dolomite + quartz + H₂O → tremolite + calcite + CO₂

The same paragenesis will develop if a calcite-bearing siliceous dolomite is metamorphosed, because calcite reacts neither with quartz nor with tremolite at low temperatures.

Late Metasomatism:—Metasomatism during the late stage of crystallization of the granitic magma produced locally intense changes
in the aureole. It is important to note that in the aureole under investigation these effects are superimposed on rocks that had already reached an advanced stage of contact metamorphism, as though the fluids moved into the aureole very late in the crystallization of the magma.

There is clear evidence of late potash metasomatism, which is demonstrated by large muscovite plates and extensive muscovitization of the andalusite porphyroblasts. The presence of abundant biotite in the amphibolite near the contact may be due, too, to potash metasomatism (Compton, 1955, p. 40; Woodland, 1965, p. 143). Muscovitization of the aluminum silicates is a common phenomenon, caused by the action of potash-bearing solutions, and in this area the source of the potash-bearing solutions could have been the residual fluids of the adjacent granitic rocks. In addition, during the cooling of the rocks some amount of retrograde effect took place as evidenced by the alteration of biotite and hornblende to chlorite.

**Nature of the Contact Metamorphism:** The location of the contact aureole indicates that it was formed by recrystallization of the rocks of the regionally metamorphosed terrane under the influence of heat supplied by the Sand Springs Range pluton. The final stage of metasomatism was clearly produced by the movement of water from the magma. If the granitic magma was originally water poor, some of this magmatic water was presumably metamorphic water that was cycled from country rocks to the magma and back to country rock again; in fact, according to Compton (1960), little magmatic water is needed to produce the
retrograde effect that was observed. The $K_2O$ that was added to the aureole during the late stage of metamorphism might also have come originally from pelitic rocks that had been assimilated by the magma (Compton, 1960).

In the area under consideration, the granitic magma intruded already metamorphosed rocks, which probably contained a good amount of combined water but very little pore water. In such circumstances recrystallization begins when temperatures are reached that will cause reactions, to which dissociation of the combined water has an important catalytic effect. The fabric of the metamorphic rocks is tight, unlike sedimentary rocks, and the dehydration water formed during the contact metamorphism cannot easily flow away. This must have some restraining effect on reactions involving the growth of nonhydrous porphyroblasts such as andalusite.

Grade of Contact Metamorphism:—The stability of the assemblage andalusite-biotite-plagioclase-quartz shows that in general the grade of contact metamorphism in the aureole was of the hornblende hornfels facies. In the outer part of the aureole where red biotite appears but no andalusite is found the conditions were probably of those of albite-epidote hornfels facies which is represented in the amphibolites by the assemblage albite-epidote-biotite-chlorite-quartz. The abrupt rise in the anorthite content of the plagioclase near the contact might be due to higher temperature where the condition of pyroxene hornfels
facies might have been reached. In such a case the temperature gradient across the contact must have been steep.

Recent data show that andalusite is the stable phase between 450° C. and 650° C. at water pressures between 1,000 and 3,000 bars (Roy, 1954). It seems that the temperature attained in the aureole of the Sand Springs Range pluton was generally within this range though it might have been exceeded at the contact. In the outer border of the aureole the temperature was lower than this limit. Figure 9 shows the probable temperature gradient in the contact aureole.

![Figure 9. Schematic representation of possible pressure-temperature fields of metamorphic facies and of granitic country. Curves: hypothetical, and possible P-T conditions in the southern part of the Sand Springs Range.](image-url)

- *facies, HH = albite-anchore hornfels, GS = granitic facies, GCr = granopyroxene-chlorite facies, HT = hornblendite hornfels facies, A = almandine amphibole facies, H = pyeomorphic hornfels facies, G = granulite facies. L, C, G are areas of lower, middle, and upper temperature respectively. KY is the possible temperature at 30 m depth for normal thermal gradients according to Birch (1952). Assuming 80% P, 20% F, calcite-quartz is stable to the left and wollastonite to the right of the curve AB.

(Drawn after Pole, Turner, and Verhoogen, 1955)
Figure 9. Schematic representation of possible pressure-temperature fields of metamorphic facies and of granitic magmas; all curves hypothetical; and possible P-T conditions in the southern part of the Sand Springs Range.

Z = zeolite facies, EH = albite-epidote hornfels, GS = greenschist facies, GIS = glaucophane chist facies, HH = hornblende hornfels facies, AA = almandine amphibole facies, PH = pyroxene hornfels facies, G = granulite facies. LL, 00 are curves of fusion of water-saturated and anhydrous granite respectively, XY is the possible temperature at 30 km depth for normal thermal gradients according to Birch (1955). Assuming $P_{CO_2} = P_{load}$ calcite-quartz is stable to the left and wollastonite to the right of the curve RT.

(Drawn after Fyfe, Turner, and Verhoogen, 1958)
CENOZOIC VOLCANIC ROCKS

Cenozoic volcanic rocks unconformably overlie the metamorphic rocks. These volcanic rocks are andesite flows, light-colored rhyolitic pyroclastics and flows, and basalt flows. For the purposes of this study they were not differentiated, and also no thin sections of the volcanic rocks were studied.

These volcanic rocks are dated as Quaternary (?) and Tertiary (?) on the basis of their relationship to other rocks in the area and to Quaternary and Tertiary volcanic rocks in other nearby areas (N. B. M., 1962; Page, 1965).

Folding: Folding is not a prominent feature in the area under investigation. The metamorphic sequence apparently forms the western limb of a south-plunging syncline, the eastern limb being in the Fairview Range (N. B. M., 1962). Small-scale folding is uncommon except for rare drag folding observed in the metamorphic rocks.

Faults and Joints: The Sand Springs Range is a north-south trending fault block; the range has been uplifted along a series of northeast- and northwest-trending faults. The fault block making up the range appears to be tilted, with the eastern side remaining higher.

The average strike of the northeast-trending faults is 280°. Topographic expression and slickenlines indicate that the predominant
STRUCTURES

Foliation:—Foliation is parallel to the original bedding throughout the metamorphic rocks. The relict bedding is discernible by the compositional variation of the original rock types. Foliation strikes NW and is about parallel to the contact of the Sand Springs Range pluton and dips away from that body. The dip is 60° to 80° SW at the northwest end of the belt and nearly vertical at the southeast end.

The only linear structure observed was in the amphibolites, where the actinolitic-hornblende needles are aligned in the direction of dip but mostly in the plane of foliation.

Folding:—Folding is not a prominent feature in the area under investigation. The metamorphic sequence apparently forms the western limb of a south-plunging anticline, the eastern limb being in the Fairview Range (N. B. M., 1962). Small-scale folding is uncommon except for rare drag folding observed in the metamorphic rocks.

Faults and Joints:—The Sand Springs Range is a north-south trending fault block; the range has been uplifted along a series of northeast- and northwest-trending faults. The fault block making up the range appears to be tilted, with the eastern side remaining higher.

The average strike of the northeast-trending faults is N50W. Topographic expression and slickensides indicate that the predominant
movement along these faults was vertical; however, the offsetting of the vertical dikes indicates that minor horizontal movement also has taken place. The strike of the northeast-trending faults averages N30E. The movement along these faults was also vertical, though minor horizontal movement can be observed.

Two well-developed systems of joints parallel the fault trends. A third joint system, striking E-W with vertical dip, is not well developed and was observed only rarely.
SUMMARY OF THE GEOLOGIC HISTORY OF THE SOUTHERN PART OF THE SAND SPRINGS RANGE

Sediments of Triassic (?) age were laid down in the Cordilleran eugeosyncline which occupied this area at that time. These sediments were calcitic dolomite, shale, silty shale, quartz siltstone, and rocks grading from quartz wacke to quartz arenite, deposited in a series of alternating thin layers—a lithology characteristic of a rapidly sinking eugeosynclinal belt.

Volcanism was sporadic and is represented by lavas, tuffs, and associated sediments. These volcanic rocks range from felsic to mafic and occur intermittently throughout the sequence. Whether there was any intrusive activity related to this volcanism could not be established definitely.

During the Nevadan Orogeny in the Middle Jurassic to Middle-Early Cretaceous time the area was subjected to considerable deformation. The rocks were folded and underwent low-grade dynamothermal metamorphism (greenschist facies). The movement produced a well-developed schistosity in the rocks.

In Late Cretaceous time (74 to 80 million years ago) the granitic rocks of the Sand Springs Range pluton were emplaced. The heat from the magma resulted in the thermal metamorphism of the rocks near the contact at what was probably a moderate depth in the earth's crust. Porphyroblasts of biotite, andalusite, tremolite, and
hedenbergitic pyroxene grew at this stage and "interrupted" the earlier formed schistosity. Potash metasomatism was a late phenomenon of this stage and led to the development of much muscovite and to the replacement of andalusite by "shimmer aggregates" of mica.

As the rocks cooled, some retrograde and/or hydrothermal metamorphic effects were produced; chlorite replaced hornblende and biotite and also appeared conspicuously as porphyroblasts in the pelitic and the semipelitic rocks.

During Cenozoic time volcanic rocks were deposited in the area as well as block faulting of Basin and Range nature raised the Sand Springs Range to its present heights. The present configuration of the range is due to erosion during this period.
REFERENCES CITED


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