PETROLOGY OF THE TIFFANY - CONCONULLY AREA
OKANOGAN COUNTY, WASHINGTON

by

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A thesis submitted in partial fulfillment of the requirements
for the degree of
DOCTOR OF PHILOSOPHY

UNIVERSITY OF WASHINGTON
1952

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF PLATES

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF FIGURES

PETROLOGY OF THE TIFFANY - CONCONULLY AREA
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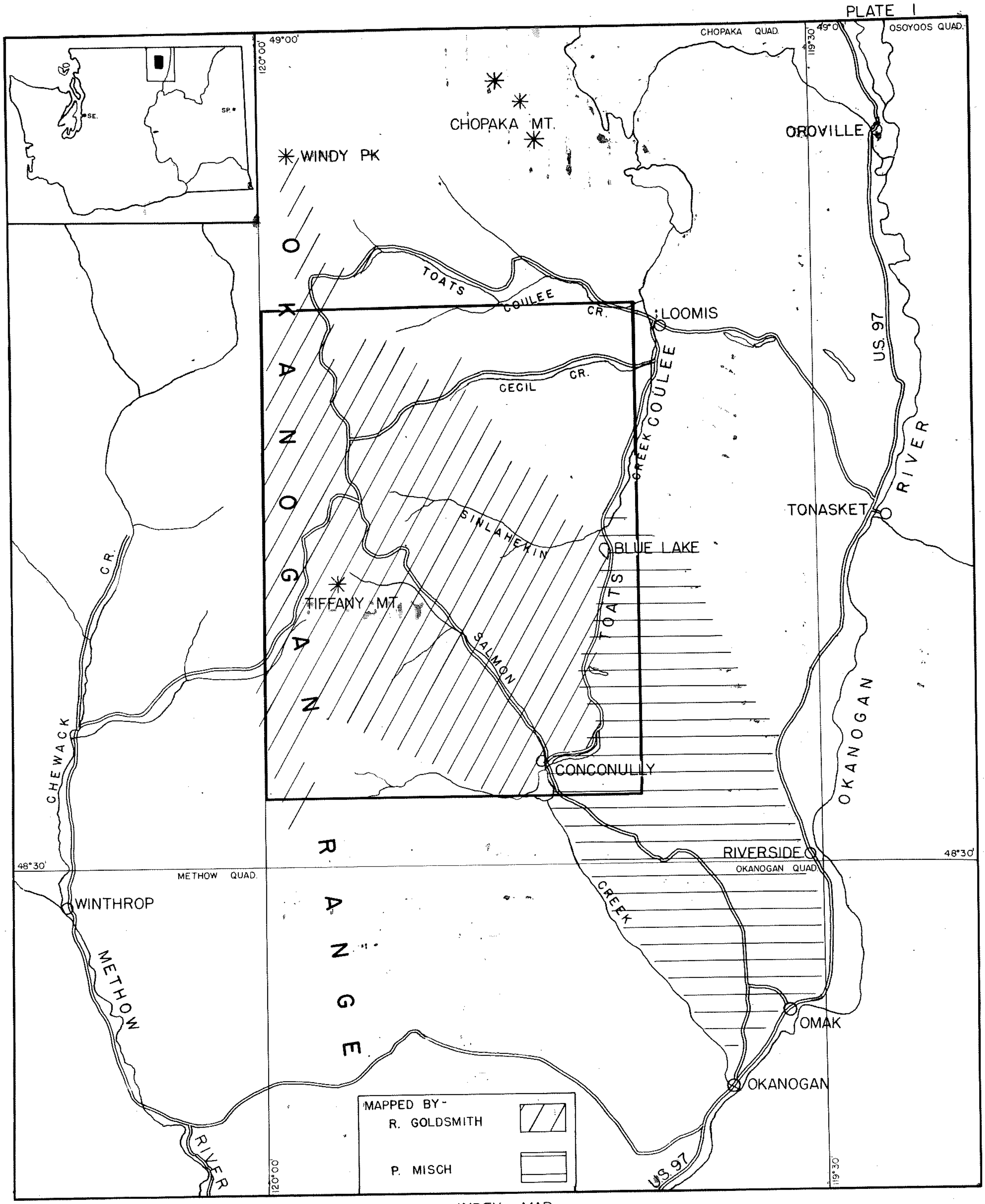
CHAPTER I
INTRODUCTION

Location of Area and Statement of Problem

Location

The area studied lies in north central Washington, Okanogan County, in the north central portion of the Okanogan Range (cf. index map, Plate I). This range forms the divide between the Okanogan River on the east and the Methow River - Chewack Creek drainage systems on the west. The area is included in the Chopaka Quadrangle which was surveyed topographically in 1902-1903 by the United States Geological Survey. In detail (cf., Plate I), the area studied, about 250 square miles, extends from the town of Conconully north

PLATE I



INDEX MAP

to Sinlahekin Creek and Blue Lake, and from Conconully and Blue Lake it extends northwestward over the crest of the Okanogan Range near the Tiffany group of peaks in the western limits of the quadrangle (120°00') and to approximately 48°50' north latitude.

The area is most easily approached through the towns of Omak and Okanogan on United States Highway 97. From these two places a paved highway runs to Conconully. From Conconully two gravelled roads traverse the area: one runs east and north through Toats Coulee to Loomis; the other maintained by the United States Forest Service, runs northwestward along the main branch of Salmon Creek into the Tiffany Mountain area where it branches, one branch descending westward to the Methow Valley near Winthrop, the other running northward along the crest of the range until it again branches; both of these branches go to Loomis, but one by way of Cecil Creek and the other by way of Toats Coulee Creek.

Topography

The north-south trending Okanogan Range forms the principle topographic feature in the area. Elevations in the group of peaks around Tiffany Mountain (8,270'), the highest point in the area, are around 8,000 feet. North of this group, the general level of peaks and ridges is around 7,000 feet. Maximum relief in the area is slightly over 6,000 feet.

From the crest of the range the ridges and peaks gradually decrease in elevation eastward toward the Okanogan Valley. On the west side of the range the slope is gentle within the area, and a rolling upland surface prevails with open meadows in the stream valleys.

Glacial cirques occur in the Tiffany group of peaks. The cirques have their greatest development on the north and east sides of the peaks. North of this group, where the general level of peaks is lower, a more gently rolling topography prevails.

Exposures

The Okanogan lobe of the Cordilleran ice sheet covered the area during Pleistocene glaciation except for the peaks in the Tiffany group.[1] As a result a considerable amount of glacial material mantles the slopes at lower and intermediate elevations. The country around Conconully is pasture land with open grassy and partly wooded slopes with scattered exposures of bed rock; although exposures are good in some of the coulee and canyon walls. At intermediate elevations a

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1 J. D. Barksdale (1941) has discussed the movement and thickness of the continental ice sheet in the Methow area and discussed the height of ice with respect to the elevations of peaks in the Okanogan Range. Drainage changes and topographic features on the eastern margin of the area related to ice stagnation and ice retreat have been described by B. Willis (1887), W. L. Dawson (1898), and O. W. Freeman (1933).

thick forest cover with occasional grassy pastures on the south slopes obscures the bed rock. Exposures are excellent in the high country near timberline, along the high ridge crests, and in the cirque walls in the Tiffany area.

Field Work

Field work was started in the late summer of 1948, continued throughout the summer of 1949, and completed during part of the summer of 1950. A total of approximately five months was spent in the field. Mapping was done on aerial photographs (Map symbols GOD and GSK, Okanogan County, Washington; United States Department of Agriculture, Agricultural Adjustment Administration) on the scale of 1:20,000 or roughly three inches to the mile and transferred to a topographic map with a scale of two inches to the mile which was obtained by enlarging the old United States Geological Survey Chopaka quadrangle to four times its scale. Some topographic corrections were made with the aid of the aerial photographs. About 1,000 rock specimens were collected. More than 450 thin-sections were made and examined.

Previous Work

Earlier published reports which have a bearing on the present area were of reconnaissance nature or were concerned with local mining investigations or with a study of glacial phenomena and generally only covered marginal parts of the present area or adjacent regions. Work done in economic and glacial geology is mentioned in other sections of the present paper. As far as more general earlier geological work is concerned, the only description of rocks actually occurring within the present area has been given by G. O. Smith and F. C. Calkins (1904). They have described some of the rocks at the eastern margin of the present area from Conconully to Fish Lake and along Toats Coulee, which they had observed during their reconnaissance near the 49th parallel in 1901. They also described in a general way some of the rocks occurring in a belt extending about five miles south from the international boundary.

R. A. Daly (1912) in his survey along the 49th parallel has described and named larger rock units of the Okanogan Range near the Canadian border including the "Anarchist Series" of metamorphic rocks and the Okanogan Composite batholith.

A. C. Waters and K. Krauskopf (1941) working some distance northeast and east of the present area, have extended Daly's "Anarchist Series" to the south and stated that the so-called Similkameen (granodiorite) batholith of Daly's Okanogan Composite batholith extended southward some distance to the west of their area. Referring to the "Similkameen batholith", they said:

> The patches of granodiorite in the west central part of the map (...) are outliers of a huge mass lying just west of the mapped area. At the international boundary, according to Daly, the batholith is 14 miles wide; its northern and southern limits are unknown, but it extends at least 40 miles south of the border. 1

This would imply that the so-called Similkameen batholith extends southward along the Okanogan Range into the present area.

In 1948 the University of Washington Geology Summer Field Course under the direction of P. Misch was held in the Riverside-Conconully area. The present writer participated in this field course. He also was employed as P. Misch's assistant when the field course was held in the same area again in 1950. The area studied in 1948 was found to consist of a variously metamorphosed and partially granitized Paleozoic sequence, which is geographically continuous with and in part stratigraphically equivalent to (cf. below) part of the "Anarchist Series" described by Waters and Krauskopf. In 1948 some reconnaissance work was also done in the present area. Misch (1949b and 1949c) has briefly summarized the regional geology of this general area and discussed the history and significance of the various types of metamorphism.

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1 A. C. Waters and K. Krauskopf, 1941, p. 1370.

Statement of Purpose

During reconnaissance near Tiffany Mountain in 1948 on the crest of the Okanogan Range, well into the supposed Similkameen granodiorite batholith, P. Misch observed widespread migmatites and relict bands of metamorphic rocks similar to those occurring to the southeast along the regional trend in the metamorphosed Paleozoic sequence of the Conconully-Riverside area. This discovery suggested the more detailed study undertaken by the writer which was to determine, if possible, the relationship between the metamorphosed Paleozoic sequence and the granodioritic complex. This implied both mapping of the area and petrographic and petrogenetic study of its rocks.

Apart from mapping a hitherto unmapped area, this study promised to make contributions along the following lines:

1. The study could aid in interpreting similar areas of plutonic rocks of batholithic dimensions where metamorphics, migmatites, and granites are in close association.

2. The study could be of aid in the analysis of various regional problems by establishing a basis for correlation between the area studied and other areas in the northern Cascades of Washington.

3. It could draw attention to unsolved or debatable problems relating to the genesis of plutonic rocks where

further research is needed.

Order of Presentation of Material

Chapter I will include a section describing the regional geology in order to provide a background for the succeeding chapters. In Chapter II, the predominantly isochemically metamorphosed rocks of the Paleozoic sequence occurring in the present area will be described and their formation discussed. In Chapter III, the migmatitic gneisses which are intimately associated with the predominantly isochemically metamorphosed rocks will be similarly treated. Chapter IV will consist of a description and genetic discussion of bodies of largely directionless granitoid[1] rocks. Two brief chapters describing the Tertiary volcanics and the economic geology follow. Chapter VII will contain a brief summary of the results of the investigation.

Terminology Employed

The nomenclature of metamorphism employed is essentially that used by P. Misch (1949a,b). Definitions have been given wherever it was considered necessary. Where rock names commonly

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1 The term "granitoid" includes rocks ranging in composition from diorite to granite. It is used merely as a descriptive term and no genetic significance is implied. The term "granitic" is also applied in the same rather broad and descriptive sense.

used in the classification of plutonic igneous rocks are employed as qualifying adjectives, such as "trondhjemitic", these terms refer only to the composition of the rock and no genetic implication is intended. The system of plutonic rock classification used here is that of Whalstrom (1947). Larger rock units within the present area are given local names in order to make the presentation clearer, e.g. "Sinlahekin quartz-dioritic gneiss" rather than the more indefinite term "quartz-dioritic gneiss".

Acknowledgments

The writer is deeply grateful to Professor Peter Misch for his invaluable advice and guidance in the field and laboratory, and for his supervision of the preparation of this paper. The writer is also indebted to Doctor Victor C. Clauson, Professor Howard A. Coombs, and Professor George E. Goodspeed for their encouragement and helpful suggestions in the preparation of this paper. Thanks are also extended to Mr. Henry F. McCormick of the United States Forest Service and to Mr. Joe Morris of Conconully for courtesies tendered the writer during the field seasons.

Outline of Regional Geology

Stratigraphy in the Adjacent Area on the East

In the area under study the rocks are so metamorphosed and invaded by granitic materials that no reliable stratigraphic succession can be established, nor have any fossils survived. However, east of this area, a thick sedimentary sequence has been well preserved, metamorphism locally being very weak, and locally fossils still occur. This sequence was studied by P. Misch in 1948 and has been found to extend into the more highly altered rocks of the present area. An outline of the stratigraphic succession in the area to the east, between Conconully and Riverside, is given below. As will be shown, some of these stratigraphic members can actually be traced into the present area.

A north-south trending belt of weakly altered thick Paleozoic geosynclinal rocks lies between the Colville batholithic complex on the east and the gneisses and directionless granitoid rocks of the Okanogan Range on the west. Northwest of Omak, the Paleozoic sediments disappear to the south and the crystalline rocks of the Okanogan Range merge with those of the Colville batholithic complex. On the north the Paleozoic sediments extend across the Canadian border where they were first studied by Daly (1912) who has named them the Anarchist Series. Later Waters and Krauskopf (1941) traced these rocks further to the south and described them under the same name. They subdivided their "Anarchist Series" into three main parts, the lithology of which is described in some detail. However, P. Misch's work in the Conconully-Riverside area has made their subdivisions questionable.

In the Conconully-Riverside area P. Misch established the following conformable stratigraphic succession (giving local names):

Scotch Creek* formation[1]	- Argillites with subordinate interbeds of quartzite, impure dolomite, and local thin limestones. Metamorphosed into black phyllites, biotite schists, andalusite schists, local kyanite and sillimanite schists, local amphibolitic schists, lime silicate and marble bands.
Evans Lake* formation	- Interbedded (1) black phyllites and schists (argillite derived) and (2) actinolite-tremolite granulites and schists (predominantly impure dolomitic sediments), locally grading into impure dolomitic rocks.
Alkali Lake* formation	- Upper - black, blue, gray dolomite, dolomitic limestone, and marble: locally fossiliferous (pelecypods, cephalopods, primitive gastropods). At the base occurs a thin member of gray dolomitic quartzite, schist, and schistose dolomite, usually strongly banded. Middle - Massive white, gray, and buff dolomitic limestone, dolomite, and marble.

1 All names of formations marked by an asterisk are unpublished.

<u>Lower</u> - Ash gray, partly dolomitic and locally argillaceous and sandy limestone; locally with brachiopods.

The molluscs found in the Alkali Lake formation indicate a definite Paleozoic and, according to a preliminary examination by H. E. Wheeler, a probable Devonian, or possible Mississippian, age. The Evans Lake formation and the Scotch Creek formation, being conformable with the Alkali Lake formation, must be largely Carboniferous in age. These two formations are equivalent to the lower[1] parts of the so-called "Anarchist Series" (cf. above). Further north, Waters and Krauskopf found fossils in the "Anarchist" that have been tentatively dated as Permian.

Northeast of the present area, near Loomis, low grade meta-volcanics including meta-basalt, and meta-sediments occur which belong to higher parts of the "Anarchist Series" than are present in the Conconully-Riverside area. Stratigraphic equivalents of these rocks may occur in the present area west of Blue Lake but no direct correlation was made. On the east side of Toats Coulee near Blue Lake, as well as farther south, namely north of Fish Lake, occur amphibolitic rocks which P. Misch considers as a possible equivalent of the Loomis meta-basalt mentioned above.

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1 This does not coincide with the "Lower Anarchist" of Waters and Krauskopf.

The sequence in the Conconully-Riverside area, according to Misch (1949b), has undergone regional orogenic metamorphism of varying grades and widespread later static recrystallization, and locally, the sequence has been selectively granitized, the Alkali Lake dolomitic sequence remaining unaffected. For example, south of Evans Lake a syncline of Evans Lake and Scotch Creek formations has been largely converted into a tongue-like granodioritic body.[1] A similar, though smaller, granitized body occurs in a recumbent syncline a few miles northeast of Conconully. On its southern and western margins, the area of metamorphosed Paleozoic sediments generally passes into gneiss and granitoid rocks. Since the regional folding trends northwest, the upper portions of the Riverside-Conconully sedimentary sequence, namely the Evans Lake and the Scotch Creek formations, which are chemically susceptible to granitization, and their associated migmatitic rocks pass into the present area at its eastern border, namely in the Conconully-Funk Mountain-Fish Lake sector.

<u>Adjacent Areas on the West and North</u>

The gneissose and directionless granitoid rocks

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1 A detailed study of the Evans Lake granodiorite was made by L. T. Grose (1949) in his University of Washington Masters thesis.

comprising the greater part of the Okanogan Range extend northward and northwestward across the 49th parallel into British Columbia. To the southwest and west the crystalline rocks of the Okanogan Range come in contact with metamorphic, volcanic, and sedimentary rocks of varied ages occurring in the Methow Valley. J. D. Barksdale (1948) has briefly described these rocks as they occur in the Methow Quadrangle. The nature of the contact of these rocks with the crystallines of the Okanogan Range is not known.

In the northern part of the present area, an extensive body of volcanic flows and breccias of Tertiary (?) age lies unconformably upon the plutonic rocks. Lithologically similar rocks have been described by Waters and Krauskopf to the east and by Barksdale to the southwest.

Structure

The regional trend of the folds in the Paleozoic sequence of the Riverside-Conconully area, although locally variable, is northwest-southeast. The rocks have been intensely folded (Misch, 1949c). Some folds, mostly isoclinal, are steep; others are recumbent and have produced some smaller overthrusts. A major overthrust appears to underlie the whole region, but the lower plate is only exposed in a few windows (Misch, 1951). From the Riverside-Conconully area individual rock units and structures continue into the present area, displaying the same regional trend and a similar degree of deformation. No exposure of the major thrust mentioned above has been found in the present area. Nor could it be expected since all the structures in the western portion of the Riverside-Conconully area, that is, close to the eastern border of the present area, display a marked axial plunge to the west and northwest.

In the present area three predominant sets of later faults are recognized. One trends northwest-southeast, parallel to the trend of the regional folding. The straightness of the northwest trending valley of Salmon Creek suggests faulting along this line. Another set varies in trend from east-west to northeast-southwest. A good example occurs along Sinlahekin Creek west of Blue Lake. A third set of faults trends north-south. These faults are associated with a set of Tertiary volcanic dikes.

CHAPTER II

PREDOMINANTLY ISOCHEMICALLY METAMORPHOSED ROCKS

In the previous chapter, the rocks surrounding the area studied have been described briefly. To develop logically the description and discussion of the rocks in the area, those rocks will be described first which are believed to represent as nearly as possible original material from which other rocks in the area that have undergone greater varieties of metamorphism have been derived. This original material is represented by the largely isochemically metamorphosed rocks of the Paleozoic geosynclinal sequence which pass into the area studied from the southeast along the regional trend.

Carbonate and Lime Silicate Rocks

Marble

Distribution. Outcrops of marble occur throughout the area of schists and gneisses from the Fish Lake road at the north end of the upper Conconully reservoir to the ridge leading from Mineral Hill to Muckamuck Mountain. No marble is found along the strike north of Pelican Creek, nor northwest of Funk Mountain because of a general plunge of the structure to the northwest. One outcrop occurs on Goat Mountain and another on the north side of Sinlahekin Creek west of Blue Lake.

The marble occurs as relatively narrow bands at various horizons in the Scotch Creek section of schists. There is no doubt that many of these bands are repeated due to folding. The bands are generally about two to four feet thick; however, where the marble is intercalated with lime silicate rocks or quartzites, the total thickness may be more, attaining an observed maximum of twenty-four feet. Wider outcrops are found locally where the marble has been isoclinally folded or where it occurs on the nose of a plunging structure.

The wider bands of marble generally form rounded knobs which stand out above the surrounding rocks. The narrow bands have little topographic expression.

Lithology. The more massive marble, which is best seen on the slopes on the southeast side of North Salmon Creek about four miles northwest of Conconully, is a coarse-grained relatively pure marble, white to grayish-white in color which weathers light gray with a granular surface. One specimen contained small flecks of molybdenite.

Certain portions, especially near the margins, consist of alternating sharp bands of marble and siliceous material. Their sharpness and uniformity suggest tectonic banding. Differential weathering has etched out the softer bands. In one outcrop the marble could be seen to have flowed around the end of an intercalated amphibolite band that had been drawn out and pinched off (boudinage structure).

The more thinly bedded marbles are usually white. Others, however, contain various amounts of impurities such as finely disseminated grains of ore minerals and lime-silicate minerals. The marbles pass into lime-silicate granulites or calcareous quartzites showing various shades of gray or light green.

All the marbles react readily with dilute hydrochloric acid.

Lime-Silicate Rocks

Occurrence. Lime-silicate rocks although usually associated with marble may also occur without marble as minor impure calcareous or dolomitic intercalations in a predominantly argillaceous-siliceous sequence of sediment. They are therefore more widely distributed than the marbles.

True lime-silicate rocks invariably are composed of narrow bands of different compositions. The colors of the bands are white, pale-green (diopside), reddish (garnet) or dark-green to black (amphibole). Some have a splotchy appearance with lenticular streaks or groups of differently colored minerals.

With an increase of argillaceous material the lime-silicate rocks pass into diopside-bearing amphibolites and amphibolites, both essentially of sedimentary derivation.

Petrography. The occurrence and relative abundance of minerals in specimens of impure marbles and lime-silicate rocks is given in Table I. Plate III is a sketch map showing the field locations of the outcrops from which the specimens were taken. The specimens have been divided into two groups on the basis of mineral content and location. They are: (a) those rocks occurring in the Salmon Creek-Funk Mountain area that contain no wollastonite and associated minerals; and (b) those rocks occurring in the Mineral Hill area that contain minerals of the wollastonite facies.

(a) The rocks from the Salmon Creek-Funk Mountain area are banded silicate-bearing marbles, banded partly carbonate bearing lime-silicate quartzites, pyroxene granulite, and gneissose and banded lime-silicate granulites of varying compositions. Most of the rocks contain thin bands which vary in carbonate and silica content. The bands may also vary in relative amounts of diopside, tremolite, plagioclase, scapolite, epidote, and hornblende.

Textures are primarily granoblastic, though porphyroblastic textures occur. The mutual bounderies of carbonate grains are polygonal rather than sutured. However, replacement of carbonate by lime-silicate minerals produces highly irregular grain boundaries at the locus of reaction. Quartz occurs as anhedral grains or as coarse interlocking aggregates which may enclose such minerals as diopside. The scapolite is the more highly birefringent variety with a large mejonite component (mizzonite?).

Diopside forms small rounded or larger irregular grains. In several instances, a partial rim of diopside can be seen forming around a tremolite crystal, both in close association with carbonate. This indicates replacement of tremolite by diopside. In other cases tremolite seems stable with diopside.

Zoisite and epidote are in part retrogressive as they may be found in the neighborhood of hydrothermally altered zones or in cross cutting veinlets with secondary calcite. However there are some rocks in which the epidote or zoisite occurs in areas in which other minerals do not appear altered. Epidote forms individual subhedral grains apparently not associated with any particular mineral or minerals, or it may occur with similar habit as part of an aggregate with diopside and magnetite. In these rocks it is interpreted as being contemporaneous with the latter two minerals.

An epidote rich rock from the north side of Salmon

Creek northwest of Funk Mountain, (Specimen 9), contains large poikiloblastic crystals of epidote which include diopside and quartz. In the same rock poikiloblastic green hornblende, which is idioblastic against calcite and scapolite, includes quartz and scapolite. Thus, in this rock epidote and hornblende represent a mineral assemblage later than the diopside and scapolite assemblage and formed at its expense.

Plagioclase occurs in polygonal grains or as irregularly spreading porphyroblasts which enclose quartz, sphene, tremolite, and diopside. The composition of the plagioclase ranges from labradorite (an 63 ±) to andesine (an 35 ±), both of which may be porphyroblastic. The more sodic plagioclases are zoned.

Microcline, where present, also forms irregularly spreading porphyroblasts enclosing all other minerals and in one instance was seen to replace plagioclase. This indicates a late development of potash feldspar. Orthoclase occurs as intergranular grains but is not common.

Sphene usually occurs in rounded, subhedral blebs, usually with a reddish tinge.

Two specimens from south and southeast of Funk Mountain represent transitional passages into more aluminous rocks. Specimen 16 was taken from an outcrop of interbedded lime-silicate rock and micaschist. It shows a granoblastic band of poikiloblastic diopside and plagioclase embedded in carbonate associated with a schistose band which in addition to the equigranular minerals also contains biotite and pale tremolitic-hornblende. Some orthoclase and muscovite are present. Some of the biotite and muscovite grains have grown across the foliation. Specimen 15 which is associated with amphibolite contains green-hornblende prophyroblasts which have formed in part at the expense of diopside. The hornblende contains streaks, central cores, and small grains of diopside. However diopside crystals also occur which contain small grains of hornblende. Carbonate occurs in the more diopsidic areas.

(b) In the Mineral Hill Area the most characteristic feature is the presence of wollastonite. The rocks are calc-silicate bearing marbles, banded and gneissose lime-silicate granulites, a garnet-diopside granulite, a hydrothermally altered diopside-bearing feldspathic pegmatitic rock, and an altered quartz-bearing diopside-plagioclase granulite with a considerable variance in grain size.

In this area some of the rocks contain wollastonite, grossularite, and vesuvianite. The most calcic plagioclase is labradorite. Scapolite, tremolite, and contemporaneous (i.e. non-retrogressive) epidote and zoisite are absent. Except for the differences in mineral facies, the textures in these rocks and the behaviour of the feldspars are essentially the same as in group (a) described above.

Discussion of Marble and Lime-Silicate Rocks

Zoning.[1] An examination of Table I reveals that the lime-silicate rocks fall roughly into two groups based on mineral assemblages. The association: calcite plus quartz plus diopside and the lack of wollastonite and grossularite in the rocks of area (a), indicate that though temperatures were high enough to form diopside from the available dolomitic material, they were not high enough to initiate the wollastonite reaction or form grossularite. This indicates a position in the cooler part of the "katazone" (high grade zone), or possibly in the boundary interval of "mesozone" and "katazone" (medium and high grade zones).

The maximum anorthite content of the plagioclase corresponds to calcic labradorite, but some of the plagioclase has a much lower anorthite content. The amount of sodium originally present in the sediment and now contained in plagioclase as compared with the amount of sodium introduced from elsewhere is not known.

The presense of scapolite with diopside confirms the zonal position suggested above. The partial occurrence of

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1 The zonal scheme used here is essentially that of Grubenmann except that the zones are spoken of in terms of temperature as "cooler mesozone," "hotter mesozone," rather than "lower" or "upper mesozone." This is done to avoid confusion with the concept of "depth zones" which in late years has been objected to by Eskola (1939), Misch (1949a). As interpreted in this study, the classical zones, katazone (high grade zone, mesozone (medium grade zone) and epizone (low grade zone) are all valid.

contemporaneous epidote and zoisite in the assemblage indicates that temperatures were near the mesozonal-katazonal boundary rather than within the true katazone. This holds true for those rocks which contain undoubted contemporaneous epidote minerals (cf. above); those rocks which do not contain contemporaneous epidote, may represent a slightly higher grade within area (a). Later (i.e. retrogressive) epidote may, of course, form in either case.

The rocks of area (b) contain diopside, and also wollastonite, grossularite, and vesuvianite. This assemblage is indicative of the high temperatures in the main part of the true katazone. These rocks do not contain primary calcite together with quartz except in one instance which may be due to incomplete reaction, or possibly to later introduction of the quartz. Epidote and zoisite are absent except in two rocks where they are definitely retrogressive, replacing the lime-silicate minerals of the original high temperature assemblage. Scapolite is absent.

The specimens examined do not show a consistent development of plagioclase. It is, however, surprising that none of the plagioclase-bearing rocks examined contains bytownite or anorthite. Slight soda introduction is probably the explanation, the plagioclase present serving mainly to bind this soda, and the remainder of the anorthite molecule having reacted with the wollastonite molecule to form grossularite (virtual absence of plagioclase in the grossularite-rich specimens).

Metamorphic history. Evidence for early deformation is difficult to observe in thin sections of those rocks which consist of readily recrystallized, equigranular minerals. The field evidence from such deformation, however, is conclusive. What the thin sections clearly show is that the early deformation visible in the field has been succeeded by a postkinematic phase of thermal metamorphism. This is especially obvious where late minerals have grown across the foliation (cf. partially schistose specimen 16).

Specimen 19 from northwest of Funk Mountain (cf. above) shows coarse porphyroblastic growth of epidote and green hornblende which is later than the diopside. This is interpreted as indicating a late phase of the static thermal metamorphism under somewhat lower temperature perhaps with a local migration of some material including water and possibly some alumina. The occurrence of late hornblende replacing diopside south of Funk Mountain (cf. specimen 15 above) is similarly interpreted.

Although some of the feldspars, both orthoclase and plagioclase, are undoubtedly present because of an original argillaceous component in the sediments, the frequently seen late porphyroblastic growth of plagioclase, especially andesine, suggests some introduction of soda. The late

TABLE I

APPROXIMATE MINERAL COMPOSITIONS OF IMPURE MARBLE - LIME-SILICATE ROCKS

	Group "a" Zone II											Group "b" Zone I				
Location	19	28	29	29	30	27	31	9	9	15	12	20	25	26	18	18
Specimen Number	1	2	3	4	5	6	7	8	9	16	15	10	14	11	12	13
carbonate	p	p	p	p	-	p	-	-	a	a	as	p	s	s	a	a
quartz	p	p	a	p	p	p	-	p	p	-	-	-	-	a	a	-
diopside	p	p	a	p	a	p	p	p	a	p	p	a	p	p	p	p
wollastonite	-	-	-	-	-	-	-	-	-	-	-	a	-	-	-	a
plagioclase	a	p	a	a	a	a	-	a	a	a	-	a	p	p	-	-
(An content)	45	60	37	35	63	36		60	38	60		Ol	?	La		
garnet	-	-	-	-	-	-	-	-	-	-	-	a	-	-	p	a
vesuvianite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	a
tremolite	-	a	a	a	-	a	a	-	-	p	-	-	-	-	-	-
hornblende	-	-	-	-	a	-	-	-	a	-	p	-	-	-	-	-
epidote-zoisite	a	ps	-	-	-	-	-	a	p	a	s	-	s	s	-	-
scapolite	p	a	-	-	-	-	-	-	p	-	-	-	-	-	-	-
biotite	-	-	-	-	-	-	-	-	-	p	-	-	-	-	-	-
talc-muscovite	-	-	-	-	-	-	a	-	-	a	-	-	-	-	-	-
potash feldspar	-	-	-	a	-	a	-	-	-	a	-	a	p	-	-	-
iron oxide	-	a	a	a	a	a	-	a	a	-	-	a	-	-	-	-
sphene	a	a	-	a	a	-	-	a	a	-	a	-	-	a	-	-
apatite	a	-	-	a	-	a	-	a	-	-	-	-	-	-	a	a
zircon	a	-	-	-	-	-	-	-	a	-	-	-	-	-	-	-

p - principal, a - accessory, s - alteration (secondary),
Ol - oligoclase, La - labradorite.
Locations of specimens are indicated on Plate III.

porphyroblastic growth of microcline which in one instance replaces plagioclase seems to indicate a still later introduction of potash. Any such evidence, however, for alkali introduction in the lime-silicate rocks is sporadic and inconclusive in contrast to the excellent evidence for alkali metasomatism in the micaschists and amphibolites (cf. below).

Locally, late, low temperature hydrothermal alteration has effected the rocks.

Quartzites, Phyllites, and Schists

Distribution

Schists are best displayed on Funk Mountain, north of the Upper Conconully Reservoir. From the Conconully-Loomis road at a point beyond the northern end of the reservoir, plates of interbedded micaschists, schistose quartzites, and minor calcareous members can be seen dipping steeply, with minor flexures, toward the northeast. However, the micaschists and related fine-grained paragneisses[1] occur throughout the

1 The term paragneiss is used here for foliated metamorphic rocks derived from sediments and having as main constituents quartz, mica, and feldspars. They are mostly fine grained, rich in biotite, and dark colored. Paragneisses differ from biotite schists in having feldspar as one of their main constituents and in being less thinly foliated. In this the writer follows Misch (1949a).

area of less highly transformed metamorphic rocks from Conconully to several miles northwest of Salmon Meadows, and from Blue Lake to the Mineral Hill-Muskemuck Mountain divide.

If only the argillite derived rocks are represented in a generalized section from the Blue Lake area to Mineral Hill, we observe a passage from northeast to southwest from phyllites through micaschists to fine-grained paragneisses. In the Mineral Hill area, near the margin of the Mineral Hill granodiorite, the fine-grained paragneisses are associated with coarse-grained flaser, augen, and dioritic gneisses. Elsewhere the progression of schist to paragneiss is repeated wherever the schists approach an area of high grade gneisses or more directionless highly feldspathic rocks, as for example towards the Rock Mountain area on the crest of the Okanogan Range.

General Statement

Although micaschists and schistose quartzites make up the bulk of the Scotch Creek Schist, they are interbedded with and grade into carbonates, lime-silicates, and amphibolites as mentioned earlier. In this section only those rocks which are without hornblende will be discussed, and to avoid confusion schistose quartzites, phyllites, micaschists and fine-grained paragneisses will be dealt with separately. Hornblende-biotite-micaschists will be considered in the chapter on amphibolites, and carbonate and lime-silicate rocks have already been discussed.

Quartzites

The quartzites are fine-grained, generally thinly banded, brownish-gray to green-black to black. They are usually micaceous and predominantly schistose, often breaking in slabs. Some of the greenish, more massive varieties are lime-silicate quartzites containing diopside. The brownish-gray to black schistose quartzites contain biotite and grade into quartz-micaschists. Gradations into quartz-biotite paragneisses with a large percentage of plagioclase varying from calcic oligoclase to andesine also occur. This means that some of the sediment was calcareous and that soda, presumably introduced, (cf. below) was an important element in the formation of the present rock. Quartz may segregate into streaks, lenticles, or augen-like aggregates. Other light bands essentially consist of feldspar and quartz and give the rock a gneissose appearance.

In thin section the texture of the quartzitic rocks is crystalloblastic and their structure usually schistose to gneissose. The schistose structure is seen to be inherited, in fact if it were not for the general alignment of undeformed biotite flakes, the structure would be called granoblastic. The bands are of varying compositions and represent original differences in sedimentation although some metamorphic differentiation may have taken place.

Some approximate mineral compositions are listed in Table II. Brown biotite (X - straw yellow, YZ - reddish brown) is the chief ferro-magnesian mineral. It occurs as isolated elongate flakes which are usually parallel to the foliation. Basal faces are well-developed, other faces are absent. Quartz occurs as irregular grains which are equidimensional or slightly elongated in the direction of the schistosity. It sometimes forms more coarse grained aggregates. Plagioclase in the quartz-rich varieties generally is elongated in the direction of schistosity. In the more feldspathic varieties this is less pronounced: the plagioclase is more equidimensional and forms a mosaic. The plagioclase is usually calcic oligoclase or sodic andesine but is occasionally more calcic indicating a gradation into lime-silicate quartzites. Accessory minerals are apatite, magnetite, orthite which generally shows a low birefringence (metamict), and zircon. The last two minerals are responsible for pleochroic haloes in biotite. Potash feldspar may or may not be present.

The preferred orientation of undeformed biotite, quartz, and plagioclase mentioned above means that these minerals participated in a period of penetrative deformation but that the deformation was accompanied and followed by crystallization.

The undeformed granulitic-hornfelsic mosaic texture of the more feldspathic varieties also indicates a phase of static (post-kinematic) crystallization.

In certain localities the quartzites become much coarser grained. In a microcline-bearing quartzite from the Salmon Meadows area (Spec. 50) associated with biotite paragneiss and gneissose trondhjemitic rocks, collective crystallization has produced large quartz super-individuals which have acquired optical uniformity and exhibit interlocking contacts. The large crystals branch out in irregular crystalloblastic projections which, even where apparently disconnected with the main grain in the thin-section plane, can be identified on the basis of identical optical orientation. Crystals of this type are common in the more highly recrystallized metamorphic rocks in the area studied.

The rock just described also contains small oligoclase and microcline grains between the quartz grains. The oligoclase is myrmekitic where it is adjacent to microcline. Microcline projects little tongues into twin seams of plagioclase and appears to have engulfed other grains. Sometimes only small perthitic streaks remain. The microcline also includes small rounded quartz grains. The above evidence would point to a late replacement origin for the microcline. It is possible that shearing stress has caused the unmixing of microcline and the formation of the oligoclase and the perthite although this rock appears to have been formed predominantly by static processes.

It is concluded that the metamorphic history of the rocks described above includes: (A) a period of synkinematic crystallization which produced the foliation; (B) a post-kinematic phase of static crystallization apparently continuous with (A) which superposed a more directionless granoblastic texture on the foliation; (C) later local collective recrystallization of some of the quartz accompanied by potash metasomatism leading to porphyroblastic microcline growth.

Biotite-Bearing Phyllites and Phyllitic Micaschists

The lowest grade of argillaceous rocks in the area occur along Sinlahekin Creek west of Blue Lake. They comprise biotite bearing sericite phyllites and phyllitic micaschists with andalusite porphyroblasts. They are interbedded with chlorite, epidote and/or hornblende bearing phyllites and phyllitic micaschists and some metamorphosed impure grit. Textures are crystalloblastic; occasional rocks related to the grit show blastopsephitic structures.

At locality (1) as listed in Table II, the phyllite is gray-black, crumpled, and weathers a dark orange. It contains minute quartz veins and spots of limonite about 0.5mm in diameter. In thin-section the rock is composed of sericite, fine-grained pale-brown sericitiform biotite, quartz, and the occasional larger patches of limonite. Cross-cutting secondary fracture-cleavage has begun to develop, sometimes marked by limonite.

To the west, at locality (2), a black shiny phyllitic schist contains andalusite porphyroblasts which stand out on the weathered surface as knots with maximum observed dimensions of 1 x 0.25 inches. In thin-section the rock is seen to be composed of quartz and fine-grained, brown biotite in streaks which mark out a pattern of folds. This type of rock frequently shows, apart from its plane foliation "s" two directions of "b" lineation, both marked by the crests of minute wrinkles and folds; the second lineation (b_2) cuts across the earlier one (b_1) at an angle of about 55°. The biotite streaks are truncated by large poikiloblastic andalusite crystals which include quartz, magnetite, muscovite, and areas of groundmass containing biotite. Some of the opaque material is carbonaceous. Near a late shearing plane containing chlorite (clinochlore) and muscovite, the andalusite marginally has been sericitized and the biotite has been partly altered to limonite. A small, strongly curved, crescent-shaped aggregate of quartz crystals representing the nose of a fold the limbs of which have been drawn out and obliterated, is evidence of the isoclinal folding which produced the plane foliation "s". Some late muscovite and chlorite flakes cut across the foliation.

The features observed in these rocks indicate the following phases of metamorphic history: (A) synkinematic metamorphism[1] in two phases including one which produced the plane foliation (s_1) and isoclinal folds parallel to it, and a second, less complete phase, which produced crumpling of the foliation and fold axis lineation (b_1) as well as an incipient cross-cutting fracture cleavage (s_2) with locally a second direction of yielding in the form of a second lineation (b_2) recorded; (B) post-kinematic metamorphism[2] which has led to the formation of non-oriented andalusite porphyroblasts and is also shown by a tendency towards production of a hornfelsic texture in the groundmass; (C) later, partly hydrothermal, retrogressive metamorphism with local deformation. The presence of chlorite, muscovite, and the partial sericitization of andalusite indicate that temperatures had decreased to those corresponding to the low grade zone (epizone).

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1 Defined by Misch (unpublished manuscript) as "metamorphism contemporaneous and connected with penetrative differential deformation of the rock affected."

2 Defined by Misch (unpublished manuscript) as "static metamorphism which was preceded by a phase of penetrative deformation of the rock."

Micaschists

Megascopic description. The micaschists in the general Salmon Creek area show a higher grade of metamorphism than the phyllitic types of the Sinlahekin area. The rocks are quartzitic micaschists and micaschists containing, in addition to quartz, biotite and muscovite, one or more of the following minerals: garnet, sillimanite, andalusite, staurolite, and plagioclase.

The less micaceous types show a slabby, planar foliation. The more micaceous varieties often show strong minor folding and crumpling. In some cases isoclinal folding with axial planes parallel to the foliation can be observed. Sometimes lighter quartz-feldspar rich lenticular bands occur in incipient ptygmatic folds.

Most of the schists weather to a rusty red color. One light-colored variety weathers pale yellow. Another variety richer in quartz and feldspar and with biotite restricted to small single flecks, has a sugary, gritty consistency and crumbles like an imperfectly indurated sandstone. The more micaceous varieties are coarser grained than the quartz or quart-feldspar rich varieties. Quartz exudations in lenses or knots are common.

Table II gives the generalized mineral compositions for the rocks described in this section. Localities from which the specimens were taken are shown in Plate III.

<u>Microscopic description and significance of minerals</u>. Quartz is a major constituent in all the rocks. It occurs, as in the quartzites, in irregular equidimensional grains or, more rarely, with preferred orientation (c - axes more or less perpendicular to the plane of foliation) and slightly elongated.

Biotite is pleochroic in reddish brown (cf. quartzites), a characteristic which is found throughout the purer argillaceous schists. It forms bands of interlocking aggregates in subparallel orientation with interstitial quartz and feldspar; or it occurs as scattered flakes in the bands richer in quartz and feldspar. Individual flakes of biotite show no sign of deformation and yet aggregates mark the flexures and folds in the foliation by an overlapping, angular arrangement of individually undeformed crystals (polygonal arcs)(cf. Plate VI). This means that the crystallization of the biotite has outlasted the deformation. Feldspars and the aluminum-silicate minerals occur primarily in the streaks rich in biotite. These represent the more argillaceous, less sandy layers.

Sillimanite occurs in two forms: fibrolite, and small crystals which in cross section usually show a diamond-shaped outline. Most of the sillimanite-bearing rocks contain both types. The origin of the fibrolite is best shown in a specimen from locality (6) (spec. 20). The rock shows strong folding and the biotite has been partly converted into fibrolite. The fibrolite is bent parallel to the folds while the remaining biotite only marks the folds in the form of polygonal arcs. Fibrolite elsewhere occurs as inclusions in plagioclase, quartz (faserkiesel), staurolite, andalusite, and muscovite, frequently forming an internal "s" (s_i) which often represents true helizitic structure. The s_i as marked by the fibrolite is much more distinct than the s_e as marked by the biotite and the fibrolite outside the host mineral. This means that the host mineral has protected the s_i-forming minerals from the post-kinematic crystallization that has affected the rocks and weakened their schistosity. In one specimen the fibrolite appears closely related to the better crystallized prismatic form. In this rock the sillimanite appears as fibrous mats often with a broader prism in the center. Biotite projects into these mats. In another specimen, subhedral sillimanite crystals are intergrown with an andalusite porphyroblast so that the 110 faces in sillimanite conform to the 110 cleavage in andalusite. This is interpreted as representing a contemporaneous intergrowth. Sillimanite grains are occasionally surrounded by augen-shaped areas of felty sericite that pass into large muscovite grains.

The foregoing description may be interpreted in terms of metamorphic history as follows: (1) a period of deformation accompanied by crystallization culminated in the production of well-formed sillimanite and of slightly later fibrolite derived from biotite. Since the fibrolite is associated with prismatic sillimanite the maximum temperature reached was katazonal. The minor folding in some of the rocks represents folding of an earlier foliation. The folding may have been a reaction of incompetent rocks to a late phase of the original deformation, or it may represent a later deformation not continuous with the first. However the minor folding is believed to be a late phase of the original deformation since a second, distinct, less complete synkinematic phase would be expected to produce a mineral assemblage indicating a lower temperature than the first. Temperatures do not appear to have dropped appreciably between phases. (2) The synkinematic phase was succeeded by a static phase. This is shown by the growth of irregular and non-oriented porphyroblasts which include remnants of the earlier schistose fabric (s_1) as well as microfolds (helezitic structure), as well as by the development of the anti-stress mineral andalusite in rocks which earlier produced sillimanite. That this phase was continuous in time with the synkinematic phase is shown by the sillimanite-andalusite intergrowth. (3) A later retrogressive, hydrothermal phase is indicated by the development of sericite around sillimanite.

Andalusite forms large porphyroblasts which enclose

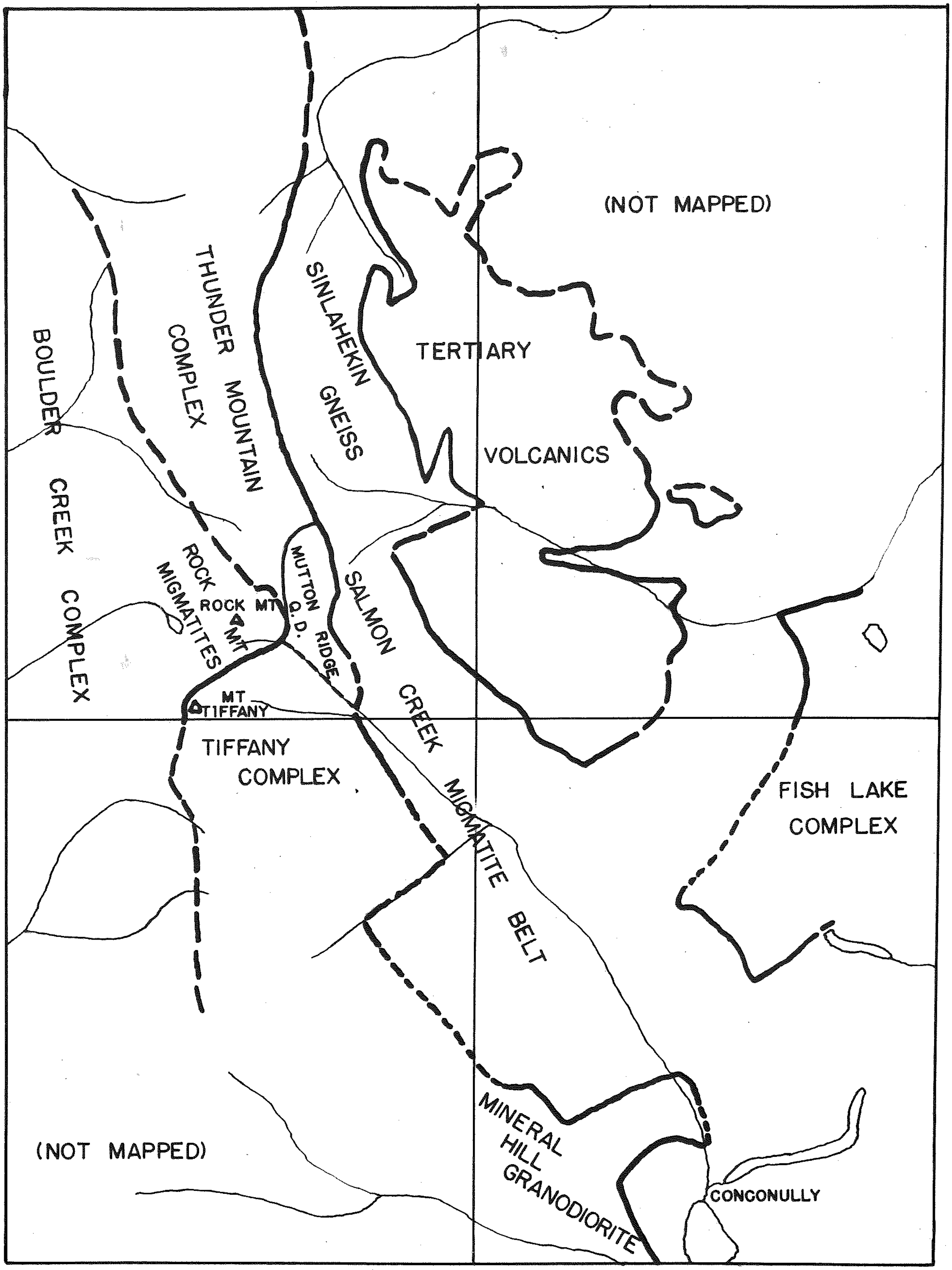

FIGURE 1. DIAGRAM OF MAJOR ROCK UNITS OF TIFFANY - CONCONULLY AREA REFERRED TO IN TEXT

groundmass minerals. Its presence confirms the existence of postkinematic metamorphism. It may be surrounded by large muscovite grains or sometimes may occur only as small irregular remnants enclosed in large patches of sericite. Alteration of andalusite to muscovite and sericite is indicated. Where such alteration has taken place some of the biotite in the rock has been converted to muscovite. The alteration of andalusite and sillimanite (cf. sillimanite) to muscovite and sericite is interpreted as a low temperature variety of potash metasomatism. This has been discussed by Turner (1948) pp. 117-118 and described by Billings (1938). In the rocks described above, the reaction involving no potash introduction, that is, orthoclase plus sillimanite (andalusite) plus water to muscovite plus silica, does not apply since the majority of the rocks containing aluminum silicate minerals lack orthoclase (cf. Table II) and potash must have been introduced to convert the andalusite and sillimanite to muscovite.

Staurolite is poikiloblastic and contains sillimanite, quartz (which may be faserkiesel), and magnetite. The fact that staurolite forms later than sillimanite indicates that temperatures locally during part of this stage declined to hotter mesozonal. In one rock andalusite and staurolite both occur.

Garnet, probably almandine, is poikiloblastic and reaches a maximum observed diameter of 1.8 mm. Crystal faces are often well-formed. In some cases the foliation bends around the garnet, in others the garnet truncates the biotite streaks. In such cases a narrow, clear, biotite-free zone exists around the garnet crystal. The garnets are usually cracked. Some have a limonite stain, a few others have incipient development of biotite along the fractures and along the borders. In one rock adjacent garnet grains occur together in an augen-like area suggesting that they are fragments of a crystal which had undergone stronger deformation than the garnets indicate elsewhere. There is no sign of rotation of garnets. The above evidence indicates that garnet is both synkinematic and post-kinematic in origin. Since garnet is a brittle mineral some of the fracturing may represent a still later phase of deformation.

Muscovite has been mentioned incidentally above. It may be in the form of sericite surrounding and replacing andalusite and sillimanite, or in more or less equidimensional, irregular grains which have formed from sericite and have grown across the foliation. Some grains are helezitic and contain fibrolite. Sometimes muscovite replaces biotite with simultaneous segregation of magnetite. In one specimen muscovite and biotite have been sheared to form streaks of sericite. The random orientation of the muscovite shows a complete independence from any directional control.

Plagioclase (oligoclase-andesine), mainly occurring in the biotite rich streaks, encloses tourmaline, apatite, quartz, magnetite and fibrolite. The included opaque material and fibrolite form helezitic structure thus indicating pre-plagioclase folding. As above, (cf. sillimanite) the s_i is more definite than the s_e. Plagioclase becomes a more common constituent in rocks that approach fine-grained paragneisses in composition and texture. Such a rock may have alternating bands of fine-grained quartz and biotite with occasional plagioclase grains, and more coarse-grained bands composed of the same minerals but with a higher proportion of plagioclase. These evidently represent originally more argillaceous bands (addition of sodium in aluminum rich bands is discussed below). The finer grain size in the quartz-rich bands is a common characteristic in the schists.

A specimen collected near a quartz-feldspar-mica pegmatite and close to an interbedded lime-silicate band contains about thirty-five per cent plagioclase (An 45-50) which occasionally forms poikiloblastic crystals slightly larger than the surrounding grains. The grain sizes are about 0.4 mm. The inclusions are quartz and biotite. This rock is evidently derived from a sediment richer in calcium than those rocks previously described in which plagioclase is not abundant and has the composition of oligoclase or sodic andesine.

Plagioclase, then, has also participated in the post-sillimanite phase of crystallization. The development of plagioclase, primarily in the more argillaceous bands, suggests soda metasomatism. The bands rich in aluminum-silicate minerals represent the originally purer argillaceous layers in the sediment. These layers would normally be poor in soda and therefore some soda would have to be introduced to help form the considerable amount of plagioclase present. The preferential development of plagioclase in the argillaceous bands rather than in the more silicious bands is considered to be a function of available alumina. The coarser-grain size in these bands would mean that here chemical reactions took place more readily than in the highly quartzose bands; crystallization in these layers may have been further aided by the metasomatism which appears to have operated in these bands to some extent. During the period of deformation, the more argillaceous bands, which as stated above are more favourable to chemical reactions, have in this area chiefly tended to develop micas, and the precipitation of metasomatically introduced sodium in these highly aluminous bands appears to be entirely post-kinematic (static) in this region. The argument for sodium metasomatism is weakened by the lack of comparative chemical analyses of the schists and the low grade rocks from which the schists were derived. A certain part of the plagioclase, of course, must be considered syngenetic; its quantity would depend on the small but variable original sodium content of the argillaceous parent rocks.

Orthoclase is not common in the micaschists. However, one gray, sugary rock (Spec. 23) contains in addition to plagioclase, about 20 per cent orthoclase scattered among the quartz grains. This rock also contains biotite and occasional cross-cutting muscovite flakes with magnetite inclusions. Another specimen taken near a granite pegmatite dike has orthoclase porphyroblasts up to 1.8 mm. in size with inclusions of quartz, biotite, and large amounts of finely disseminated magnetite. Biotite partly replaces garnet, and muscovite partly replaces biotite. Some of the muscovite is intergrown with quartz in a replacement pattern resembling myrmekite.

Most of the potassium in the micaschists is bound in biotite. Syngenetic orthoclase was observed in considerable quantity in only one band. The orthoclase porphyroblasts formed in the vicinity of the granite pegmatite dike are interpreted as the result of potash metasomatism. The added potash and silica are believed to have been derived from the area of the pegmatite dike.

Magnetite is a fairly common minor constituent and occurs as finely disseminated inclusions, rounded grains, or elongate feathery-edged grains along cleavage cracks and along the margins of biotite. Some of the magnetite may represent original excess iron, and some of it may represent iron set free as a result of replacement of biotite by feldspar or muscovite. Occasionally, however, replacement of biotite by muscovite or sericite is not accompanied by the segregation of magnetite. The iron here must have migrated elsewhere.

Tourmaline occurs in some of the micaschists. Its pleochrism is: e - colorless, o - olive-green.

Much of the evidence described above is duplicated in a specimen from locality (23). The specimen comes from a thin layer of andalusite-sillimanite micaschist intercalated with marble. It contains helesitic andalusite porphyroblasts which include folded fibrolite. The andalusite is marginally surrounded by later sericite. Besides occurring in the andalusite, the fibrolite occurs in quartz, plagioclase, and in sericitic streaks that traverse the rock. Occasional cross-cutting muscovite flakes are present. Fresh appearing plagioclase (approximately An 29) occurs in the sericitic streaks and besides including sillimanite contains magnetite and tourmaline. It seems to have formed from sericitic material and to have included undigestible fibrolite. The plagioclase is zoned but the borders are only slightly more sodic. There can have been little migration of calcium into this rock from the marble; for under the fairly high temperature indicated by the well-formed andalusite, a plagioclase considerably more calcic than oligoclase would have formed if there had been appreciable calcium introduction. The lime-silicate bands nearby contain labradorite. Some segregation of furry-edged magnetite has occurred in the sericite-sillimanite streaks which must represent shear zones which formerly contained biotite. The tourmaline in this rock has pleochroism: O - tan, e - colorless. This may be the magnesium tourmaline, dravite.

Conclusion. The various features of the micaschists which have been described above, are interpreted in terms of the following phases of metamorphic history.

(A_1) Early part of synkinematic phase. During this phase, presumably the main phase of progressive metamorphism, the foliation was produced. The essential mineral was biotite; garnet and some well-crystallised sillimanite formed. Temperatures were katazonal.

(A_2) Later part of synkinematic phase. This was continuous with A_1. It was characterised by folding of the foliation and development of fibrolite, and partial deformation of garnet.

(B) Static phase. This was continuous with A_2 as is shown by local sillimanite-andalusite intergrowth. It was characterised by development of irregular and non-oriented porphyroblasts enclosing minerals which participated in the earlier phase of deformation. These porphyroblasts are staurolite, andalusite, and plagioclase. Minerals such as quartz and biotite, which had been forming during the synkinematic phase, continued to crystallise, often with the result that some hornfelsic texture was superposed on the inherited schistosity. Temperatures were essentially hotter mesozonal.

(C) Retrogressive hydrothermal stage. This was locally associated with a late phase of repeated deformation. It is characterized by the sericitization of sillimanite and andalusite, development of muscovite crystals which are almost completely free from any directional control, and further plagioclase development. This phase evidently reached a minor peak with the formation of muscovite porphyroblasts and plagioclase. The plagioclase that formed only locally in sericite streaks is oligoclase. Temperatures were mesozonal, probably cooler mesozonal, and in part even lower. Some of the minerals formed during this stage have subsequently been sheared in the development of sericitic streaks. Some of the sericite and muscovite development in this phase may be associated with phase D.

(D) Local potash metasomatism perhaps connected with some new rise in temperature. This is characterised by porphyroblastic growth of orthoclase, development of muscovite, and partial biotitisation of garnet. This local phase may have occurred during the later part or perhaps at the end of the main static phase of metamorphism (B).

Fine Grained Paragneisses

Megascopic description. Fine grained paragneisses (cf. definition above) make up a large percentage of the metamorphosed argillaceous rocks in the vicinity of North Salmon Creek. Two types can be distinguished: (a) those which are fairly homogeneous, and (b) those that are distinctly banded.

(a) Megascopically type (a) is not markedly banded. The layers of uniform composition are several inches to several feet wide. Different layers vary in the biotite/quartz-feldspar ratio and exhibit varying shades of gray. The color in any one band is not entirely uniform however; small scattered, irregular, light-colored patches are often present. Microscopic examination shows that these patches consist of quartz-plagioclase aggregates or of slightly larger plagioclase grains. Some rocks show one-quarter to one-half inch bands that have an almost aplitic texture and which contain quartz, feldspar, and small flakes of biotite, and sometimes small garnet crystals. Short schlieren-like, mica-rich streaks are often present.

(b) Type (b) are dark rocks exhibiting alternating bands or streaks, part of which are almost purely micaceous, and part of which, varying from lighter to darker, are composed of mixtures of biotite, quartz, and feldspar. The rocks sometime contain little knots or small augen-like lenticles composed of feldspar, quartz, and a small amount of biotite. These lenticles sometime coalesce to form light-colored pinching and swelling streaks. The composition of the surrounding rock is uniform up to the margins of these lenticles.

The light-colored knots and streaks can not be produced by metamorphic differentiation since the surrounding rock is not impoverished in feldspar or enriched in mafics. The composition of the surrounding rock is uniform up to the contact. The knots and streaks differ only by their slightly larger grain size and a relatively greater abundance of plagioclase and a smaller amount of biotite. The minerals present are the same, and the type of plagioclase is essentially the same. It would seem impossible for the injection of a silicate melt to produce isolated knots and augen-like structures which are surrounded by undeformed rock; moreover the composition of the minerals crystallized from such a melt would probably be different from that of the minerals in the country rock. The lenticles, knots, and streaks might be taken as representing bands containing larger amounts of feldspathic material of sedimentary origin. However, static soda metasomatism following the inherited foliation of the rock could produce the same results and would better account for the coarser grain size in these quartzo-feldspathic lenticles.

Local evidence of potash metasomatism in these rocks will be discussed below. Many narrow, cross-cutting granodioritic dikes with features that indicate intrusion as well as replacement occur in the schists. Larger, sill-like bodies of granodioritic composition and uniform aplitic texture are present. These will also be described below.

Microscopic description. Under the microscope the lighter colored, more uniformly textured type (a) shows an almost granoblastic texture. Irregular-shaped grains of biotite are oriented more or less uniformly to produce a schistosity; yet some of the grains lie across the schistosity at various angles indicating, as in the micaschists, that during the latest part of the period of biotite crystallization directional control was lacking.

Biotite occurs as streaks of interlocking flakes (cf. schlierenlike streaks mentioned above), but more commonly it forms more equidimensional grains that are often indented on their 001 faces to accomodate plagioclase crystals. In bands where quartz and plagioclase are relatively coarser grained, biotite is less abundant and some of it appears only interstitially in the quartz-plagioclase mosaic. This does not necessarily mean that plagioclase is replacing biotite since there is no definite evidence for such a reaction either in the pattern of their contacts or in the presence of reaction products. It is suggested that, as crystallization continues, biotite is evidently not able to exert sufficient crystalloblastic force to maintain crystal faces against growing plagioclase.

Quartz occurs in irregular grains. Sometimes it forms an aggregate of interlocking grains that include some biotite or plagioclase.

Plagioclase is xenoblastic and equidimensional. Polysynthetic twinning follows both the albite and pericline laws. Zoning is infrequent and the zones show only slight variation in composition. The plagioclase in the paragneisses is sodic andesine. It includes biotite, apatite, and quartz. Occasionally a plagioclase grain is included in garnet. This suggests that at least part of the plagioclase has formed before or during the growth of garnet. The grain size is about 0.4 to 0.6 mm. Some plagioclase forms small porphyroblasts that reach a size of 1.0 mm.

The composition and abundance of plagioclase in these rocks indicates that calcium was a minor but relatively important constituent; yet sodium is still more abundant and must in part have been introduced. The presence of biotite and quartz in plagioclase and its development at the expense of biotite indicate a preferential growth of plagioclase during a later phase that is ascribed to soda metasomatism. It might also be interpreted as the result of thermal metamorphism of an originally feldspathic metamorphic rock under conditions favorable to plagioclase development; however, there is no indication that the sodium contained in the relatively late plagioclase was present in the rock during its earlier phases of crystallization. A certain percentage of the plagioclase would, of course, be syngenetic.

Orthoclase or microcline is frequently present, sometimes in considerable amounts where the rock is adjacent to a dike rich in potash feldspar. The potash feldspar is poikiloblastic and includes quartz, biotite, and plagioclase. Some of the inclusions of plagioclase are partly to completely transformed to myrmekite. Plagioclase crystals adjacent to potash feldspar crystals have myrmekite on their borders. In specimen 59 potash feldspar is localized in areas that seem to have a pre-potash feldspar cataclastic structure which has been subsequently recrystallized. This may actually be a replacement texture resembling cataclastic structure comparable to the "psuedo-cataclastic structure" described by Anderson (1934).

(b) The above description also applies to type (b), the sharply banded paragneisses. It only need be added that the more strongly defined bands contain interlocking elongate flakes of biotite and sometimes of muscovite grains. These bands are actually thin bands of micaschist and display features similar to those described under micaschists. Among other features, bands occur in which muscovite has partly replaced biotite; this late muscovite includes sillimanite (specimen 41).

Common accessory minerals are xenoblastic sphene, indicating calcium in the original sediment, apatite, and magnetite which often has furry edges. Orthite is occasionally present; tourmaline is less common.

Discussion. The paragneisses add little to the metamorphic history determined in the phyllites and micaschists except to emphasise the post-kinematic phase (B). The evidence indicating some soda metasomatism is fairly conclusive. Most of the paragneisses are fine grained and not porphyroblastic; in other words, as far as sodium metasomatism has occurred, it has not reached a degree strong enough to produce the more typical porphyroblastic forms of replacement. A preferential growth of plagioclase during a late phase, especially in the coarser grained types, suggests some addition of material. The occasional light colored knots and streaks observed megascopically are interpreted as the beginning of a true gneissose structure produced by structurally controlled soda metasomatism.

Metamorphic History

The position of metamorphic isograds in the micaschists is complicated by evidence of a more varied metamorphic history

TABLE II

RELATIVE MINERAL COMPOSITIONS OF SOME PHYLLITES, QUARTZITES, MICASCHISTS, AND PARAGNEISSES

	Zone III			Zones I and II																																
Locality	1	2	3	6	6	6	7	9	9	9	9	9	16	24	23	22	10	11	12	13	14	19	21	21	17	18	8	8	8	42	37	34	35	38	36	12
Specimen No.	17	18	51	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	52
quartz	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	3	1	3	1	3	1	3	3	2	2	1	2	1	2	2	1	1	2	2	1	1
biotite	4	3	2	2	2	2	2	2	3	3	3	2	2	3	2	5	2	1	2	1	2	1	2	3	2	2	1	2	3	4	2	2	3	3	4	3
muscovite & sericite	2	4	3	3	4	t	4	t	2	2	2	-	4	-	3	1	4	-	4	2	4	4	t	-	t	3	-	-	-	-	-	-	-	-	-	-
plagioclase	-	?	-	t	t	3	t	3	-	4	t	1	3	1	5	2	3	2	3	4	1	2	11	1	1	t	2	3	1	1	1	3	1	1	3	2
orthoclase	-	-	-	-	-	-	-	4	-	t	-	-	4	4	-	t	-	-	-	-	-	-	1	1	1	t	t	-	-	3	-	1	4	4	2	-
sillimanite	-	-	-	-	3	5	-	-	4	t	4	-	-	-	6	4	5	-	-	6	-	-	-	-	-	t	-	-	-	-	-	-	-	-	-	-
andalusite	-	2	-	t	-	4	-	-	-	-	-	-	-	-	4	4	-	-	-	t	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
garnet	-	-	-	-	-	-	3	-	-	-	4	t	5	5	-	-	-	-	-	-	2	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-
staurolite	-	-	-	-	-	-	t	-	t	-	-	-	-	-	-	-	-	-	-	t	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
tourmaline	-	-	-	t	-	t	-	-	-	-	-	-	-	-	-	5	t	-	-	-	-	t	t	-	-	-	-	-	-	-	t	-	t	-	-	-
opaque min.	3	5	4	4	t	-	5	5	5	-	t	t	-	6	t	6	t	-	t	5	5	t	t	t	t	-	-	t	t	t	t	t	t	t	t	4
chlorite	-	t	-	t	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	t	-	-	-	-	3	-	-	-	-	-
apatite	-	-	-	t	t	t	-	-	t	t	-	t	-	t	t	-	t	t	-	-	-	t	t	t	t	-	t	t	t	-	t	t	t	t	t	-
zircon	-	-	-	-	-	t	t	-	-	t	t	-	t	-	t	-	t	t	t	t	t	t	t	t	t	t	t	t	t	t	-	t	-	t	t	-
orthite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	t	-	t	-	-	t	t	t	t	t	t	t	t	-	t	-	t	t	-
sphene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	t	-	-	-	-	-	t	-	-	-	-	-	t	-	-	t	-	-	-
epidote-zoisite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	t	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	t

Numbers refer to order of abundance; t refers to trace.
Localities from which specimens were taken are shown on Plate III.

than was seen in the lime-silicate rocks. In order to systematize the evidence observed in the micaschists, each applicable metamorphic classification will be considered separately.

I Isochemical metamorphism

A. Synkinematic metamorphism. The synkinematic phases A_1 and A_2 have been discussed above. The first, A_1, was the principal phase of progressive metamorphism and produced the foliation. In part of the area, temperatures were raised high enough to permit formation of the katazonal mineral sillimanite. The second phase of deformation, A_2, folded the foliation. The production of fibrolite in this phase was probably at slightly lower temperature.

B. Postkinematic metamorphism. High temperature conditions continued after cessation of the deformation although a slight decrease in temperature seems to be indicated. Staurolite, indicative of hotter mesozonal temperatures is found enclosing sillimanite. Somewhat later andalusite, locally enclosing staurolite, forms large porphyroblasts. This mineral has a wider temperature range than staurolite, but if well-formed, it is at least mesozonal. In the Sinlahekin area (Zone III, cf. below) andalusite occurs in phyllitic schists. Here it represents temperatures as high or probably somewhat higher than those that had been achieved during synkinematic metamorphism, which here was coolest mesozonal. In the Mineral Hill and Salmon Meadows areas sillimanite is occasionally present, characterizing the synkinematic phase as katazonal. Since later andalusite and staurolite are lacking in these areas, it may be assumed that katazonal temperatures continued into the post-kinematic phase although strong metasomatism in this area may have eliminated aluminum-excess minerals which would indicate the temperatures prevailing during this static phase.

Post-kinematic crystallization during phase B is everywhere evident. The tendency toward production of a hornfelsic texture, the polygonal arcs, the porphyroblastic growth of non-oriented aluminum-silicates, the inclusion in quartz, muscovite, plagioclase, andalusite, and staurolite of minerals marking the earlier foliation, have been noted above.

A retrogressive phase, C, accompanied by local deformation and hydrothermal activity is marked by the development of chlorite and sericite. It corresponds to epizonal conditions.

II Metasomatic metamorphism

Metasomatic metamorphism is at present discussed only with regard to the rather limited and local metasomatic phenomena observed in the schists. All the stronger degrees of metasomatism as a result of which schists and amphibolites have been converted into gneisses and granodioritic rocks will be described in Chapter III.

A. Synkinematic metamorphism. No definite evidence of metasomatism exists in the schists. However, the development of parallel bands and streaks of quartzo-feldspathic material in the paragneisses suggests soda metasomatism. Preferred orientation of plagioclase grains was observed occasionally (cf. quartzites) indicating the presence of plagioclase during deformation. This plagioclase however could be authigenic. There is no evidence for potash introduction during the synkinematic phase.

B. Post-kinematic metamorphism.

1. Sodium metasomatism. The greatest development of plagioclase has occurred after the period of sillimanite formation. Plagioclase includes sillimanite, is frequently poikiloblastic with quartz inclusions, and is occasionally porphyroblastic. Its growth is favoured relative to that of biotite. Sometimes late plagioclase occurs in areas where potash-feldspar might be expected, as for example in streaks of sericite, muscovite, and biotite. Some sodium and calcium would have to be added here unless the sericite was in part paragonitic. The schistose quartzites which would normally be expected to be low in sodium contain appreciable amounts of plagioclase.

The most significant evidence for sodium metasomatism is the increase in plagioclase content in the argillaceous rocks from the Sinlahekin area to the Salmon Creek-Mineral Hill area (cf. Table II and Plate III). Here large amounts of plagioclase varying from calcic oligoclase to sodic andesine indicate the presence of more sodium than would normally be expected in argillaceous sediments. The scarcity of aluminum excess minerals in the Salmon Creek-Mineral Hill area also suggests that plagioclase developed at the expense of these minerals.

The low grade phyllitic schists of the Sinlahekin area which are accompanied by no paragneisses contrast markedly with the sillimanite-bearing and staurolite-bearing micaschist bands and streaks of the Salmon Creek area which are associated with quartz-feldspathic knots and streaks and with abundant feldspar-rich, fine-grained paragneisses. This indicates a definite connection between the degree of feldspathization and the degree of regional metamorphism in the two areas. Obviously, the additional heat required for the formation of the higher grade minerals was supplied in connection with the feldspathization process. The rocks heated by a direct influx of heat would be those directly subjected to metasomatic feldspathization, but, of course, the temperature would also rise in adjacent rock masses undergoing isochemical metamorphism.

2. Potassium metasomatism. Examples of potassium introduction in the schists have briefly been mentioned. An

example of potassium introduction in a quartzite at a fairly high temperature without the formation of muscovite has been given (cf. p. 58). Here potash-feldspar replaces plagioclase. This indicates that the metasomatic plagioclase formation was earlier than the late stage of potassium introduction. An example of the formation of orthoclase and muscovite has been given above and been assigned to a late stage of B.

Late sericitization of andalusite and non-fibrolitic sillimanite with subsequent collective crystallization of the sericite into muscovite porphyroblasts is interpreted as due to a more general spread of a lower temperature potassium metasomatism. This may either be an expression of the main phase of potassium metasomatism in the area but representing its outer, cooler, margin; or it may be a separate low temperature hydrothermal phase of potassium metasomatism, though this appears much less likely (cf. below).

In the Sinlahekin area (Zone III, cf. below) the effects of potassium metasomatism are not as apparent. Slight sericitization of andalusite and some of the fine grained muscovite associated with late chlorite might perhaps be interpreted as suggesting minor potassium addition under low temperatures. No low temperature hydrothermal stages of metasomatism are included under phase C.

<u>Zoning</u>

On the basis of the evidence found in the phyllites, quartzites, micaschists, and paragneisses, the twofold zonal scheme established on the basis of the lime-silicate rocks can be enlarged to include a third zone comprising the phyllitic schists of the Sinlahekin area. It has been shown, however, that the synkinematic and static phases revealed in different areas of metamorphic argillites represent slightly different zonal conditions.

The zones are largely established on the basis of the lime-silicate minerals and partly on the synkinematic minerals of the metamorphic argillites. Slight variations in zoning produced in post-kinematic time are considered as superimposed on the primary zonal assemblages. Plate III shows the position of the metamorphic isograds and the places from which the critical specimens were taken.

Zone I is equivalent to area (b) of the lime-silicate rocks and is characterized by wollastonite, grossularite, and sillimanite. These minerals characterize the katazone.

Zone II is equivalent to area (a) of the lime-silicate rocks and is characterized by the association diopside-quartz-calcite plus scapolite. Sillimanite is also present in this zone indicating that it appears at a lower temperature within the katazone than wollastonite. This zone corresponds to the coolest part of the katazone. A certain lowering of temperature in post-kinematic time is indicated by the superimposed statically-formed staurolite and andalusite.

Zone III is established on the basis of the andalusite-bearing phyllitic schists. It corresponds to the coolest mesozone as far as the synkinematic metamorphism is concerned. A slight rise of temperature in post-kinematic time is suggested by the superimposed statically-formed andalusite porphyroblasts. Thus, in post-kinematic time temperature conditions in the areas of the synkinematic zones II and III had become more nearly equal.

Amphibolites

Distribution

Amphibolites, subsidiary hornblende-micaschists, and rocks that can be shown to be metasomatically derived from these are widespread in the area. Amphibolites extend well into the granodioritic terrain on the west that makes up the high country on the crest of the Okanogan Range.

The amphibolites include rocks probably both of sedimentary and igneous derivation. Amphibolites interbedded with marbles, lime-silicates, and micaschists in the Scotch Creek and Evans Lake sequence that contain diopsidic as well as quartz-bearing bands are probably para-amphibolites derived from impure dolomitic sediments. More homogeneous, usually directionless amphibolites, presumably higher in the stratigraphic section are probably ortho-amphibolites. The amphibolites prevail in the Salmon Creek area. The supposed ortho-amphibolites occur in the Blue Lake area in the somewhat less strongly metamorphosed northeastern part of the region. Meta-volcanics of the "Anarchist" series have been identified several miles northeast of the area mapped.

In this chapter only those rocks will be described which show little or no metasomatic transformation. Metasomatic derivatives of the amphibolites including gneissose and directionless varieties will be discussed in Chapter III.

As in the micaschists, the grade of metamorphism increases to the west and southwest. For purposes of description the amphibolites are divided on the basis of grade of metamorphism rather than of genesis.

Amphibolites of the Cooler Part of the Mesozone

The lowest grade amphibolites occur in the Sinlahekin Blue Lake area. The rocks are chlorite and biotite-bearing fine grained amphibolites. They are characteristically dark green to black and are less foliated than the more argillaceous rocks with which they are associated. To the west their metamorphic grade increases and they pass into dioritic gneisses.

In thin section these relatively low grade amphibolites are schistose, but with a superposed hornfelsic texture. All these rocks are fine grained. Some are porphyroblastic. Ferro-magnesian minerals predominate.

Hornblende is the dominant mineral with pleochroism: X - pale greenish yellow, Y - green, Z - green to blue-green; and with an extinction c/Z about 25 degrees. However in some of the rocks a pale green actinolitic hornblende occurs with X - colorless, Y and Z - light green, and with extinction c/Z about 16 degrees. The paler variety may form garbenschiefer, more commonly so, than the green hornblende. Other crystals form elongate prisms or more equidimensional but still feathery-edged subhedral grains which are commonly in aggregates. Where hornblende is included in quartz or feldspar it forms long acicular prisms. The actinolitic hornblende which usually forms garbenschiefer represents a slightly lower grade than the strongly pleochroic green hornblende.

Biotite is relatively abundant and occurs in decussate aggregates, individual flakes, or within hornblende aggregates. It is the olive-green variety of biotite that occurs throughout the area in rocks that contain, or have contained, green hornblende. Its pleochroism is X - pale straw, Y,Z - olive green. Biotite is replacing hornblende in many rocks. Evidence for this is the presence of irregular biotite flakes marginal to the hornblende and also the superposition of randomly oriented biotite flakes on partly directional hornblende aggregates.

Chlorite is present both in rocks which contain the pale hornblende and in rocks which contain the green hornblende, but more commonly in the former. The optical properties indicate that it is clinochlore. It is best developed in one specimen (8.25.50.16G) in which it forms large porphyroblasts reaching a maximum observed size of 2.0 mm that stand out prominently on the weathered surface. In thin section these porphyroblasts appear as individual flakes or interlocking aggregates with undulatory extinction. The chlorite follows no definite pattern in the rock. It encloses hornblende and biotite, and is obviously later than the hornblende and biotite. This fact, together with the lack of preferred orientation of the chlorite and its porphyroblastic habit, suggests that the chlorite represents a secondary peak of crystallization during a slightly retrogressive stage.

Quartz is occasionally present. It may be scattered throughout the groundmass or localised in clusters. Plagioclase is generally fine grained. When it occurs in the groundmass it is untwinned oligoclase, but in rocks that contain green hornblende it often forms small irregular porphyroblasts of sodic andesine that are frequently twinned. The porphyroblasts contain needle-like inclusions of hornblende. The porphyroblasts usually occur in an aggregate consisting of differently oriented, smaller plagioclase crystals.

Fine grained potash feldspar is present in several specimens. It is more abundant in those rocks in which much biotite has formed at the expense of hornblende. It is also present in minute hornblende-free veinlets in association with biotite and quartz.

Biotitization of hornblende and associated formation of potash feldspar suggest some introduction of potash, apparently at a low temperature and of short duration. It probably corresponds to the sericite-muscovite alteration of andalusite seen in the phyllitic micaschists.

In one amphibolite, which occurs at the contact of a later diorite dike that apparently was rich in volatiles, diopside, epidote, pyrite, calcite, and scapolite have formed.

Mesozonal to Katazonal Amphibolites

These rocks occur chiefly in the area around the North Fork of Salmon Creek. They include amphibolites, banded amphibolites partly containing lighter green diopside-bearing laminae, quartz-bearing plagioclase-biotite hornblende granulites, and microdiorites.[1]

The finer grained varieties are dark greenish-gray to

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1 The term "microdiorite" is used for a fine grained rock similar to a non-schistose amphibolite but containing plagioclase in excess of hornblende. Biotite may or may not be present. The texture is granoblastic but in some rocks the texture has an igneous appearance.

black. One lighter colored gray-green band on Funk Mountain north of the creek resembles the schistose actinolite-tremolite granulite of the "Evans Lake formation" that occurs to the southeast in the Conconully-Riverside area (cf. Chapter I). This rock represents a lower metamorphic grade than the black amphibolites around it.

In less fine-grained varieties, the light colored minerals, usually plagioclase, become more distinct and form streaks and lenses giving the rock a gneissose appearance. Sometimes small dioritic-looking areas with large hornblende crystals and much distinct plagioclase material surround a pod of hornblendite. Such dioritic looking areas also occur in the form of bands. These local areas are interpreted as the result of coarser recrystallization produced chiefly by the addition of volatiles. Larger areas of the same type of recrystallized amphibolite reach the dimensions of mappable units. One such occurs north of Mineral Hill and southwest of Salmon Creek (cf. geologic map).

The amphibolites also grade laterally into much larger units of dioritic and quartz-dioritic rocks. These passages will be described in Chapter III.

In hand specimens as well as microscopically, the amphibolites exhibit an imperfect parallel structure. The hornblende forms poorly oriented individual grains or aggregates giving the rock a granoblastic texture. This indicates that crystallization continued after the end of deformation as in the micaschists described above.

Banding is of three types: (1) alternations of bands with fine grained and with more coarse grained hornblende; (2) alternations of plagioclase rich and hornblende-rich bands; (3) alternations of hornblende-plagioclase bands with hornblende-pyroxene-plagioclase or pyroxene-plagioclase bands. Where banding of type (1) occurs, the plagioclase generally increases and decreases in grain size along with the hornblende. This differential coarser recrystallization is interpreted as being due to the introduction of more abundant volatiles along those layers. Banding of type (2) may be due both to metamorphic differentiation and to original differences in the quantity of argillaceous material. The pyroxene bands in type (3) represent layers of more dolomitic and less argillaceous sediment.

In one thin section (8.28.50.9G) the fine banding is crumpled, suggesting continuing deformation. However a granoblastic texture has been superimposed indicating that crystallization has lasted longer than deformation. In this specimen which represents an intermediate grade between the amphibolites of the cooler mesozone and those of the mesozonal-katazonal boundary region, the hornblende forms irregular aggregates and also randomly oriented individual subhedral grains. This glomeroblastic tendency was described in the amphibolites of the cooler mesozone. However in this rock the tendency is to form more compact, equidimensional clusters and grains rather than garben or feathery-edged grains. The more compact, equidimensional hornblende is characteristic of amphibolites statically crystallized under warmer mesozonal and katazonal conditions in the area studied.

In other amphibolites along Salmon Creek and north of Rock Mountain, the textures are also granoblastic, the structures schistose and occasionally banded as described above. Hornblende is pleochroic in green and blue-green. The extinction angle is consistently about 25 degrees. In the finer grained rocks (approximately 0.5 mm grain size), it forms subhedral grains of uniform size. Aggregates have a decussate texture. In amphibolites in which the grain size is larger (about 0.9 mm), the hornblende becomes more irregular in shape, frequently showing concavity where it is in contact with plagioclase. Often the concavity develops to such an extent that hornblende almost or completely surrounds smaller plagioclase grains. These rocks are not porphyroblastic. However, very rarely, in the finest grained amphibolite (0.15 mm), the hornblende may become porphyroblastic (0.8 mm observed maximum) marginal to a plagioclase-rich band. This suggests that some material associated with the development of the plagioclase, probably solvents, aided in producing favorable conditions for hornblende growth.

Plagioclase is equidimensional but xenoblastic. Both albite and pericline twinning are present; however the plagioclase is often untwinned. Plagioclase includes small hornblende grains and hornblende grains project into it marginally. It sometimes occurs in lenses with a decussate arrangement often with a larger grain in the center. Megascopically such aggregates resemble small augen. Lateral coalescing of such lenses produces the feldspar-rich streaks seen megascopically. The composition of the plagioclase ranges from labradorite to sodic andesine.

From the description of the hornblende and plagioclase in the amphibolites described so far, the following sequence of crystallization appears as higher grades of metamorphism are reached: (a) growth of hornblende in "garben" or feathery-edged aggregates and the formation of irregular plagioclase grains enclosing acicular hornblende; (b) development of better formed and compact hornblende grains and aggregates, and the development of more equidimensional plagioclase with few inclusions; (c) increase in grain size, and mutual envelopment of hornblende and plagioclase so that irregular margins are more common, especially in hornblende, and remaining small grains of one mineral may be found as inclusions within the other.

As the grade of metamorphism increases, the plagioclase becomes more calcic and increases in amount relative to hornblende (cf. Table III). Without the addition of sodium, however, the plagioclase does not become dominant at the expense of hornblende. Some soda may have been added to some of these amphibolites but this is difficult to prove without chemical analyses.

The pyroxenes that occur in some of the bands in the rocks vary from diopsidic-augite to a diopside rich in the hedenbergite molecule. Pyroxene forms small rounded grains, larger aggregates, or irregularly shaped larger poikiloblastic grains. The bands in which it occurs represent more dolomitic and less argillaceous layers.

Epidote is rare and occurs as a product of retrogressive alteration accompanied by the formation of chlorite (penninite). In one banded pyroxene-bearing amphibolite, however, the epidote forms small porphyroblasts enclosing hornblende and pyroxene, and it disregards the directional element in the rock. This is apparently an occurrence similar to the post-diopside stage of formation of epidote seen in the lime-silicate rocks. It is interpreted as a secondary peak of recrystallisation during a slightly retrogressive stage.

Quartz is rarely present. It occurs in only two specimens of amphibolitic rocks. One specimen (9.2.48.26, 58 in Table III) taken from an amphibolitic layer grading into a hornblende-quartz micaschist contains quartz in small sub-rounded grains. The plagioclase in this rock forms aggregates and small porphyroblasts which enclose hornblende and more frequently quartz. The other specimen (7.21.49.26), a gneissose amphibolite from the crest of the range north of Rock Mountain, contains medium grained quartz that partly replaces and partly envelops all other minerals. The quartz introduction is largely localized in narrow bands. This rock grades laterally into a coarse grained quartz-dioritic gneiss. In the former specimen (9.2.48.26) the quartz is considered syngenetic; in the latter specimen (7.21.49.26) it is considered to be of replacement origin.

Sphene is a fairly common accessory mineral in the amphibolites. It usually forms small rounded grains. Olive-green biotite is occasionally present and usually forms on the margins of hornblende grains. Where much biotite has formed, the amount of sphene increases slightly. Such additional sphene can perhaps be interpreted as binding calcium released from hornblende during biotitization of hornblende. Other accessory minerals are apatite, iron oxides, and retrogressive chlorite and sericite.

A few quartz-rich hornblende-biotite-plagioclase granulites show textures similar to those of the paragneisses and represent a more argillaceous sediment. The hornblende in these rocks is in small subhedral grains similar to the hornblende in the amphibolites. These rocks are believed to represent a slightly more dolomitic sediment than that which formed the biotite paragneisses.

<u>Metamorphic History and Zoning</u>

The amphibolites add little to the metamorphic history except to emphasize, by their superimposed hornfelsic texture, the post-kinematic phase of crystallization.

The late chlorite porphyroblasts in the Blue Lake area are believed to correspond in time with the slightly higher grade retrogressive development of epidote in some of the amphibolites and lime-silicate rocks of the Salmon Creek area. This establishes a secondary peak of crystallization during the period of retrogressive metamorphism which can be added to the proposed scheme of metamorphic history.

Pyroxene and labradorite occurring in the amphibolites in the Salmon Creek area (Zone II) indicate katazonal conditions, probably corresponding to the coolest part of the katazone and thereby matching the metamorphic grade determined in the lime-silicate rocks. The actinolitic-hornblende which in the Blue Lake area (Zone III) occurs in association with common green hornblende confirms that this area belongs to the cooler mesozone. The sodic andesine which occurs in the amphibolites of this area in addition to oligoclase, may represent a short-lived period of warmer mesozonal temperatures which did not produce any marked increase in grain size. The formation of andalusite porphyroblasts in the phyllitic schists

TABLE III

APPROXIMATE MINERAL COMPOSITIONS OF SOME AMPHIBOLITES AND RELATED ROCKS

	Zone III						Zone II					
Location	4	5	39	40	59	41	32	33	44	45	46	47
Specimen Number	53	54	55	56	57	58	59	60	61	62	63	64
labradorite				35					40		45	
andesine		40	40		45	35	40	45		30		40
oligoclase	35											
hornblende	60	60	50	55	55	40	50	50	50	65	50	40
biotite	-5	-	-5	-	-	-5	-	tr	-	-	tr	10
quarts	-	-	-	tr	-	20	tr	-	-	-	-	tr
pyroxene	-	-	-	5	-	-	-	-	-	-	-	-
sphene	-	-	-	tr	tr	-	-	tr	tr	-	tr	tr
iron oxide	tr	tr	tr	-	-	tr	tr	tr	tr	-5	tr	-
orthoclase	tr	-	-	-	-	-	-	-	-	-	-	-

Also apatite, orthite, chlorite, sericite, and epidote: tr - trace, -5 means less than 5 per cent but greater than 1 per cent. Locations of specimens are indicated in Plate II.

may correspond to the period of andesine formation in the amphibolites.

Summary of History of Isochemical Metamorphism in Area Studied

Synkinematic metamorphism - development of schistose fabric.

A_1 Initial foliation throughout the area; minerals of progressive metamorphism culminating in:

Zones in map plate III	I	II	III
Corresponding general metamorphic zones	high grade	coolest portion of high grade to highest medium grade boundary interval	medium grade
Metamorphic argillites	sillimanite	sillimanite	biotite
Lime-silicate rocks	wollastonite, grossularite	diopside, calcite, scapolite, quartz	
Amphibolites	green hornblende, diopsidic augite	green hornblende, diopsidic augite	actinolitic hornblende

A_2 Less complete deformation - folding of the foliation; development of fibrolite in Zones I and II. Probably at slightly lower temperatures. Passes into next phase:

Post-kinematic metamorphism - development of directionless fabric.

B Continued fairly high but somewhat decreased temperatures through most of the area. Mesozonal temperatures prevail; staurolite (Zone II), andalusite (Zones II and III). Local metasomatism; plagioclase development. Continuous with:
Later retrogressive phase, partly hydrothermal, with secondary peak of crystallisation. Epidote (Zone II), chlorite (Zone III), sericite followed by muscovite indicating slight secondary rise of temperature (Zone II and III). Local deformation.

C Disconnected later, low temperature phase. Chlorite, sericite, epidote in all zones. Local deformation.


1
2
3
4

PLATE V

Banded, diopside-bearing para-amphibolite. Hornblende, dark; diopside, clear, high relief; plagioclase, clear, low relief. Cougar Mountain (7.26.49.1g). Plane light, x 19.

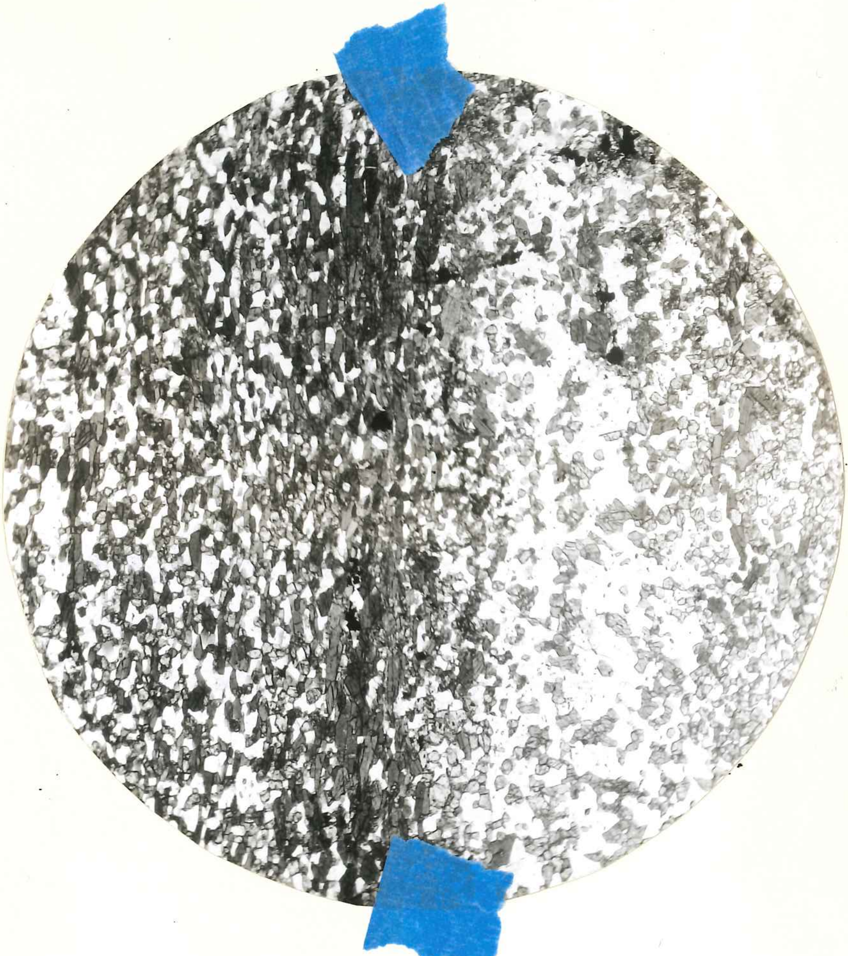


PLATE VI

Sillimanite-bearing micaschist. Fibrolite occurs in the wide, dark micaceous bands (top). Folding of the foliation. Polygonal arcs formed by biotite indicate that crystallization outlasted deformation. Locality 6, Plate III, (8.15.50.8g), x 18.

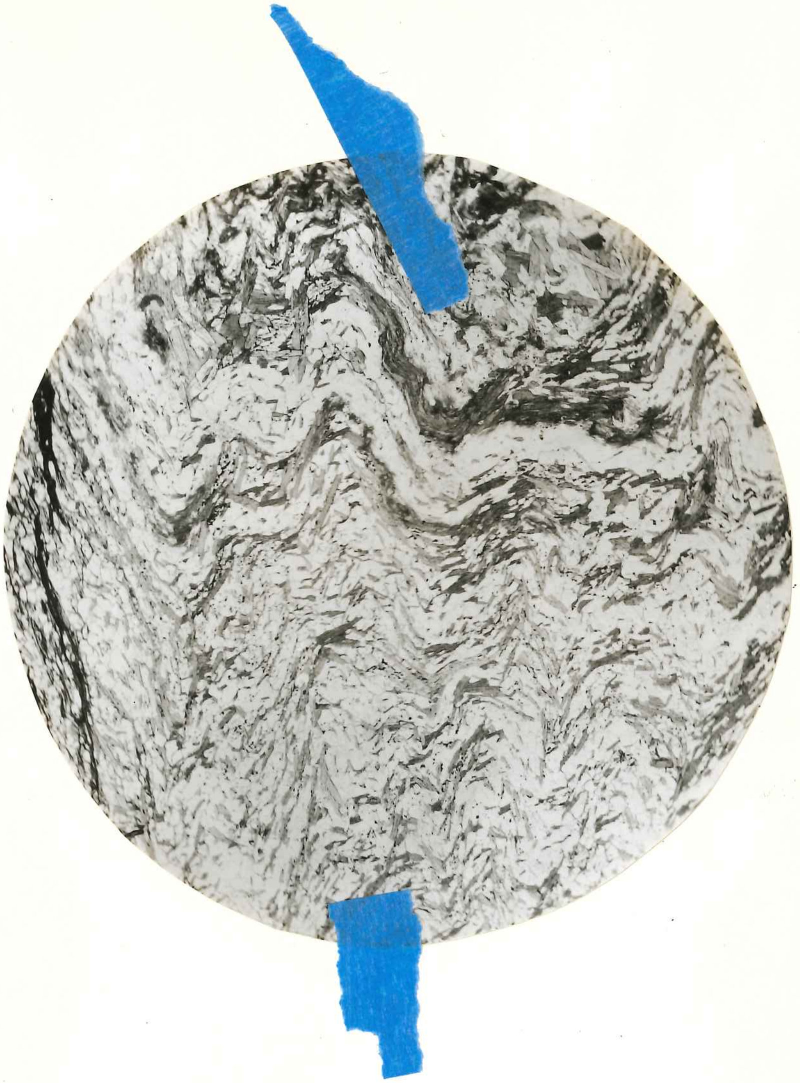


PLATE VII

Two micaschist. Undisturbed postkinematic muscovite porphyroblast (M) with helesitic structure. Folded material included in muscovite is biotite and opaque substances. Northwest side of Funk Mountain (8.11.50.2g). x 19.


M

PLATE VIII

A. Andalusite and sillimanite-bearing two micaschist. Postkinematic andalusite porphyroblast (dark, center), enclosing synkinematic fibrolite and other earlier minerals. Dunn Creek, Salmon Creek-Mineral Hill area. (8.3.50.14g). Crossed nicols, x 17.

B. Sillimanite-bearing two micaschist. Postkinematic sericite and muscovite forming around burst of fibrolite. Funk Mountain (8.6.50.9g), x 16.

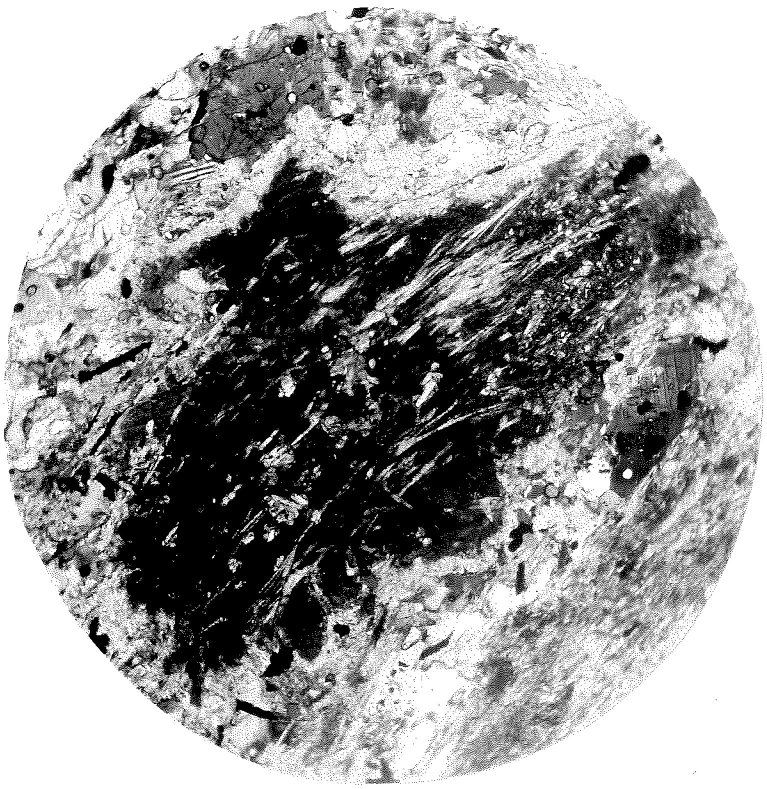
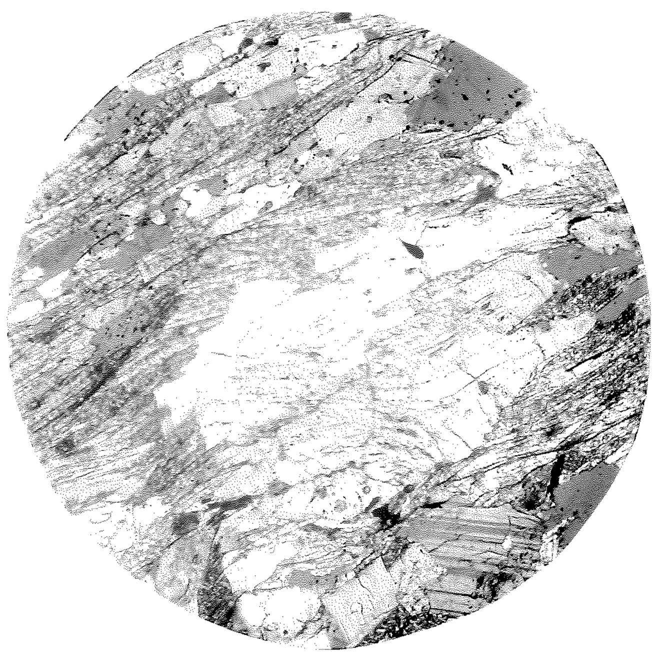


PLATE IX

A. Micaschist. Late- to postkinematic oligoclase porphyroblast forming in biotite-rich streak. Inclusions are fibrolite and opaque material. Big Canyon area (8.15.50.2g). x 16.

B. Same, crossed nicols.



CHAPTER III

MIGMATITIC GNEISSES

The isochemically metamorphosed rocks have been described in the previous chapter and a metamorphic history and zonal scheme established for them. However, the isochemically metamorphosed rocks make up only a small part of the area. Migmatitic[1] gneisses and directionless migmatites are much more widespread.

In Zone III, in the northeastern part of the area, evidence for only a slight potassium metasomatism at relatively low temperature was noted. Aplite and pegmatite dikes are lacking although a few minute veinlets are present. Aplite and pegmatite dikes appear and increase in number to the southwest accompanied by evidence for metasomatism of a higher grade in the formation of feldspathic streaks and lenticles and the local muscovite-potash feldspar growth in the predominantly non-granitized micaschists and paragneisses

---

1 Migmatites are defined as mixed rocks - country rocks mixed with material added from elsewhere, but excluding hybrid and contaminated magmatic rocks.

(cf. paragneisses).

In Zone I and II, especially Zone I, migmatitic gneisses with intercalations of non-granitized rocks are abundant. In the granodioritic complex to the west and southwest isochemically metamorphosed rocks are no longer preserved, but relict structures, and textural and compositional variations suggest that this area forms an "inner" zone of migmatitization.

Northwestward along the regional trend, a similar progression takes place. For example, massive augen gneisses[1] suggesting a marginal zone of migmatitization enriched in volatiles[2] passes into less uniform, more thoroughly metasomatized synkinematically banded gneisses and granodioritic gneisses. Amphibolites are eventually transformed into hornblende bearing quartz-dioritic and granodioritic gneisses.

---

1 Augengneisses are characterized by elongated, lenticular, individual, well-defined, large feldspar grains or groups of crystals. (Misch, unpublished manuscript). Augengneisses may have a fine grained matrix of the texture and mineral content of a schist, but augengneisses may also have, as they do in the area mapped, a coarser grained matrix which no longer resembles a schist.

2 The occurrence of augengneisses in marginal belts of migmatitic areas has been discussed by Misch (1949a p. 232).

Migmatitic Gneisses in Zones I and II

Migmatitic gneisses trending into the area from the southeast along Salmon Creek are, in the Mineral Hill area, interbedded with bands of biotite paragneiss, marble, lime-silicate granulite and amphibolite of the Scotch Creek Schist. These migmatites consist of directionless to gneissose dioritic and quartz-dioritic rocks, biotite and hornblende-biotite banded gneisses, flasergneisses[1] and augengneisses. Local bands of granodioritic composition occur. These rocks grade into each other and into the inter-bedded non-granitized metamorphic rocks. Migmatitic gneisses derived from purer argillaceous rocks are subordinate. The bulk of the migmatites are hornblende bearing and derived from amphibolitic rocks as the writer will try to show below.

The late, widespread static recrystallization observed in the non-granitized schists has strongly affected the migmatitic gneisses and has weakened or obscured any sharp parallelism formed during earlier synkinematic metamorphism. Many portions of the migmatites lack evidence for a synkinematic phase and are entirely recrystallized under static conditions.

---

1 Flasergneisses are "characterized by an uneven and lenticular parallel structure, usually with mica-rich fabric weaving around irregular elongated lenticular portions of quartz and feldspar." Misch (unpublished manuscript).

These directionless areas and layers in the gneisses are subordinate but gradational with the gneisses and so will be described with them.

<u>Flasergneisses</u>

These rocks vary from types in which biotite is the chief ferromagnesian mineral to those in which hornblende prevails. Dioritic gneisses transitional with trondhjemitic and granodioritic flasergneisses are rich in hornblende.

The rocks form a series in which amphibolites or hornblende micaschists with individual plagioclase porphyroblasts or feldspathic lenticles pass into flasergneisses with a more general development of feldspars. The flasergneisses have a wavy, uneven parallel structure marked by mafics which weave around lenticular feldspar, or feldspar and quartz, aggregates. Fine and medium grained flasergneisses pass into augengneisses with the development of large individual feldspar porphyroblasts which may be plagioclase but are usually potash feldspar.

In the field these rocks contain streaks and bands of hornfelsized amphibolitic rock. These streaks and bands are all parallel to the foliation in the rocks and to the trend of the rock units. They are similar to the hornfelsized schists and amphibolitic rocks of the non-granitised areas. They are interpreted as in situ relicts of the original material from which the gneisses were formed. The flasergneisses are gradational on the one hand with gneissose, partly banded dioritic rocks and on the other with hornblende-biotite augengneisses.

Microscopically the texture of the flasergneisses is crystalloblastic. Grain sizes are highly variable. Mafics occur in clusters or streaky patches and rudely weave around the quartz-feldspathic areas.

The plagioclase shows both carlsbad, pericline, and albite twinning. Its average size is about 1.8 mm, its observed maximum size is 4.2 mm. Rocks in which such large plagioclase grains occur approach augengneisses. The composition of the plagioclase is sodic andesine. The crystals are elongate with a ratio of length to width of about two to one. The borders are crenulated. Plagioclase and biotite have irregular contacts, with neither mineral developing crystal faces. Plagioclase includes biotite, hornblende, and rarely, quartz. The inclusions represent minerals present during the growth of plagioclase. Quartz and potash feldspar are seen to replace plagioclase. In some specimens the plagioclase tends to assume a preferred orientation. This suggests the presence of stress during crystallization. The plagioclase shows a partly healed cataclasis by displaced segments of crystals, bent twin lamellae, and occasionally a small amount of mortar.

Hornblende, biotite, and potash feldspar have grown in the cracks in the plagioclase. This indicates that the hornblende and biotite, although being essentially pre-plagioclase, have still later on continued to recrystallize and even been able to move, obviously by means of solution and reprecipitation.

The hornblende has pleochroism: Z - bluish-green, Y - green, X - yellowish-green. It is xenoblastic. It is partly biotitized; the biotite has formed at the margins of the hornblende grains as well as in patches in their interior. Some of the hornblende forms large (about 4.5 mm.) poikiloblastic grains which include apatite, plagioclase, quartz, and biotite. Contemporaneous growth of plagioclase and hornblende is indicated since plagioclase also includes hornblende.

Olive-green biotite forms randomly oriented flakes, either isolated or with hornblende, or it appears in clusters or aggregates with hornblende and sphene. Some of the biotite may be early, the rest appears to have been formed from hornblende.

Sphene is the dominant accessory mineral. It generally occurs with hornblende and biotite and forms either aggregates of rounded grains or individual sub-diamond shaped blebs. Iron oxide is frequently associated with it.

Quartz is present in variable amounts and forms grains of all sizes, some of which enclose plagioclase. It is often present in plagioclase in the form of myrmekite. Quartz sometimes forms myrmekite-like areas in biotite. These areas are considered replacement features. Quartz also replaces hornblende and plagioclase. Its active development is contemporaneous with the potash feldspar development in the rocks.

Potash feldspar has grown along the grain boundaries of the other minerals and has a highly irregular form. Occasionally it occurs as filling in fractures in plagioclase, or as antiperthitic inclusions in plagioclase. It appears in fine grained cataclastic-appearing areas in the groundmass with quartz and plagioclase, but it also forms larger grains which engulf these same minerals. Inclusions are more common at the margins of these grains. Occasionally a faint grid pattern of the microcline type is seen.

Epidote is occasionally present. It is associated with hornblende and biotite. It is less often observed in rocks south of Salmon Creek than in rocks north of Salmon Creek near Zone III. In the latter region, much of the epidote contained in the rocks was present before the final stage of development of potash feldspar and is either "primary" (a product of progressive metamorphism) or was formed as a product of biotitization of hornblende during potassium metasomatism (also cf. Fish Lake Granodiorite, Chapter IV). In the former region which includes Zone I and part of Zone II, "primary" epidote is not present and the epidote is mostly definitely retrogressive and occurs with chlorite (pennine) and late magnetite. Such retrogressive epidote could, of course, be present in either region. South of Salmon Creek, the calcium released during the biotitization of hornblende was apparently used to form more plagioclase rather than epidote.

Orthite, pleochroic in reddish-brown and pale brown, is a minor but common accessory mineral.

Occasional light colored veinlets that traverse these rocks are rich in quartz and potash feldspar.

Approximate mineral compositions of some of the flasergneisses are given in Table IV. The time relations of the minerals may be illustrated as follows:

```
                      early                late
plagioclase              -----------
hornblende              -------------
early epidote(?)        - - - - - -----
sphene                  - - - ---------          ---
biotite                 - - ------------
quartz                     - - ------------
potash feldspar                  ------
chlorite, seri-
 cite and second-
 ary epidote                                    ------
```

Figure 2

Time Relations of Minerals of Hornblendic Flasergneisses

(Widely spaced dashes indicate possible occurrence)

<u>Augengneisses</u>

The augengneisses are composed of the same minerals

TABLE IV

AVERAGE MINERAL COMPOSITIONS OF SOME HORNBLENDIC GNEISSES

Mineral	Flasergneisses Mineral Hill (5 specimens)	Quartz-dioritic gneisses Headwaters Sinlahekin Creek (5 specimens)	Salmon Creek (5 specimens)
andesine	65	60	60
quartz	10	20	-15
potash feldspar	5	tr	-5
hornblende	10	10	-10
biotite	10	5	5
sphene	tr	tr	tr
also epidote, orthite, apatite, iron oxide, chlorite			

and show the same textures and structures as the potash feldspar bearing hornblende-biotite flasergneisses, except that they contain large poikiloblastic microcline crystals. These porphyroblasts have an observed maximum size of 5 cm. They show carlsbad twinning and they contain inclusions of quartz and biotite. Megascopically the large crystals have fairly good crystal form whereas smaller ones are more irregular. In some of the rocks the porphyroblasts have a tendency to follow the foliation, most of the augen, however, are oriented at random. This shows that the maxima of potash feldspar growth in these rocks was post-kinematic. Some bands of augengneiss however, contain elongate, lenticular porphyroblasts in parallel orientation which indicates deformation contemporaneous with the porphyroblastic growth. The groundmass of these rocks contains distinctly smaller porphyroblasts of plagioclase and irregular microcline. Excluding the large porphyroblasts then, the composition and texture would be close to that of the flasergneisses described above. Dark lenticles of almost pure biotite are occasionally present.

Under the microscope, the microcline porphyroblasts display highly crenulated margins with irregular projections extending into the groundmass. Portions of the groundmass are enclosed. Included minerals are plagioclase, quartz, myrmekite, hornblende, and biotite. The inclusions of plagioclase range in size from 1 mm to perthitic blebs. Any plagioclase occurring adjacent to microcline invariably contains myrmekite. The plagioclase, as in the flaser-gneisses, is andesine. Thin albitic rims occur on some of the plagioclase inclusions in the microcline. This might suggest that some soda accompanied the potassium which was introduced to form the microcline porphyroblasts. In partial confirmation of this suggestion, sharp bordered pegmatites, belonging to the same general phase of potassium introduction, occurring elsewhere as fracture filling with apparently little or no involvement of the actual wall rock, contain sodic oligoclase as a primary constituent.

Replacement of the earlier minerals by both quartz and potash feldspar, and the biotitization of hornblende indicate late potassium and silica introduction. The amount of potash feldspar present in the gneisses, especially in the augengneisses, is far greater than could be expected to have formed from the original hornblende-micaschist or amphibolite as exemplified by the relict streaks and bands in the rock. The textures indicate that the potash feldspar formed in place in the pre-existing rock in some places contemporaneously with its deformation but for the most part after its deformation. The potash feldspar formed after the plagioclase had already attained a good development in the pre-existing rock.

The relict amphibolitic and micaschist streaks and bands in the flasergneisses and augengneisses are taken as approximately representing the composition of the original rocks, and the minerals hornblende, sphene, some biotite, and plagioclase are interpreted as representing material inherited from the original rocks.

Gneissose Dioritic Rocks

Gneissose diorites showing weak parallel structure form bands in the migmatitic gneisses. They are transitional with quartz-dioritic hornblende-bearing flasergneisses and augengneisses and they contain relict bands of hornfelsized amphibolite. The dioritic gneisses vary from fine to medium grained. Their texture is crystalloblastic and resembles that of the more equigranular amphibolites, except for the coarser grain size and the greater abundance of plagioclase. The plagioclase has labradoritic centers and rims of sodic andesine. It occasionally forms small porphyroblasts. Some biotite has formed from hornblende. The minerals are the same as in the flasergneisses except that no potash feldspar and very little quartz is present. These rocks may represent the stage of metamorphic development prior to the deformation preceding the potash introduction in the flasergneisses.

The gneissose diorites grade into layers of more or less structureless rocks which show no evidence of deformation and are essentially statically recrystallized. It is thus demonstrated that not only has there been differential metasomatism, but also differential deformation in the area. These structureless rocks have a variable texture. Some patches are fine-grained-microdioritic, others coarse grained-dioritic. Feldspar rich patches are irregularly distributed. Their lack of alignment suggests static recrystallization. These patches are attributed to local differential metasomatism. Plate XXV B illustrates the formation of feldspathic veins and patches in these rocks. The dike-like band in the center of the figure is composed of the same material as the wall rock, except for the additional feldspathization along it. It is interpreted as a narrow shear zone which was also an avenue for the introduction of metasomatic material.

Amphibolite-Trondhjemite Sequences

Transitional sequences from amphibolite to gneissose quartz-dioritic and trondhjemitic rocks occur in the migmatite zones. These form either mappable, fairly wide belts, or narrow bands in which transition is more rapid, and, at the same time, frequently repeated so that banded gneisses result. The transitional gneisses parallel the northwest-trending amphibolites and diopside-bearing amphibolites of the Scotch Creek-Evans Lake unit.

The change in mineral composition of two fairly wide belts which typically display the transitional sequence is illustrated diagramatically in Figure 3. The features to be noted are: the decrease in the anorthite content of the plagioclase, the decrease in the amount of hornblende, and the increase in the amount of quartz and plagioclase. Little potash feldspar is present in these rocks.

Textural rearrangement accompanies the compositional changes. The texture in the amphibolites along Salmon Creek is granoblastic as a result of the superposed post-kinematic crystallization which occurred in the area. The fabric has been described in the chapter on amphibolites. As the amphibolites pass into rocks of quartz-dioritic composition, hornblende at first concentrates in large irregular grains that often enclose smaller plagioclase grains. At the same time the total amount of hornblende decreases and the rocks become light-colored. Plagioclase becomes larger in grain size and less calcic. In the amphibolites, the plagioclase varies from labradorite to andesine and often has inclusions of hornblende. The plagioclase becomes sodic andesine (oligoclase at Rock Mountain, cf. below) in the quartz-dioritic gneisses. As the plagioclase grains become larger, they clear themselves, but retain their irregular outlines. In some veinlike areas in the rocks where volatiles have been more active, the plagioclase forms much larger crystals and approaches crystal

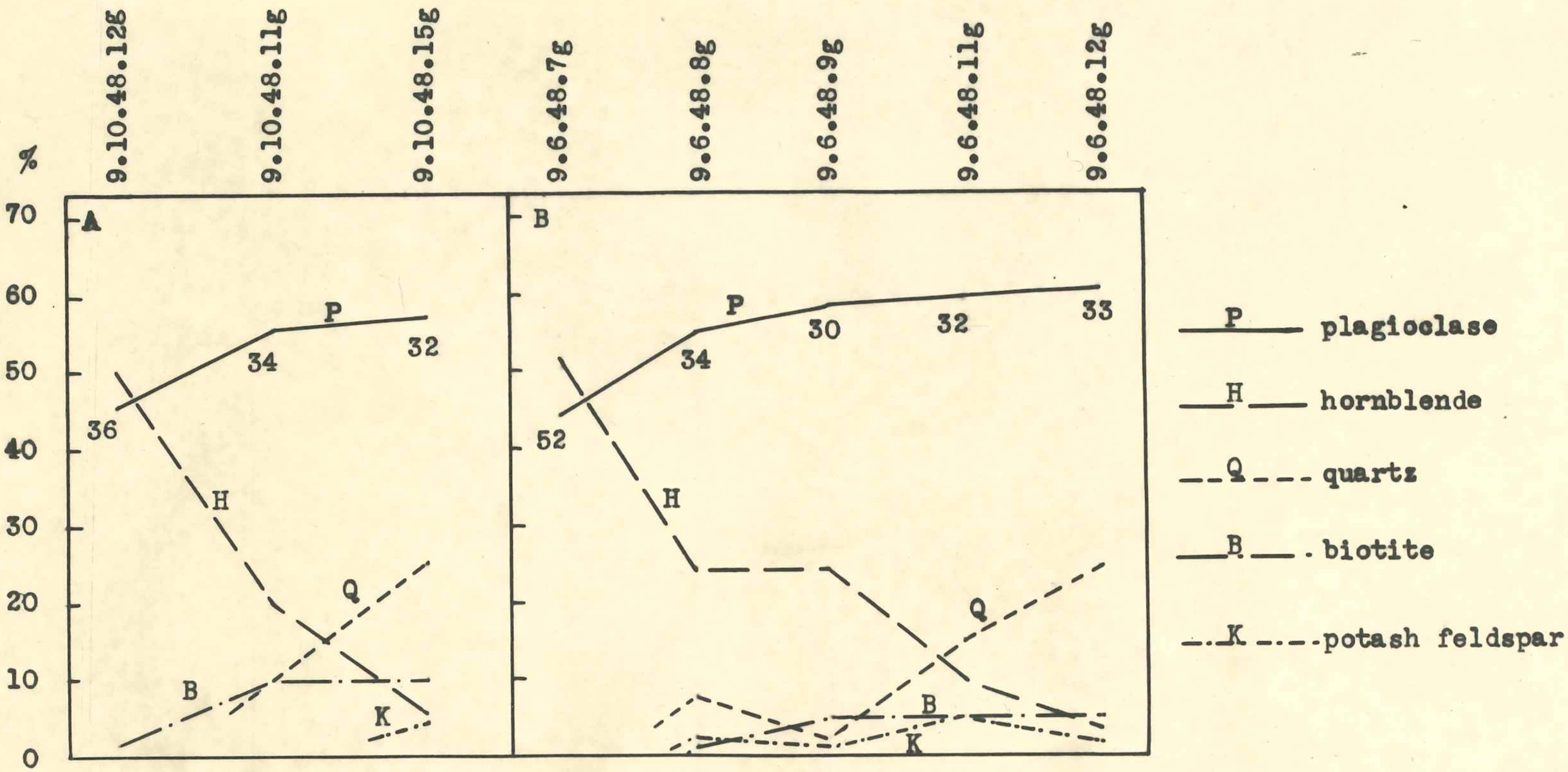


FIGURE 3

CHANGES IN MINERAL COMPOSITION IN TWO AREAS ILLUSTRATING THE TRANSITIONS FROM AMPHIBOLITE TO TRONDHJEMITIC GNEISS

A. Salmon Creek, three quarters of a mile west of Salmon Meadows. Transition zone is fifteen yards wide. B. North side of road on Mutton Ridge, three miles northwest of Salmon Meadows. Transition zone is 100 yards wide. Accessory minerals are apatite, sphene, iron oxide, orthite, chlorite, epidote. Biotite altered to chlorite in 9.6.48.11 and 12. Numbers under the line representing plagioclase refer to the anorthite content.

form. With the increase in the amount of plagioclase and quartz, hornblende becomes poikiloblastic in a passive sense, i.e. its form is determined by its rearrangement by solution and re-precipitation around more actively growing minerals, and it becomes more and more relegated to an intergranular position. The overall change in texture is illustrated in Plate XIII. The volume of quartz shows the greatest increase. Some of the more predominantly leucocratic, quartz-rich rocks have a recrystallized cataclastic texture. The recrystallization which healed the cataclastic structure was connected with considerable introduction of quartz. The replacement of earlier minerals by quartz in this case is later than the development of the sodic plagioclase and apparently not connected with it. The introduction of much quartz is, throughout the remainder of the area, generally linked with predominant potassium metasomatism; although in several areas the introduction of quartz continued after the main period of potassium introduction had ended. However, in the northwestern portion of the Salmon Creek migmatite zone in which the amphibolite-trondhjemitic gneiss sequences occur, potash feldspar is subordinate and appears only in incipient forms locally in the intergranular or it appears in small cross-cutting pegmatitic veinlets.

The decrease in the anorthite content of plagioclase and the increase in the total amount of plagioclase suggest an addition of soda. Similar changes in the plagioclase are observed elsewhere in the area wherever migmatitic rocks derived from amphibolitic materials occur, as in the banded gneisses on Rock Mountain. Here the plagioclase is usually oligoclase.

One lenticular body of quartz-rich granodioritic rock, appearing along the trend of an impure diopside bearing quartzite-amphibolite sequence, appears to have formed from the rocks of this sequence. The granodiorite contains irregular poikiloblastic diopside and hornblende grains. These are considered to be recrystallized remnants of minerals of the lime-silicate quartzite amphibolite sequence. It appears particularly significant that diopside has been inherited from the lime-silicate rocks and now occurs in a light colored acidic rock. Diopside and hornblende also occur as shreddy relics in plagioclase. As in the flasergneisses, a post-plagioclase pre-quartz-potash feldspar deformation has occurred which has been partly obliterated during the stage of quartz and potash feldspar growth. The deformation has not been sufficiently directional in this rock to induce a gneissose structure. The plagioclase is oligoclase. Sphene is a common accessory.

Hornblende-Bearing Banded Gneisses

Megascopic description. Banded gneisses are best developed in the Rock Mountain area on the crest of the Okanogan Range. The crest of the range is largely above timberline and glaciation has produced cirques which provide excellent rock exposures. However, banded gneisses also occur to the southeast in the Mineral Hill-Salmon Creek area.

Near Rock Mountain the rocks are predominantly banded gneisses and flasergneisses of quartz-dioritic and trondhjemitic composition. Augengneisses are not typically developed here although porphyroblasts of potash feldspar are locally abundant. The gneisses here lie in the prolongation of the strike of the amphibolite-derived gneisses of the Mineral Hill-Salmon Creek area. However, there is no physical continuity of the two gneiss area, because the largely directionless Hutton Ridge quartz-diorite body intervenes. To the west and southwest the banded gneisses of the Rock Mountain area continue into a vast complex of varied gneissose and directionless granodioritic and trondhjemitic rocks that make up the western slope of the range. Actually the Rock Mountain gneisses are marginal to this "inner" complex. On the south the banded gneisses pass into the largely directionless Tiffany Diorite complex.

In general, the development of banded gneisses in the hornblendic rocks is from stringers of individual feldspar porphyroblasts to parallel lenticles and streaks of feldspathic material, and finally to light colored pinching and swelling bands. These bands may revert again along their strike to stringers of individual porphyroblasts and finally disappear again.

The banded gneisses of the Rock Mountain area contain layers of hornfelsized and partly biotitized amphibolite and also relict pods of gneissose amphibolite. The relict schistosity in these basic remnants is parallel and continuous with the foliation of the enclosing gneisses. Most darker bands are not truly amphibolitic any more, but are still richer in hornblende and biotite than the light colored bands. Some of these bands are hornblende-plagioclase-biotite schists, others less schistose, are weakly gneissose dioritic granulites composed of the same minerals. The darker bands pass laterally into lighter colored, more directionless bands rich in feldspar and quartz, and low in mafics. Sometimes the mafic-rich bands are only thin streaks in wide bands of light colored rock; sometimes it is the light bands that are subordinate. The darker bands are usually finer grained than the light bands. Sometimes both darker and lighter bands are coarse grained and differ only in the proportion of mafics. All gradations and all types of banding occur and the widths of any one type of band may have a wide range from fractions of an inch to many feet. Many of the bands have a flaser structure. Locally large potash feldspar porphyroblasts occur as individuals or form pegmatitic patches in the gneiss.

Microscopic description. The darker bands are rich in green hornblende and olive green biotite. The biotite has formed in part from hornblende and although individual flakes do not have a strict parallel orientation, aggregates of biotite form linear streaks which provide the directional element in the rocks. The lack of strict parallelism of the micas in the rocks illustrates again continued crystallization during a post-kinematic phase. Hornblende and plagioclase are xenoblastic. In the darker bands plagioclase forms small grains about 0.5 mm. in size, but it occasionally shows porphyroblastic development to grains about 1.0 mm. in size. These small porphyroblasts include hornblende, biotite, and quartz.

The darker bands pass into and alternate with lighter bands that are usually more coarse grained. In these bands plagioclase sometimes forms augen with an observed maximum size of 8.0 mm., but usually the plagioclase averages slightly less than 4.0 mm. A preferred orientation of plagioclase is often present. Biotite has largely supplanted hornblende as the dark mineral. The lighter bands are enriched in quartz and impoverished in mafics. Quartz replaces plagioclase or appears as filling in fractures in plagioclase. The healing of the fractures in the plagioclase indicate a stage of deformation which was apparently slight, prior to quartz introduction, similar to the pre-quartz deformation seen in the trondhjemitic belts of the Salmon Creek zone. In some wider, more coarse grained bands, quartz forms coalescing grains surrounding smaller, equidimensional plagioclase grains. Occasional streaks rich in biotite mark the foliation in the rock. Occasional large partially biotitized xenoblastic hornblende grains occur. Often biotite, sphene, and epidote occur in aggregates with remnants of hornblende. Microcline is common in the lighter bands and sometimes forms large porphyroblasts. The microcline replaces and encloses plagioclase. Myrmekite is usually present. Microcline, more commonly than plagioclase, forms augen.

In the gneiss as a whole, textures are crystalloblastic and in any one portion of the rock grain sizes are highly variable. The plagioclase is fairly consistently a calcic oligoclase. There is no apparent difference in composition between the larger and the smaller plagioclases in the rocks, nor any marked difference in composition of the plagioclase in the darker and lighter colored bands except that in the lighter bands, the plagioclase may become more sodic (about An 23). Often the plagioclase is antiperthitic.

The observed mineral paragenesis is the same as that in the flasergneisses and augengneisses in the Mineral Hill area to the southeast.

Locally, biotite has been altered to chlorite and magnetite. The chlorite (pennine) appears along cleavage planes in the biotite where it forms streaks partly rimmed by magnetite. Sphene and leucoxene, apparently mobilized by solution and re-precipitated, sometimes forms a lacy or dendritic network following a cleavage and fracture pattern in plagioclase or other minerals.

Chemical changes - discussion. The composition of the lighter bands ranges from quartz-dioritic to trondhjemitic to granodioritic. Some approximate mineral compositions of lighter and darker colored bands are listed in Table V. The table shows the enrichment in quartz and potash feldspar and the decrease in mafics, especially hornblende, in the lighter bands. The apparent loss of calcium suggested by the decrease in hornblende in the rock may be accounted for in two ways: either it has been carried off in solution or it has been fixed in epidote or in additional plagioclase. Little epidote is present. If the calcium set free during the elimination (to a large extent biotitization) of hornblende has been fixed in additional plagioclase, an introduction of sodium must be assumed,[1] since the plagioclase in the light colored bands is never more calcic and may be somewhat more sodic than the plagioclase in the hornblende-rich darker bands. Moreover an actual increase in total

1 There can be little doubt that sodium has been added during an early stage of evolution of these rocks. Reference is made to the discussion of the same question with regard to the amphibolite-trondhjemite transitional sequense (cf. above).

volume of the rock would appear to have occurred since the percentage of plagioclase is usually somewhat lower in the light colored than in the darker bands; however, it is very likely that the slight relative decrease of plagioclase in the light colored bands has to be interpreted in a completely different way, namely in terms of part of the plagioclase having been replaced by quartz and microcline during a late stage of evolution of the rock (textural evidence for such replacement is very widespread). This replacement of plagioclase by quartz and microcline would imply probable removal of some calcium together with sodium at this late stage - unless a considerable volume increase has occurred during this stage.

A third alternative would be a combination of removal of some of the calcium and of fixation of the rest.

Magnesium and iron also decrease in amount as is shown in the total decrease in mafics. The same question arises whether this decrease is relative or absolute. That silica and potassium were introduced to form quartz and potash feldspar as shown by the replacement textures referred to above, indicates an open system which might very well have permitted the escape of some other substances such as calcium and sodium as well as magnesium and iron.

Origin of banding. As stated above, the proportion of light and dark bands as well as their individual thickness are extremely variable. This precludes that the bands could have formed by metamorphic differentiation in which case a reasonably constant proportion of light and dark bands would have to be expected (cf. Misch, 1949a, p. 229). However, local metamorphic differentiation is represented by thin plates of almost pure biotite localized along zones of strong differential movement. Such local deformation is merely a subsidiary mechanism and not accountable for the general and major banded structures. More sharply bordered light colored bands that can be attributed to actual injection of material also occur, although these bands are very local and belong to a later stage of aplitic replacement and injection which generally forms cross-cutting contacts but that sometimes form bands which parallel the earlier foliation.

On the basis of the following features, the light bands are interpreted as formed by lit-par-lit replacement (cf. Misch 1949a p. 230): The presence of all kinds of gradations between the schistose amphibolitic bands and the lighter gneissic bands; the gradational nature of the contacts; the extensions of light bands into thin and discontinuous stringers of individual porphyroblasts that eventually disappear in the dark rock; and the absence of structural features indicative of a splittling open of the schistose country rock by a forcesbly injected liquid. The parallelism of all the bands and the relict parallel structure within the quartzo-feldspathic bands suggest that replacement was controlled not so much by differences in composition between layers, as by oriented differential deformation which provided avenues for the introduction of metasomatising fluids. As mentioned above, post-kinematic recrystallisation has weakened or partly obliterated the earlier kinematic structures.

Sequence of Metasomatism

On the basis of the evidence obtained from the dioritic gneisses, flasergneisses, and banded gneisses, the following sequence of metasomatism is deduced: Sodium was first introduced to form more abundant and more sodic plagioclase. Silica possibly was introduced throughout the period of metasomatism but reached a maximum during and after the period of potash introduction. Potassium first biotitized hornblende before it formed potash feldspar.[1] Sodium appears to have been present in the introduced fluids throughout the metasomatic history; for albitization has occasionally occurred contemporaneously with or slightly after potash introduction (albitic rims around plagioclase in potash rich rocks, and presence of sodic oligoclase in fissure-filling pegmatites which were segregated during a late stage).

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1 Certain physical-chemical conditions apparently occur under which hornblende persists without being biotitized although potash feldspar appears (cf. Fish Lake granodiorite, Chapter IV).

TABLE V

APPROXIMATE MINERAL COMPOSITIONS OF DARK AND LIGHT BANDS IN GNEISSES FROM ROCK MOUNTAIN AREA

Specimen	1		2		3	4	5	6
Type of Band	D	L	D	L	D	L	Fl	QD
andesine								65
oligoclase	60	60	55	50	60	55	60	
quartz	10	35	10	30	20	25	20	15
potash feldspar	tr	tr	tr	15	tr	15	tr	-5
hornblende	15	tr	15	tr	tr	tr	5	5
biotite	15	-5	15	5	20	5	10	10

Also sphene, apatite, orthite, iron oxide, epidote.

D - dark, L - light, Fl - trondhjemitic flasergneiss, QD - quartz-diorite.

Figures are in percentages.

PLATE XIII

A. Katazonal amphibolite. Plagioclase and hornblende. Granoblastic texture. Mutton Ridge (9.6.48.7g). Plane polarized light, x 17.

B. Quartz-dioritic gneiss transitional with amphibolite shown in A. Decrease in hornblende; increase in plagioclase; quartz now present. Some of the hornblende tends to form larger poikiloblastic grains at this stage. Mutton Ridge (9.6.48.8g). Plane polarized light, x 17.

C. Trondhjemitic gneiss. Type transitional with quartz-dioritic gneiss shown in B. Further decrease in hornblende. Hornblende poikiloblastic but in a passive sense. About one mile northeast of Lone Frank Pass (10.23.48.17g); plane polarized light, x 17.


P
K

PLATE XII

Potash feldspar (K) replacing plagioclase (P) in hornblende biotite flasergneiss. Mineral Hill (7.28.50.4g). Crossed nicols. x 19.


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PLATE XI

A. Hornblende-biotite augenflasergneiss. Tendency toward random orientation of potash feldspar porphyroblasts (note part of porphyroblast in upper right corner) indicates that the augen were largely statically formed. Mineral Hill (7.26.50.9g).

B. Portion of margin of potash feldspar porphyroblasts in hornblende-biotite augengneiss showing irregular projections and zone of incipient replacement around the margin (psuedo-cataclastic texture). Mineral Hill (8.2.50.8g). Crossed nicols, x 17.


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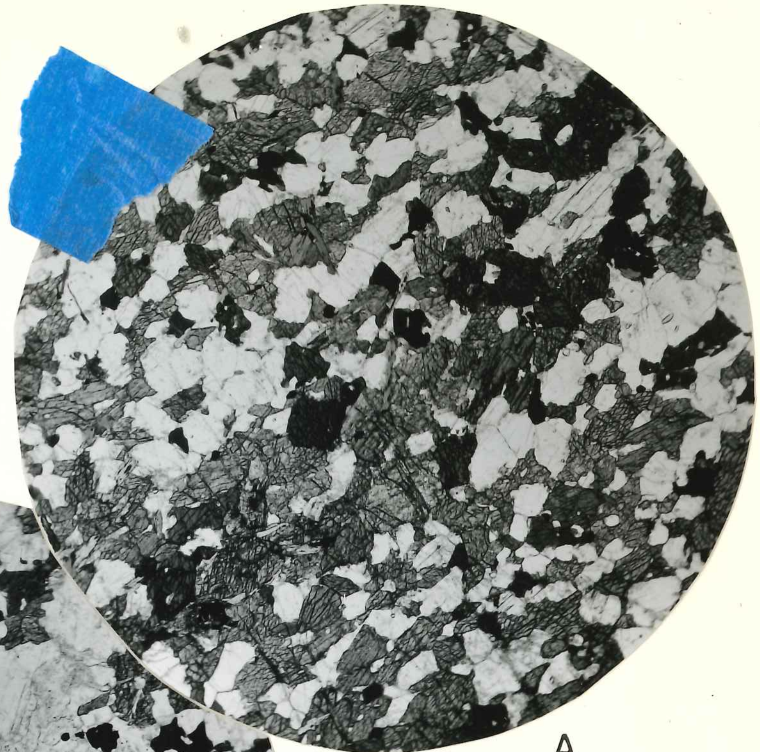

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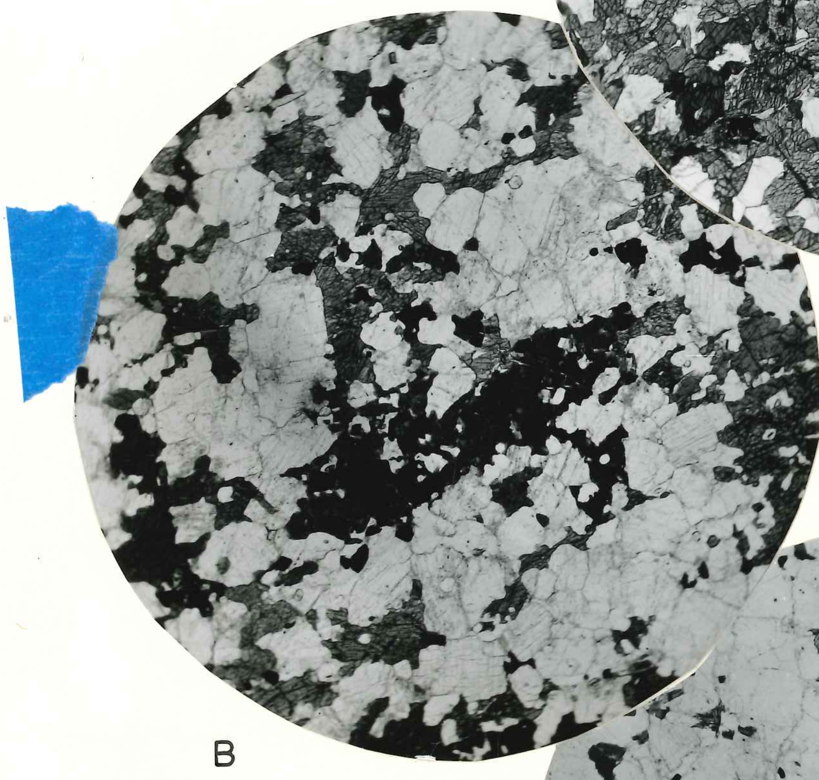

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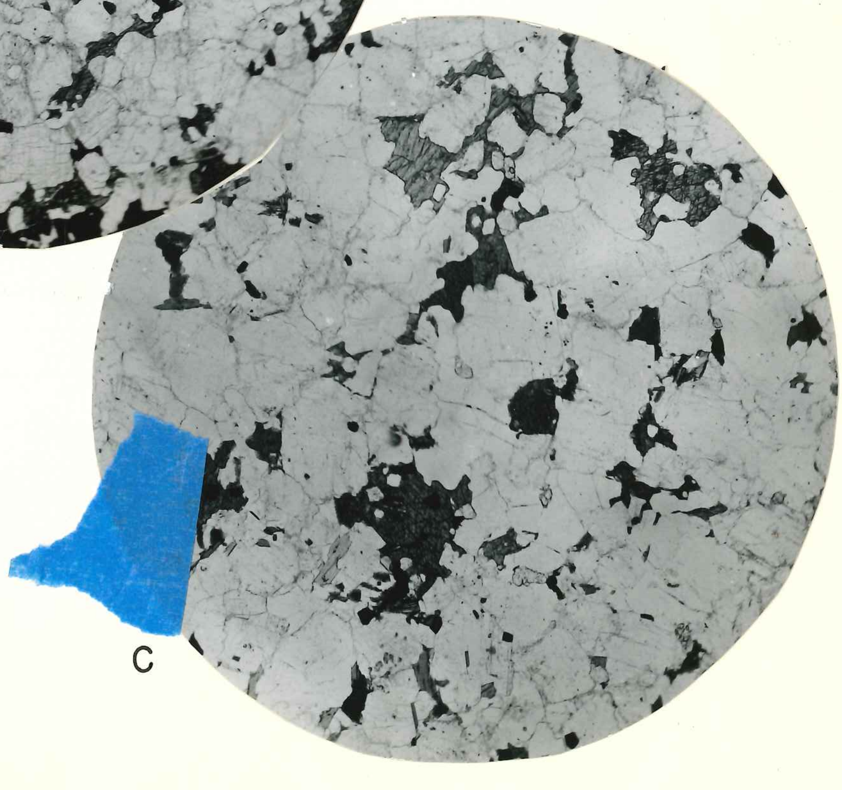

C

PLATE XIV

A. Late introduction of quartz (Q) which is replacing plagioclase (P) in synkinematic trondhjemitic gneiss. Mutton Ridge (9.6.48.12g). Crossed nicols, x 17.

B. Same, plane polarized light. Mafics are biotite, retrogressive chlorite, and hornblende, x 17.


Q
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P

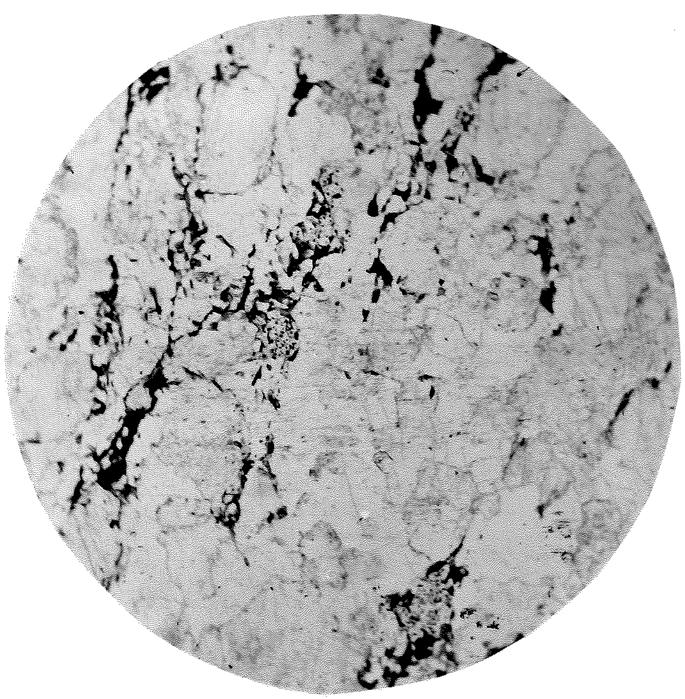
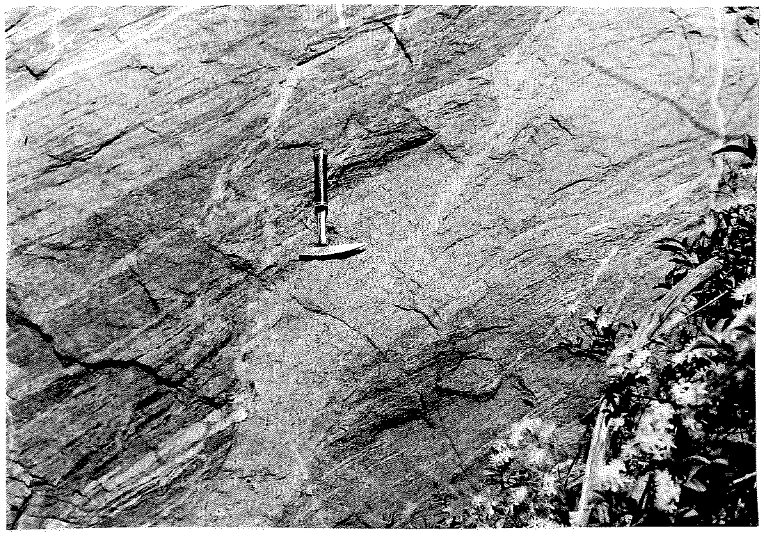


PLATE XV

A. Postkinematic replacement band of porphyroblastic rock transecting synkinematic, amphibolite derived hornblendic banded gneiss. Feldspathization apparently fracture controlled. Relict gneissose structure passes through porphyroblastic rock near hammer. Northwest of Conconully (ph. 8.4.50.3).

B. Migmatitic banded gneiss - amphibolite derived. Irregularity in texture in both light and dark bands. Variations in widths of bands. Cross-cutting quartzo-feldspathic veinlet typical of postkinematic stage. Local concentrations of mafics at top center associated with feldspathic patches ascribed to local differentiation. Rock Mountain (9.3.48.6g).



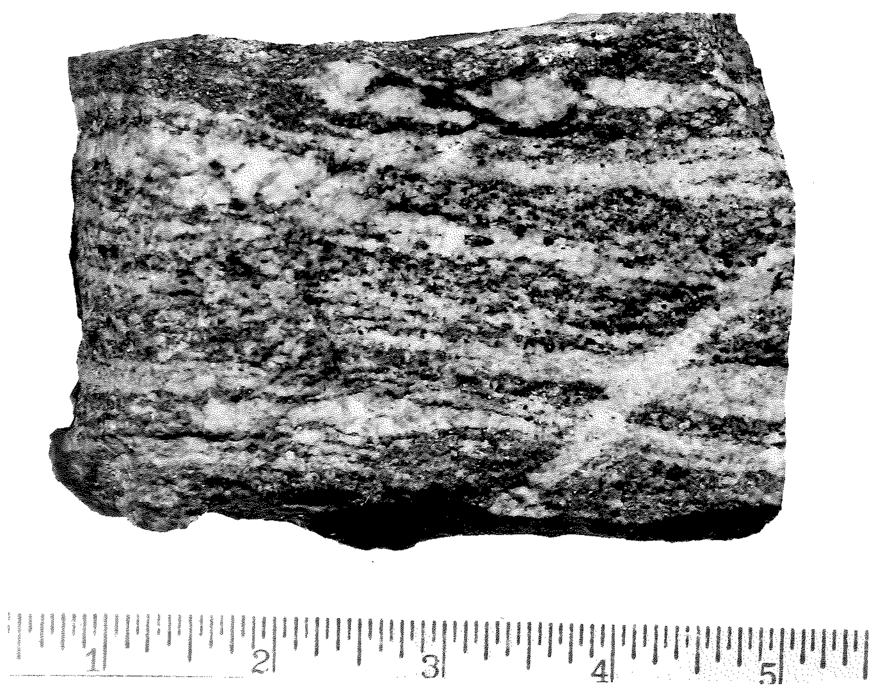

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PLATE XVI

A. Medium grained synkinematic banded gneiss with superimposed static recrystallization. Light colored band containing plagioclase and quartz replacing more fine grained hornblende, biotite, plagioclase, quartz rock. Amphibolite derived. Rock Mountain (9.7.48.11g), x 17.

B. Same, crossed nicols.

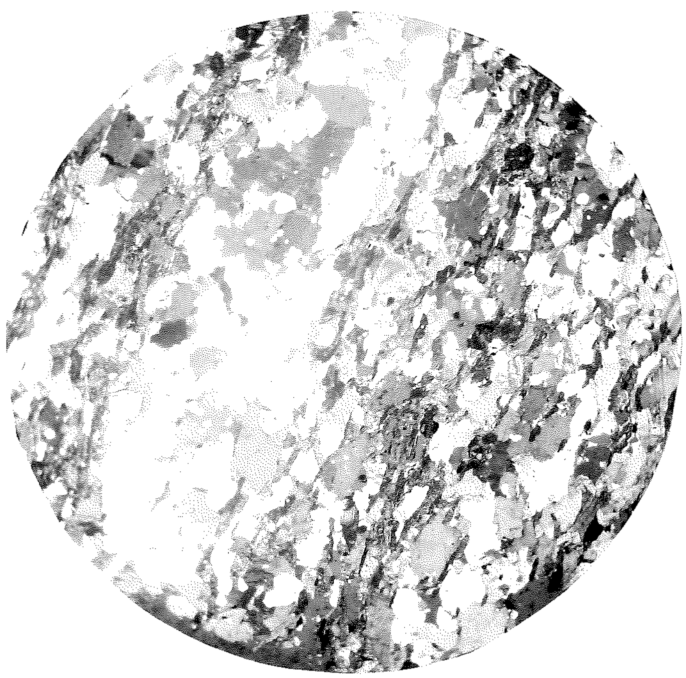
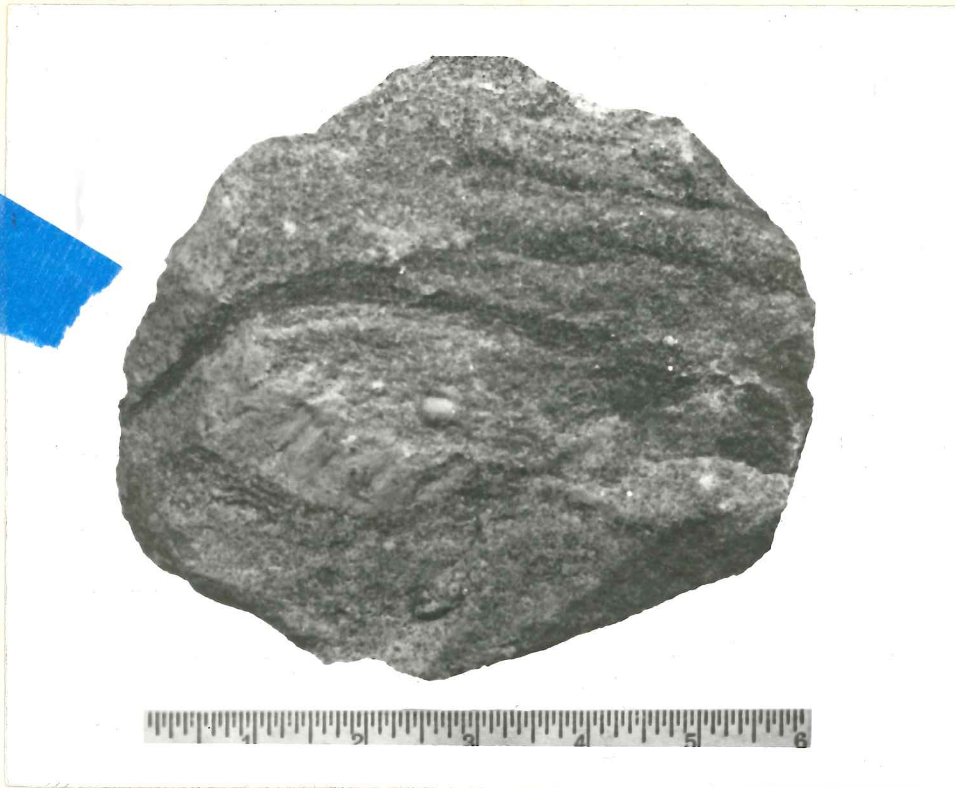


PLATE XVII

A. Statically formed potash feldspar porphyroblast (P) in trondhjemitic banded gneiss. Curvature of dark bands near porphyroblast suggests some increase of volume in area of porphyroblastic growth. Dark bands are amphibolite-derived hornblende-biotite-plagioclase granulite. Rock Mountain (8.30.48.6g).

B. Nearly directionless, predominantly statically recrystallized migmatitic dioritic rock derived from amphibolite, with relict parallel structure. Uneven texture. Mineral Hill (7.28.50.3g).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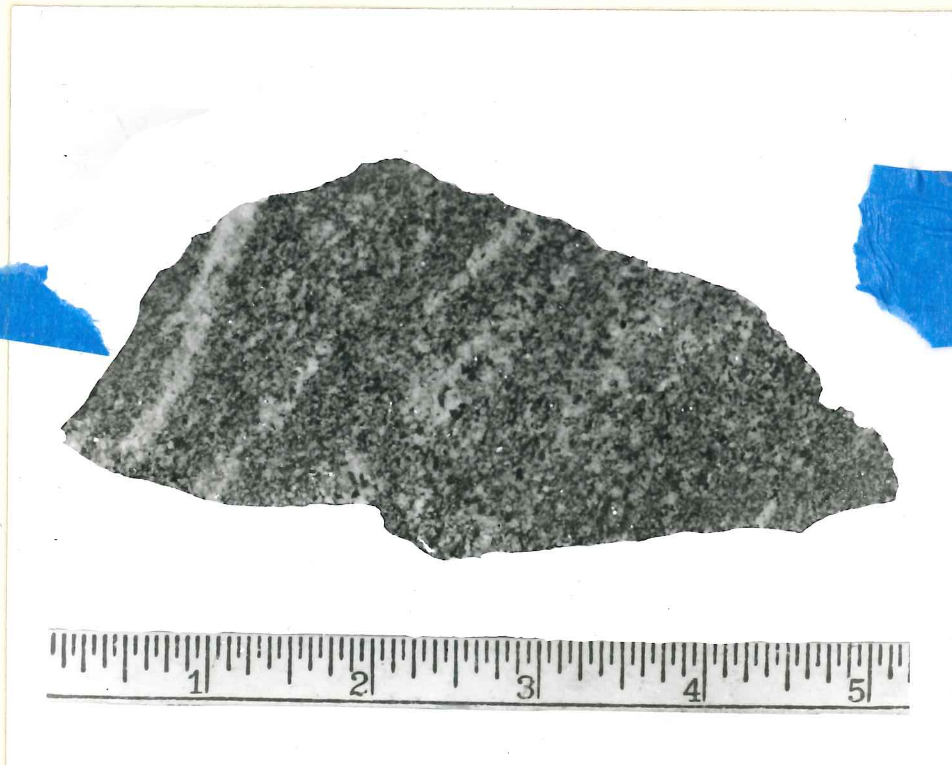
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Special Types of Migmatites in the Rock Mountain Area

The excellent exposures in the Rock Mountain area (cf. above) offer an excellent opportunity to study various special types of migmatitic rocks which occur in the prevailing gneisses of this area. These gneisses comprise, apart from the banded gneisses just described, flasergneisses and gneissose quartz-dioritic rocks. The latter rock types are similar to those described from the Salmon Creek area except that they are generally more coarse grained.

The special features which are more locally developed within the gneisses include: irregular local areas of intense late potash metasomatism leading to pegmatite patches and dikes, late aplite dikes, dark relatively basic dikes, intrusive and replacement breccias, and other features connected with late deformation in the gneisses including both fracturing and plastic reaction.

Local Areas of Late Potassium Metasomatism and Pegmatites

Large, pink, hypidioblastic potash feldspars have formed in part in the gneisses. They have spread out irregularly or concentrated in clusters which finally have "coalesced with the coarsely recrystallized remnants of the gneiss into patches and veins of pegmatite" (Misch 1949b, p. 689). The potash feldspar rich patches largely disregard the earlier structures in the gneisses and spread out over or cut across them (cf. Plate XV), thus demonstrating their essentially post-kinematic origin. Potash feldspar porphyroblasts sometimes occur in small, local, flexures in the gneisses at positions of little stress near fold axes. The location of these patches then, is controlled by contemporaneous stresses of a local nature.

Beside these irregular patches and bands, sharp bordered, cross cutting, pegmatite dikes with uniform widths occur. These range in size from inches to several feet and show alternations with aplite or with other pegmatite dikes. Some may have aplitic centers with pegmatite in contact with the wall rock on either side, or the aplite may be marginal. In some, the border may be rich in potash feldspar and the center rich in quartz. In many dikes the potash and silica have penetrated the wall rock replacing minerals occurring there and forming implication textures. Some dikes contain recognizable, but partly transformed, streaks of country rock.

The minerals are gray quartz, yellowish-white plagioclase, pink microcline, and biotite in thin plates. Some of the crystals comprising the pegmatite reach a maximum observed diameter of 10 inches. Small amounts of muscovite sometimes occur, mostly, however in those pegmatites in the micaschists in the Salmon Creek-Funk Mountain area. Small reddish-brown garnets are occasionally present. Microscopically, micropegmatite is common. Quartz however, sometimes appears in a similar pattern in oligoclase. Some of the pegmatites that megascopically present replacement features show replacement features microscopically, as for example the replacement of plagioclase by microcline along alternate albite twin lamellae. The plagioclase is as sodic as An 18. The pegmatites vary in composition from granitic to quartz-monzonitic.

Aplites

The aplites are more variable in composition. They range from pink alaskitic aplites to granitic, quartz-monzonitic, granodioritic, or even trondhjemitic aplites. The more sharply defined dikes are the more typically granitic ones. Some of the dikes containing more mafics have apparently incorporated much of the country rock material in them either by shearing of the country rock with simultaneous introduction of feldspathic material, or by static replacement of the country rock.

Microscopically the texture is granoblastic. Parallel structures are mostly lacking. Replacement features within the aplites are common. Plagioclase has been partially replaced both by quartz and potash feldspar. Biotite is the chief ferromagnesian mineral. The accessory minerals are similar to those occurring in the country rocks, i.e. sphene (rare), iron oxide, apatite (rare), epidote, and chlorite. Myrmekite is common. The plagioclase is oligoclase and is commonly zoned with more calcic cores.

Criteria for both dilation and replacement origins for dikes were observed.[1] Criteria for dilation dikes are: (1) sharp borders; (2) chilled borders - exceptionally present; (3) uniform widths; (4) uniform composition; (5) flow structures parallel to dike walls - some of the flowage may have been induced by a squeezing together of the wall rock; (6) offsets of wall rock structures proportional to the width of the dike and the angle of intersection - this was observed only in a few cases; (7) apophyses retaining the same composition of the parent dike; (8) rotated inclusions of wall rock, or inclusions of country rock of a type not found immediately adjacent to the dike at the locality in question. Taken singly, of course, some of these criteria might not be valid.

Criteria for replacement dikes which were observed include: (1) structures in wall rock present on both sides of dike without offset or with disproportionate offset - the

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1 Goodspeed (1940) presents criteria which can be used to distinguish dilation dikes from replacement dikes particularly in cases where no faulting movement has occurred. King (1948) discusses similar criteria and presents excellent illustrations.

latter case is more common. Evidence for differential movements of the wall rock along the dikes (i.e. small scale faulting) is common; (2) extreme variation in width of dike; (3) undisturbed inclusions of wall rock which preserve the same structural alignment in the dike as in the wall; (4) bridgelike septa of wall rock crossing and interrupting the dike - this was not observed in the aplites, but was observed in several quartz-monzonite dikes in the Tiffany complex; (5) coarse textures along the borders - this is not a good criterian, for in this area the temperatures in the wall rocks appear to have been approximately the same as in the dikes; this is suggested by their identical mineral facies; (6) gradational as well as sharp borders - frequently, one contact controlled by a fracture or a small fault in the country rock is relatively sharp, and the other contact quite gradational; (7) transitions from dikes to irregular replacement veins which finally peter out in the country rock.

Both replacement and dilation aplite dikes are so similar in composition and texture, although numerous intersections indicate variations in age, that it appears likely some of the material formed by in situ replacement may have become mobilized, presumably through the agency of differential stress, and thus have been intruded into dilational openings. However no conclusive proof of the formation of such rheomorphic dilation dikes was found although in many cases evidence was obtained that aplitic bodies formed by in situ replacement have been squeezed or plastically moved just sufficiently to produce certain superimposed minor intrusive features. It may be suggested that the occurrence of similar dikes which are more or less transitional between the in situ replacement type and the intrusive type, supports the interpretation of the more fully intrusive dikes as mobilized (rheomorphic). Aplitic material has also been involved in both intrusive and replacement breccias.

Replacement and Intrusive Breccias

Replacement and intrusive breccias are common in both the Rock Mountain and in the Conconully areas. Excellent examples involve dark, fine grained, relatively basic dikes[1] which have been both intruded and replaced by aplitic and more coarse grained granodioritic material.

Criteria indicating a replacement origin for a breccia include the presence of features incompatible with a forceable injection of magma, gradational borders of fragments, and variable composition and grain size. Some of the breccias fulfill these requirements (cf. Plates XXV B or XXXV B). In the breccias on Rock Mountain the presence of thin septa

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1 Dark relatively basic dikes of varying ages occur in association with the aplite and pegmatite dikes. Some of the earlier basic dikes have been replaced and intruded by aplitic material. The problem of the basic dikes is discussed in Chapter IV.

connecting larger blocks indicate a replacement origin. Rounded edges of fragments (although not conclusive in themselves), and thin wedges or irregular vein-like projections of feldspathic material that disappear into a block without displacing parts of the block, are also criteria that tend to confirm an origin by replacement.

Most of the breccias in the Rock Mountain area, however, that involve the dark, fine grained, relatively basic dikes and light colored aplitic material show a sharp contrast in color and contacts are sharp both megascopically and microscopically (cf. Plate LIII A). The sharpness in contact at the boundaries of rounded fragments of the dark material and the more coarse grained granitoid material may be the result of slow diffusion of volatile-poor metasomatising material along rather stationary originally fracture-controlled local fronts into the not easily invaded, homogeneous, fine grained basic rock. In view of the considerable amount of feldspar in these dark rocks (cf. Table XII), even without chemical change, a coarse grained recrystallization of the dark dike material would produce a more light colored rock. However contacts are still sharp even though the dark material near the contact with the aplite becomes more granoblastic in texture, slightly more coarse grained, enriched in quartz, and has more biotite in proportion to hornblende. Most of the aplitic material is considered to be intrusive although apparently silica and alkalis were able to migrate from the aplite into the dark, basic material. The aplite sometimes exhibits finer grained margins and is usually uniform in texture and composition except in brecciated zones where incompletely assimilated smaller fragments of the dark rock remain.

Intrusive breccias show dilation of the wall rock; angularity of fragments; sharp, angular blocks which fit into each other, although this and the previous feature may not be present if assimilation has occurred; rotated blocks of gneissose rock; presence of blocks not occurring among the wall rocks immediately adjacent. Intrusion and replacement may be combined. Some superimposed intrusive movement has occurred in some replacement breccias (cf. Plates XXI A, XXIII, and XXIV).

The intrusions of quartz-monzonitic and granodioritic material in the area occurred after the gneisses had already formed. How much later the replacement and intrusion of the potash rich material was than the formation of the synkinematic gneisses, cannot be locally determined. An attempt to answer this question can be made only on the basis of all obtainable evidence on a regional scale. This attempt will be made in Chapter IV.

Quartz-Monzonitic Dike-like Zones

Wider dike-like bodies of quartz-monzonitic and granodioritic rocks intermediate in texture between pegmatites and aplites occur in the Rock Mountain gneisses. In the field the wider zones form small saddles where they cross ridges. The pattern produced by these bodies resembles on a large scale the pattern of small scale features connected with potassium introduction seen in individual rock outcrops. Some are trending parallel to the foliation of the gneisses, others are cross-cutting. Table V gives approximate compositions of such rocks. The mineral paragenesis is the same as in the gneisses except for the lack of hornblende and a greater development of late quartz and microcline.

These rocks also participate in both replacement and intrusive breccias. Similar rocks occur in the Tiffany complex and are more fully described in that section (cf. Chapter IV).

Hornblendite Pods

Occasional partially cross-cutting pods of hornblendite several yards in diameter occur in the gneisses. These pods contain centers of coarse grained, matted, actinolitic-hornblende. The outer portions contain ordinary green hornblende. Toward their margins these pods become more dioritic because of an increasing content of poikiloblastic andesine. The amphibole has been partly biotitized, especially the more hornblendic portion. Much magnetite is present and apatite needles with an observed maximum length of 1.5 mm occur in the plagioclase. The centers of these pods are similar to actinolitic-hornblendite lenses occurring in the Mineral Hill area, and might be compositionally and possibly stratigraphically equivalent to the actinolite granulites so characteristic of the Evans Lake formation farther east (cf. above). These hornblendite pods may represent relicts of such rocks which have undergone recrystallization accompanied by partial sodium and potassium metasomatism. However an interpretation of these bodies as relicts of sedimentary layers seems unlikely in view of the fact that the pods seem to be related less directly to the gneisses than they are to the dark, relatively basic, fine grained dikes cutting the gneisses. Another possible interpretation would be that these pods represent concentrations of basic material by local metamorphic differentiation.

Hornblende-Plagioclase "Pegmatites"

Local areas of hornblende-plagioclase "pegmatites" similar to those described in the amphibolites (cf. above p. 69) occur in the more basic rocks of the Rock Mountain area. These form small veinlets, or larger streaks and patches in the rocks. They are characterized by a coarse grained development of andesine and euhedral hornblende. Sometimes the hornblende is pseudomorphosed by biotite.

These "pegmatites" are interpreted as areas in which volatiles have been active promoting recrystallization of amphibolite material associated with some metasomatism.

The conception of development of hornblende with good crystal form through special conditions of recrystallization is important to keep in mind when larger bodies of hornblendic rock occur containing varieties with well-formed hornblende crystals (cf. Tiffany diorites, Chapter IV).

Small Scale Structural Features in the Rock Mountain Migmatites

Local differential deformation during potash introduction has been mentioned above in the description of the augengneisses near Conconully, some of which contain drawn out lenticular potash feldspar porphyroblasts. In the Rock Mountain area occasional drawn out augen occur in the banded gneisses, and some porphyroblasts have formed in areas of minimum stress in minor flexures and folds in the gneisses.

Most of the other features connected with potassium introduction, such as the irregular potash felspar-rich pegmatitic patches, the pegmatitic and aplitic dikes, and the replacement and intrusive breccias are essentially cross-cutting and were formed under dilation.

Flexures and drag folds often accompanied by shearing have formed during the migmatitization of the rocks (cf.

Plate XVIII). The folds are cut by aplitic dikes and yet involve aplitic and pegmatitic material. They indicate a yielding to compressive stresses in a direction which differs from that of the earlier foliation of the gneisses. The axial planes of the flexures have a gentler dip than the usually steeply dipping parallel structure of the banded gneisses. The flexures are interpreted as a plastic behaviour of the rocks under long continued stresses.

A realignment of the schistosity in the wall rock parallel to some dikes represents shearing parallel to the direction of fracturing controlling the dike and concomitant recrystallization (cf. Plate XXV).

Small shears and minor faults cemented by alaskitic aplite represent a more brittle reaction which perhaps was due to rapidly acting stresses.

The local fracturing that made possible the replacement and intrusive breccias and dilation dikes were connected with dilation and thus due to tensional conditions. The breccias contain fragments of gneiss similar to the unbrecciated country rock. This indicates that when brecciation occurred the gneisses had already reached their final stage of development.

Another brittle reaction to stress while temperatures were still relatively high, but declining, is shown by a massive breccia occurring east of Rock Mountain. The fragments are of migmatitic gneisses, but the matrix included a partially fluid phase. This body was formed essentially after the main phase of potash introduction, while silica was still being introduced, and while biotite and some feldspar were still able to recrystallize.

Movements then, of both a compressive and tensional nature occurred during migmatitization of the rocks. While the earlier movements which had formed the banded and flaser-gneisses were of a differentially compressive nature and produced parallel structures, the later movements were local and of a tensional nature and the features produced depart from this parallelism and are cross-cutting. The cross-cutting contacts of dilational dikes and breccias are undisturbed indicating the absence of later rock deformation apart from local late shear zones.

The migmatites in the Rock Mountain area suggest the following history of deformation:

(1) Differential deformation produced a generally steeply dipping gneissose structure parallel to the regional trend.

(2) Recurrent deformation superimposed local folding and flowage of a plastic nature accompanied by some shearing with a new and flatter direction of yielding.

(3) Deformation of a tensional nature led to fracturing and brecciation. This deformation was accompanied by small

scale replacement and small scale intrusion of mobilized materials.

Local shear zones characterized by gouge, hydrothermal alteration, and metallization cut all the rocks. These zones indicate still later movements accompanied by hydrothermal activity.

The description of the migmatites given in the preceding pages shows that metasomatism took place during all these stages. Sodium metasomatism, partly associated with later potassium metasomatism, is linked with the formation of the banded and flasergneisses. The local deformation during stage (2) occurred during the main phase of potassium introduction. The physico-chemical conditions associated with metasomatism facilitated the plastic behaviour of the rocks. Continued potassium metasomatism reached a maximum under the tensional conditions of deformation - stage (3) - and led to recrystallization, replacement and local intrusion of mobilized material. Stage (2) is closely linked with stage (3) through the continuity of potash feldspar development. Local deformation of a tensional nature continued during declining temperatures with silicification predominating.

PLATE XIX

A. Synkinematic banded gneiss traversed by dike containing wall rock material plus added quartzo-feldspathic material. Interpreted as replacement band localized along fracture or shear zone. Some differential movement between hanging wall and foot wall suggested by apparent displacement of dark band left above notebook. Dike material probably affected by such movement. Relict hornfelsic amphibolitic band upper center. Rock Mountain (ph. 9.6.48.B4).

B. Folding in synkinematic banded gneiss. Amphibolite derived microdiorite in crest area of fold, upper left. Recrystallized cross shear, center. Rock Mountain.

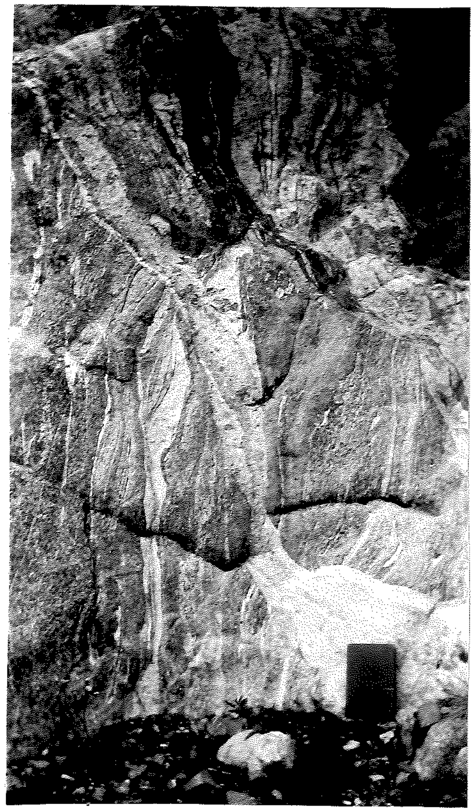


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PLATE XX

A. Static replacement. Hornblendite grading through gabbroic to dioritic rock on margin of hornblendite pod. Rock Mountain (9.2.48.7g).

B. Another portion of margin of hornblendic pod. Sharp fracture controlled contact with granodioritic dike. Biotite replaces hornblende in the hornblendic rock near the contact indicating some migration of material between dike material and hornblendic rock. Clots of mafics in dike suggest involvement of some of the hornblendic rock. Note finer grain size in dike near contact. Rock Mountain (9.2.48.6g).


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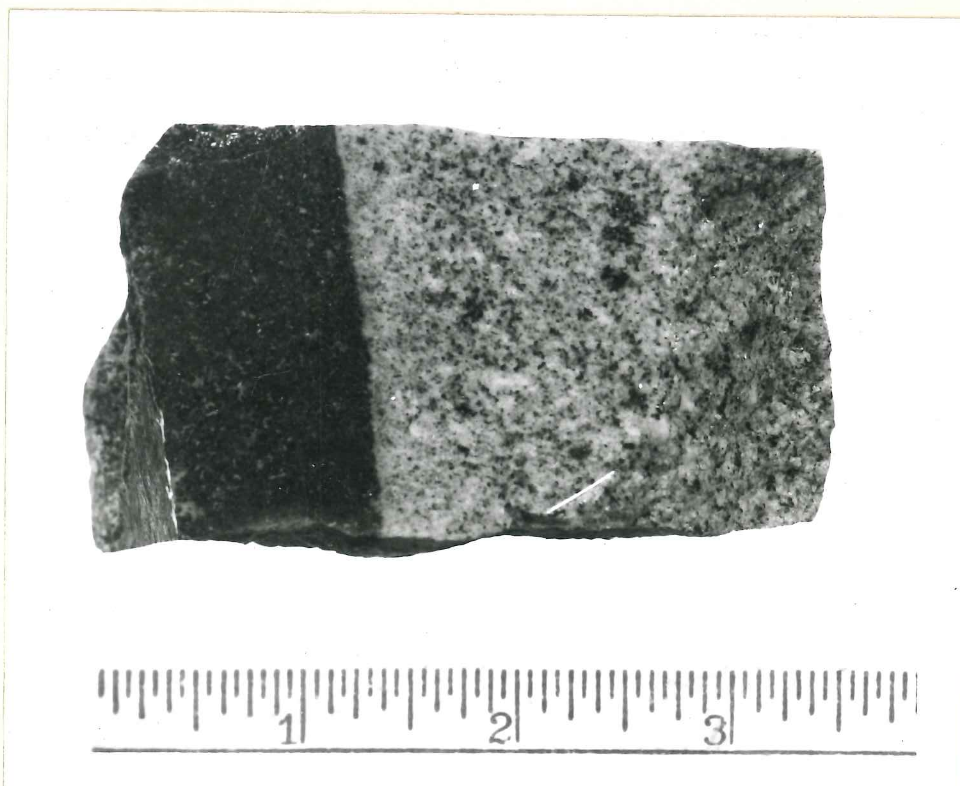
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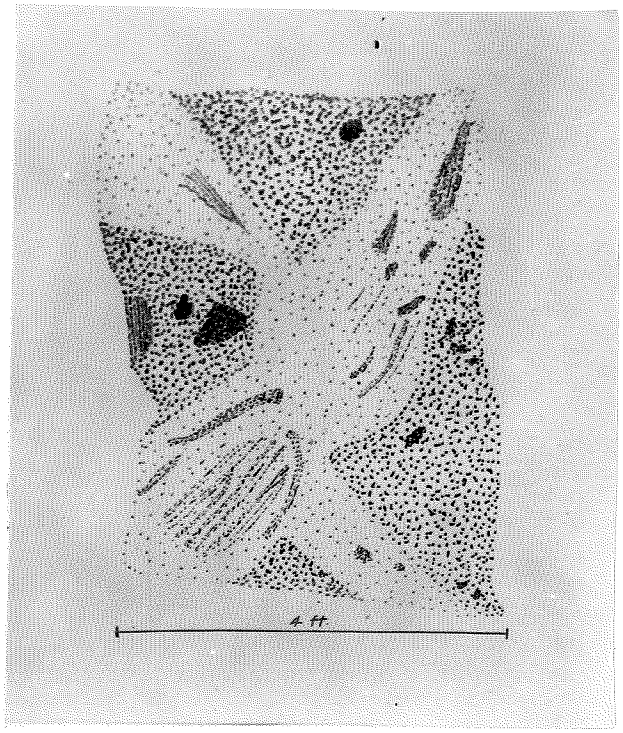
PLATE XXI

A. Postkinematic stage, period of mobilization. Sketch showing block of intrusive breccia. Dioritic rock containing inclusions of gneissose and directionless amphibolite cut by granodioritic rock containing fragments of diorite and banded gneiss in various stages of assimilation. Middle Tiffany Mountain (sk. 7.31.49A).

B. Light colored trondhjemitic band formed by replacement in synkinematic banded gneiss. Rock Mountain (sk. 7.16.49F).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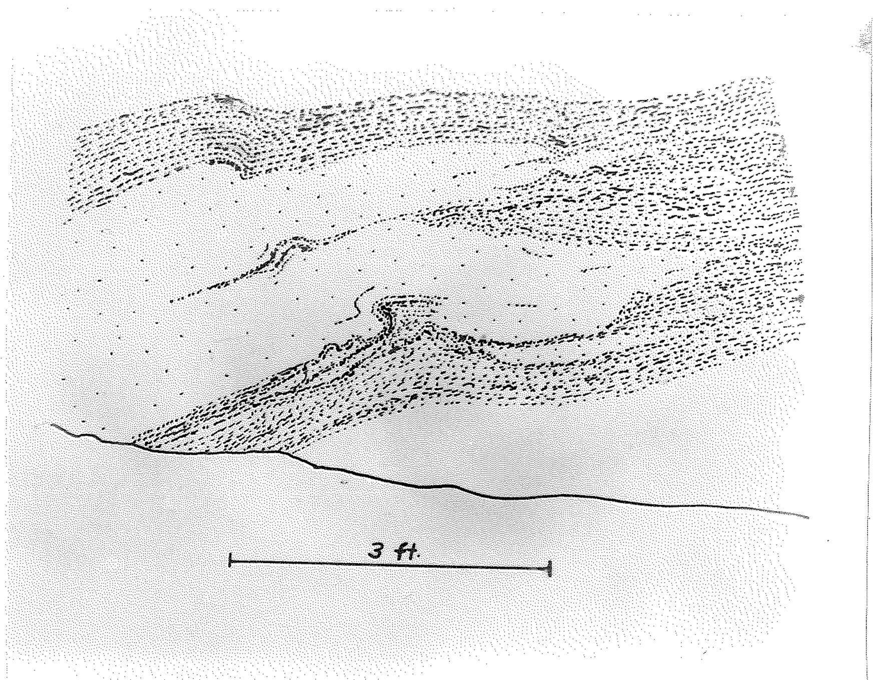
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PLATE XXII

A. Intrusive breccia. Granodioritic aplite intrusive into brecciated dark, fine grained dike material. Some assimilation of more finely fragmented dark, dike rock has apparently taken place. Note the thin septae of dark dike rock connecting blocks and the elongate shape of one fragment. Both features are usually considered incompatible with forcible emplacement of magma.

B. Contact of aplite and dark fine grained dike rock. Sharp contrast in color at margins. Uniformity in grain size throughout the light colored rock. Rock Mountain (10.23.488g).

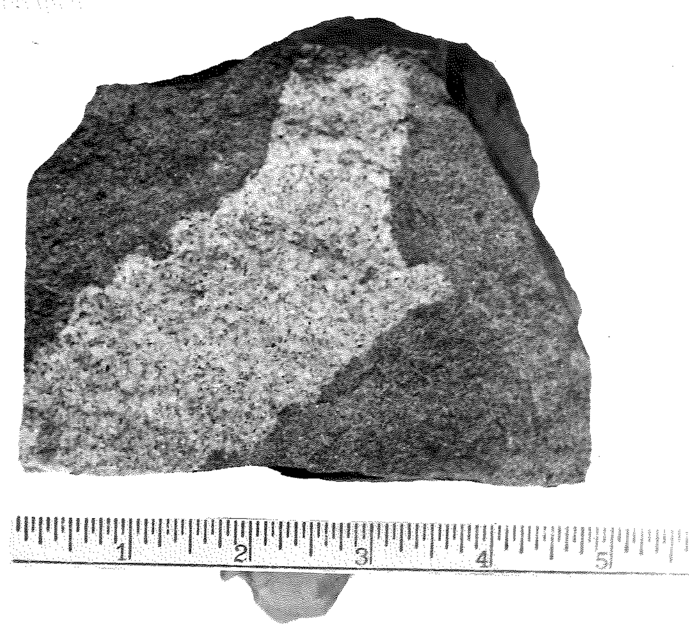
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PLATE XXIII

A. Dark, fine grained, relatively basic dike rock brecciated and then intruded by granodioritic rock. Black patches are lichen. Southeast face of Middle Tiffany Mountain (ph.9.7.50.1).

B. Detailed view of portion of outcrop showing streaks of dark dike material in the granodioritic rock and porphyroblastic marginal area in the granodioritic rock near the contact. Plastic flow in the granodioritic rock. Black patches are lichen.

PLATE XXIV

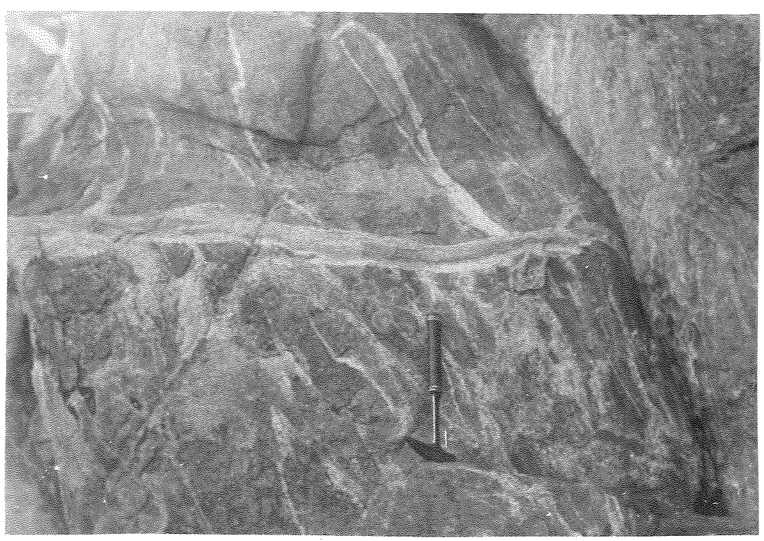
A. Allocthonous block of dioritic rock in intrusive granodioritic rock. Intrusion of granodiorite later than the formation of the dioritic rock which elsewhere in the area has formed from amphibolite. At right is dark, fine grained dike material. Saddle east of Tiffany Lake (ph. 7.60.1).

B. Same outcrop. Intrusive granodioritic rock replacing dark, fine grained dike rock below, and in sharp contact with it above. Intermediate stage of replacement shown by block in upper right (ph. 7.60.2).

PLATE XXV

A. Postkinematic alaskitic aplite dike. Schistosity (s_2) in wall rock parallel to dike superimposed on earlier schistosity (s_1) of flasergneiss. Local deformation during postkinematic stage. West side of Clark Peak (ph. 7.18.49.2).

B. Dike produced by feldspathization along shear zone in statically feldspathized non-schistose amphibolite. Northwest of Mineral Hill (ph. 8.1.50.1).



Boulder Creek Gneiss Complex

Description

The area southwest of the Tiffany group of peaks and extending northward along the western slope of the range contains a varied assemblage of rock types. This complex spreads westward as well as to the north and to the south beyond the limits of the area mapped. The rocks are typically developed near the headwaters of the Boulder Creek drainage. Work in the Boulder Creek gneiss complex was in the nature of reconnaissance, and only a belt close to the crest of the Range was studied.

Many varieties of directionless rocks occur but most of the area consists of light colored gneissose rocks of granodioritic or quartz-dioritic composition. Many of these gneisses contain dark schlieren-like streaks or sometimes wider bands resembling the darker bands in the gneisses near Rock Mountain. The schlieren-like streaks and the gneissose structure of the rocks, although locally variable in direction, are as a whole parallel to the regional trend which here averages N 10 W, thus being more northerly than in the Salmon Creek area. This belt is continuous with the gneisses of the Rock Mountain area.

The rocks vary from light colored, coarse grained, banded granodioritic or trondhjemitic gneisses containing a small amount of fine grained biotite, to light colored, coarse grained, gneissose quartz-dioritic rocks containing more abundant and larger biotite and hornblende. There occur also light colored, medium grained gneissose granodioritic rocks which lack banding but are somewhat variable in composition and occasionally contain darker streaks.

A zone of patchy, gneissose granodiorite and quartz-monzonite containing large, irregular "poikilitic" potash feldspar crystals passes through Old Baldy Mountain. The rock resembles the granodioritic augengneiss of the Mineral Hill area, but contains fewer mafics, has a less well defined parallel structure, and a coarser grained matrix. The anhedral large feldspars and the clusters of mafics produce a highly irregular texture. In contrast to the hornblende-biotite augengneiss, this rock does not contain relict streaks of hornblende-biotite schist.

Occasional narrow zones of a darker banded gneiss occur. Medium colored, hornblende-bearing flasergneisses are locally present. These are similar to the flasergneisses in the Salmon Creek area but are coarser grained and lighter in color.

Directionless rocks include coarse grained, pink, quartz-monzonite and granodiorite, and a medium-grained, bluish-gray biotite granodiorite. The color is due to the even distribution of fine-grained biotite flakes. Aplitic dikes are common. Occasional darker, fine-grained dikes occur.

Microscopically, the same crystalloblastic textures and replacement features are present as were described in the migmatitic gneisses of Rock Mountain. The textures are typically granoblastic and often porphyroblastic. Plagioclase ranges in composition from sodic andesine (approximately An 34 - 32) in the trondhjemitic rocks to sodic oligoclase in the potash feldspar rich types. In some of the latter, the oligoclase is strongly zoned and the marginal zone may be as sodic as An 12. Plagioclase includes biotite and quartz, but more often it is free of inclusions. Plagioclase often exhibits some well developed crystal faces and many of the rocks approach a "hypidiomorphic granular" texture. Potash feldspar is present in all specimens studied although it varies widely in amount. It shows forms ranging from small, irregular, intergranular individuals to spreading porphyroblasts. A similar habit was seen in the migmatitic gneisses of Rock Mountain and Salmon Creek. Potash feldspar replaces plagioclase. Biotite is the predominant ferromagnesian mineral and forms irregular grains. In the directionless rocks it is either evenly or irregularly distributed. In the banded types it occurs in relatively darker streaks or bands. Compared to the banded gneisses of Rock Mountain, these bands and streaks are more subordinate in number, usually have a lower concentration of biotite, and the individual biotite flakes are more randomly oriented. This indicates that the metasomatism and recrystallization were more complete here than in the Rock Mountain area. If only the rocks composing single bands, either of the darker or the lighter variety are considered, they resemble the rocks in the wider zones of more uniform, directionless material occurring in the Boulder Creek gneiss complex. Muscovite is usually present in amounts less than 5 per cent. It forms small irregular grains up to an observed maximum of 1 mm. in size and occurs with biotite or in the central portion of plagioclase. It appears to have formed from both biotite and plagioclase at a late stage. This mineral was not observed in the migmatitic gneisses previously described except in some of the aplitic bodies in the Rock Mountain area. Accessory minerals are iron oxide, apatite, sphene, orthite, and epidote.

Discussion

Although some of the rocks may locally have become intrusive as in the Rock Mountain migmatites, the character of the Boulder Creek gneiss complex as a whole indicates a migmatitic rather than a magmatic origin. Among the features mentioned above, the following suggest a migmatitic origin: the structural continuity of the Boulder Creek gneiss with the Salmon Creek-Rock Mountain migmatites; the presence, in the Boulder Creek gneiss, of dark schlieren and streaks which correspond to the dark bands in the Salmon Creek-Rock Mountain migmatites; the variability in composition and texture within small outcrop areas of some of the rock types, often combined with megascopically visible porphyroblastic textures; the crystalloblastic and replacement textures observed microscopically. The appearance of the light colored trondhjemitic and granodioritic banded gneisses, the granodioritic augengneiss, and the coarse grained flasergneiss suggests that these rocks underwent a process of recrystallization and feldspathization similar to that in the banded gneisses, augengneisses, and flasergneisses of the Salmon Creek migmatite zone, but that in the Boulder Creek gneisses, process was more thorough so that the original material that has remained as distinct relicts in the Salmon Creek zone, has here been lost except for faint recrystallized traces. The banded and augen structures seen in the Boulder Creek gneisses are relict structures.

Sinlahekin Gneiss

Occurrence and Megascopic Description

A large, fairly uniform body of quartz-dioritic gneiss occurs in the north-central part of the area around the head waters of Sinlahekin Creek. A considerable portion of this body is concealed by unconformably overlying Tertiary volcanics. However, scattered exposures of gneiss occurring

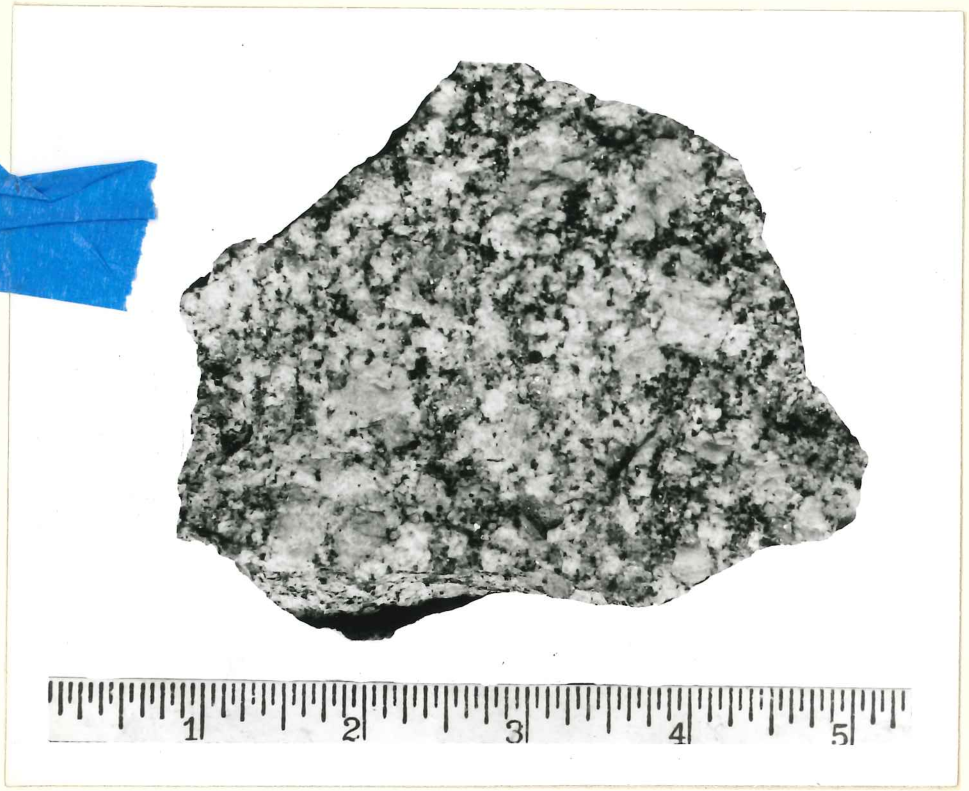

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PLATE XXVII

A. Trondhjemitic gneiss in Boulder Creek complex. Brown Meadow (9.25.50.20g).

B. Coarse grained trondhjemitic banded gneiss. Dark fine grained streak of relict hornfelsic micaschist material in lower left. Boulder Creek complex. Brown Meadow (9.28.50.21g).


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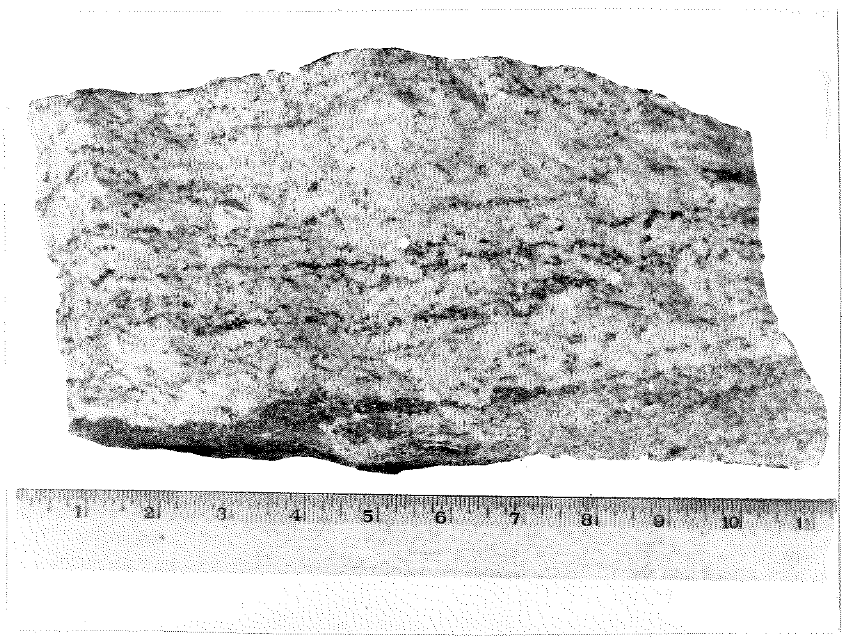
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along the margin of the volcanics indicate that the gneiss extends northward well beyond the limits of the area.

To the west the gneiss is in contact with the directionless Thunder Mountain complex (cf. below). Where the contact is exposed it consists of a narrow, complex migmatite zone[1] composed of partly gneissose dark hornblende-rich dioritic and light colored granodioritic rock types.

On the south and southwest the Sinlahekin gneiss borders the amphibolites and intercalated gneisses of the Salmon Creek Belt of metamorphics with a gradational contact. Other zones of amphibolite occur locally within the Sinlahekin gneiss. Structural parallelism is preserved throughout this area. The amphibolite zones of the Salmon Creek belt as well as those occurring within the quartz-dioritic Sinlahekin gneiss pass into this gneiss along the strike as well as across it. The most persistent zone of amphibolite finally disappears along the strike somewhere west of the crest of the range near point 7000 feet.

Zones of micaschist-derived, gneissose, biotite trondhjemite that parallel the zones of amphibolite and hornblendic gneiss in the Salmon Creek belt on the southeast, were not observed projecting into the main body of the

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1 Hornblendic gneiss in sharp, cross cutting contact with the directionless granite of the Thunder Mountain complex was observed on Windy Peak about five miles south of the Canadian border.

Sinlahekin gneiss. One small outcrop of trondhjemite that might possibly represent such a zone was observed near the southern margin of the Sinlahekin gneiss near Lone Frank Creek. The fact that micaschists and micaschist-derived migmatites are subordinate or lacking in the northwestern portion of the map area, is probably due to an axial plunge to the northwest. Eastward toward Blue Lake the gneiss contains epidote and passes into epidote-bearing metasediments.

In the area around the headwaters of Sinlahekin Creek the gneiss is coarse to medium grained, rudely foliated, and contains hornblende, biotite, quartz, and plagioclase as its principle constituents. An average of approximate mineral compositions of specimens of the gneiss is given in Table IV. Hornfelsic amphibolitic streaks and bands occur locally. Cross cutting aplite and dark, fine grained, relatively basic dikes occur also but are not as abundant as in the Rock Mountain migmatites. Features connected with potassium introduction such as pegmatitic patches and dikes, are virtually non-existent in the Sinlahekin gneiss. Banded gneisses occur only marginally near the amphibolites of the Salmon Creek belt. Local minor folds of a "mobile" character occur in the Sinlahekin gneiss, but identical features are present in the isoclinally folded amphibolites of the Salmon Creek zone that project into the gneiss. All are regularly aligned parallel to the prevailing local trend.

Microscopic Description

In general the mineral composition and texture are similar to those observed in potash feldspar-poor hornblendic gneisses previously described. The mineralogical changes in the transitional sequences from amphibolite through quartz-dioritic gneiss to trondhjemitic gneiss which have been described above, are identical with those seen in the transitional sequences from amphibolite to Sinlahekin gneiss. However the extreme loss of mafics occurring in some of the trondhjemitic end products at other places, occurs only locally in the Sinlahekin gneiss and is not characteristic of this unit which thus appears generally not to have gone beyond the more intermediate stages of transformation. A brief description of the gneiss is necessary to show its distinctive characteristics.

The texture is crystalloblastic. The fabric is uneven-granular with grain sizes varying from about 0.05 mm to about 4.0 mm. Occasional fine-grained patches occur that contain dots of iron oxide. Crystalloblastic plagioclase (andesine) often shows complex twinning and includes earlier hornblende and biotite. Green hornblende is xenoblastic and poikiloblastic. Olive-green biotite sometimes occurs in subhedral flakes in part crystallizing contemporaneously with hornblende, but it also is seen to be forming from hornblende. Sphene sometimes appears along cleavage planes in biotite. A small amount of xenoblastic potash-feldspar occurs in the intergranular and, with quartz, replaces plagioclase. Some of the specimens show a late, but pre-quartz, deformation. Plagioclase twinning lamellae have been bent and plagioclase has been cut by fractures which have been healed by a slightly more sodic plagioclase and quartz. Quartz is not affected by this deformation.

Local Porphyroblastic Variety of Sinlahekin Gneiss

On the southwestern margin of the Sinlahekin gneiss narrow zones locally occur of a more potassic and pronouncedly porphyroblastic gneiss. These zones are five to fifteen yards wide and are intercalated in the amphibolite and the normal Sinlahekin gneiss described above. Apart from their higher content in potash feldspar and their conspicuous porphyroblastic texture, these gneisses have approximately the same composition and the same crystalloblastic texture as the normal Sinlahekin gneiss. Their plagioclase is dark with finely disseminated opaque dust. The rims of the plagioclase, however, are clear of the dust, and have crenulated margins. The rims are oligoclase while the dusty centers are calcic andesine. The plagioclase occurs in glomeroblastic groups and in porphyroblasts which have formed by the coalescing of the former. These porphyroblasts reach an observed maximum size of 4.0 mm. Complex twinning is common in the plagioclase; although the rims are often untwinned. Differently oriented areas of clear plagioclase traverse the dusty grains, giving them a streaked and mottled appearance. Inclusions of biotite, quartz, and hornblende are common in the plagioclase, especially in its irregular, clear rims. The features described are typical of the middle stages of porphyroblastic development in the area studied. Hornblende is xenoblastic, small in size, but with a glomeroblastic tendency. Occasionally a cluster of hornblende grains will include a light green variety with an extinction angle, c/Z, of 17° rather than the usual 23° extinction angle observed in the common green hornblende in the area. Biotite is usually associated with hornblende. Quartz is widely distributed in small irregular grains. Potash feldspar forms spreading, irregular shaped porphyroblasts, but it is only half as large as the plagioclase. It includes all other minerals and replaces plagioclase. Accessory minerals are similar to those in the main body of the Similkameen gneiss. Minute apatite prisms are sometimes concentrated in finer grained, mafic rich areas. A similar rock occurs in the northern heterogeneous variety of the Tiffany diorites (cf. Chapter IV).

Epidote Bearing Variety of the Sinlahekin Gneiss

Eastward toward the Blue Lake area epidote becomes one of the more abundant ferromagnesian minerals in the gneiss and the gneiss passes into a schistose epidote-hornblende-biotite-quartz granulite. The granulite will be described briefly. Megascopically it is gray-green, poorly foliated, and contains lenticles of quartz. Microscopically, it shows a hornfelsic texture superimposed on an earlier schistose fabric. The rock is composed of: green biotite in imperfectly oriented flakes; irregularly shaped blue-green hornblende; quartz, either in small irregular grains or in lenticular aggregates with a mosaic pattern; compact but irregularly shaped epidote grains; zoned plagioclase with centers of sodic andesine and rims of oligoclase (approximately An 22); and microcline in small porphyroblasts or highly irregular grains in the groundmass. Epidote is less abundant in those portions of the rock where hornblende predominates over biotite. Some biotite has formed from hornblende. Some of the epidote therefore is considered as a product of the biotitization of hornblende. However, much of the epidote appears to be earlier as it gives the impression of having crystallized contemporaneously with the earlier minerals in the rock.

The schistose epidote-bearing granulite passes into the epidote-bearing gneiss within a few inches. The gneiss is medium grained and contains about twenty per cent dark minerals. Its texture is crystalloblastic. Epidote occurs in subhedral grains associated with biotite and hornblende and apparently contemporaneous with them, or it occurs as subhedral to anhedral grains in plagioclase. The latter association suggests either simple inclusion of excess epidote in the later-formed plagioclase, or less likely, the breakdown of a more calcic plagioclase with segregation of epidote and recrystallization of a more sodic plagioclase. No consistent relation between zoning and the position of the epidote inclusions was observed in the plagioclase. Some olive-green biotite is later than the hornblende since the hornblende has fringes of biotite and biotite has formed along cleavage planes in the hornblende. The biotite includes epidote or occurs in aggregates with it. Epidote has been able to form crystal faces against biotite. This epidote is believed to have been segregated during the biotitization of part of the hornblende. The plagioclase is zoned, but the rims are not as sodic as those in the plagioclase of the epidote-bearing granulite. This suggests that during the time of growth of the plagioclase grains temperatures were slightly higher in the gneiss than in the granulite since in both rocks an excess of potential anorthite component was available in the form of epidote. Small plagioclase porphyroblasts occur. Inclusions in the porphyroblasts are principally epidote, but some biotite projects into it marginally. Plagioclase also occurs in aggregates, often with a group of epidote grains in the central portion. Xenoblastic quartz occasionally forms aggregates with a mosaic pattern resembling the quartz lenticles in the granulite. Quartz also occurs in patches of myrmekite-shaped intergrowths in biotite. Potash feldspar occurs in the intergranular.

A specimen (8.22.49.11g) from one outcrop in the same area appears megascopically to be mylonitic; however, under the microscope it is seen to be well recrystallised. Quartz and feldspar form a mosaic in which flecks and streaks of biotite accompanied by epidote occur. Some largely biotitized hornblende is present. In the groundmass small (1.8 mm.) plagioclase porphyroblasts have formed. They include groundmass material and are turbid. Some grains grow across the recrystallised mylonitic foliation indicating that they are porphyroblasts and not recrystallised porphyroclasts. The plagioclase is sodic andesine. The large amount of epidote indicates that a considerable amount of calcium was present in the original rock.

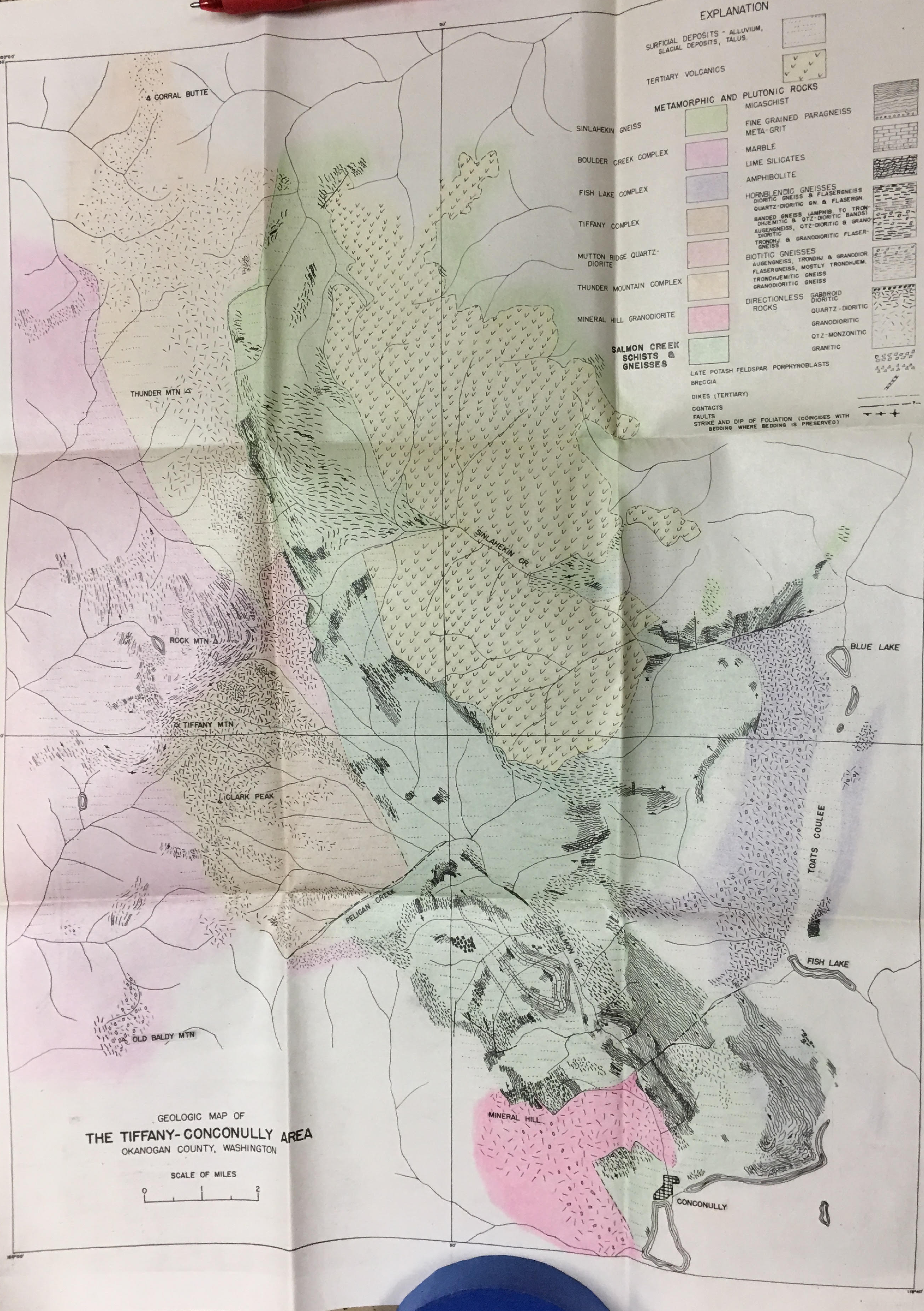
All three rocks described above - the schistose granulite, the epidote-bearing gneiss, and the blastomylonite - are believed to be derived from the same original material. All are comparatively rich in calcium and were perhaps of epidote amphibolitic affinity. Each underwent penetrative differential deformation followed by varying degrees of recrystallization during a stage of sodium and more subordinate potassium metasomatism. Although much of the epidote may have been present as a constituent of the original isochemically metamorphosed rock, i.e. prior to alkali metasomatism, some of it has formed as a result of biotitization of hornblende during potassium metasomatism. During the time of plagioclase growth, some part of the epidote was used up as a source for the anorthite component, but much of the epidote was left over, obviously because temperature did not permit formation of a more calcic plagioclase. Declining temperatures during the later part of metasomatism are indicated by the oligoclase rims of the plagioclase which have formed in the presence of epidote which represents an excess supply of potential anorthite component.

Origin of Sinlahekin Gneiss

The Sinlahekin gneiss is interpreted as having formed from amphibolitic rocks by metasomatic processes during both synkinematic and static phases. Earlier deformation produced the gneissose structure. This was a period of predominant sodium metasomatism and recrystallization which produced andesine. Later, weaker deformation, probably repeated, occurred after the formation of the andesine but prior to a period of predominant silica introduction. Minor amounts of potassium and sodium were introduced with the silica. Replacement and partial recrystallization followed the deformation.

This interpretation is based on the following features described above: the projection of undisturbed zones of amphibolite of the Salmon Creek area into the gneisses and the eventual disappearance of these amphibolites by their passing into the gneiss along the strike; the occasional occurrence elsewhere in the gneiss of conformable amphibolite bands; the transitions across the strike from amphibolite into quartz-dioritic gneiss; the megascopically visible gneissose structure combined with the general microscopic crystalloblastic texture; the occasional deformation of plagioclase crystals and their rehealing by more sodic plagioclase and quartz; the progressive mineralogical-chemical changes that indicate sodium, silica, and potassium introduction; the relations between the gneiss and the adjacent metamorphics with regard to mineral facies and certain mineralogical-chemical features, as illustrated by the epidote content in the gneiss where it is in contact with epidote-bearing rocks, and the lack of epidote in the gneiss where it is adjacent to the higher grade amphibolites to the southwest.

PLATE LV


GEOLOGIC MAP OF
THE TIFFANY-CONCONULLY AREA
OKANOGAN COUNTY, WASHINGTON
SCALE OF MILES
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EXPLANATION
SURFICIAL DEPOSITS - ALLUVIUM, GLACIAL DEPOSITS, TALUS
TERTIARY VOLCANICS
METAMORPHIC AND PLUTONIC ROCKS
SINLAHEKIN GNEISS
BOULDER CREEK COMPLEX
FISH LAKE COMPLEX
TIFFANY COMPLEX
MUTTON RIDGE QUARTZ-DIORITE
THUNDER MOUNTAIN COMPLEX
MINERAL HILL GRANODIORITE
SALMON CREEK SCHISTS & GNEISSES
MICASCHIST
FINE GRAINED PARAGNEISS
META-GRIT
MARBLE
LIME SILICATES
AMPHIBOLITE
HORNBLENDIC GNEISSES
DIORITIC GNEISS & FLASERGNEISS
QUARTZ-DIORITIC GN. & FLASERGN.
BANDED GNEISS (AMPHIB. TO TRONDHJEMITIC & QTZ-DIORITIC BANDS)
AUGENGNEISS, QTZ-DIORITIC & GRANODIORITIC
TRONDHJ & GRANODIORITIC FLASERGNEISS
BIOTITIC GNEISSES
AUGENGNEISS, TRONDHJ & GRANODIOR
FLASERGNEISS, MOSTLY TRONDHJEM.
TRONDHJEMITIC GNEISS
GRANODIORITIC GNEISS
DIRECTIONLESS ROCKS
GABBROID DIORITIC
QUARTZ-DIORITIC
GRANODIORITIC
QTZ-MONZONITIC
GRANITIC
LATE POTASH FELDSPAR PORPHYROBLASTS
BRECCIA
DIKES (TERTIARY)
CONTACTS
FAULTS
STRIKE AND DIP OF FOLIATION (COINCIDES WITH BEDDING WHERE BEDDING IS PRESERVED)
CORRAL BUTTE
THUNDER MTN
ROCK MTN
TIFFANY MTN
CLARK PEAK
OLD BALDY MTN
SINLAHEKIN CR
BLUE LAKE
TOATS COULEE
FISH LAKE
PELICAN CREEK
SALMON CR
MINERAL HILL
CONCONULLY

PLATE XXVIII

A. Quartz-dioritic gneiss. Sinlahekin gneiss. Head of Sinlahekin Creek (7.21.49.4g).

B. Epidote bearing variety of Sinlahekin gneiss near junction of Coxit and Sinlahekin creeks (8.22.49.6g).

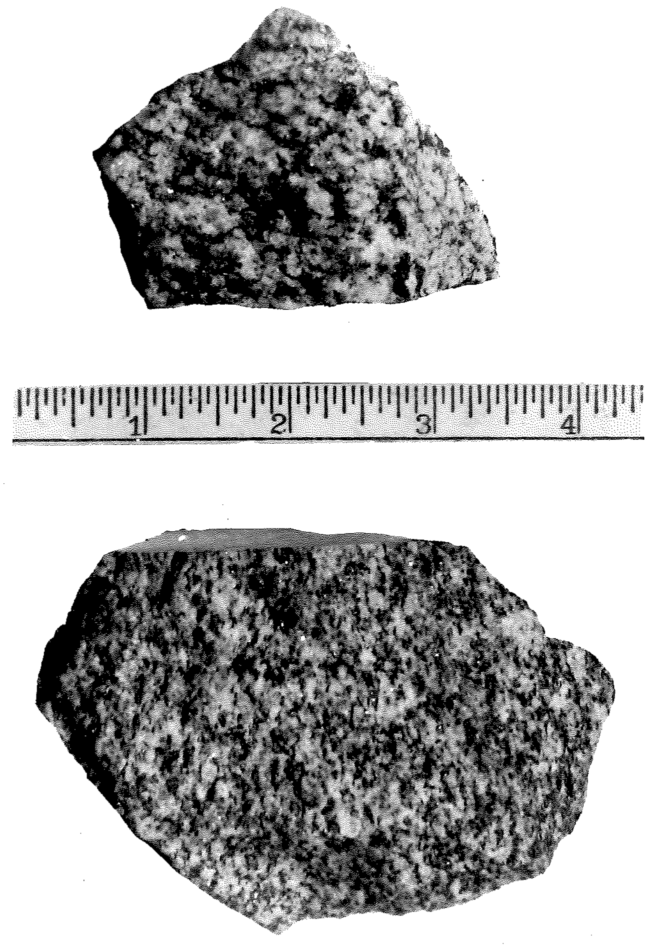
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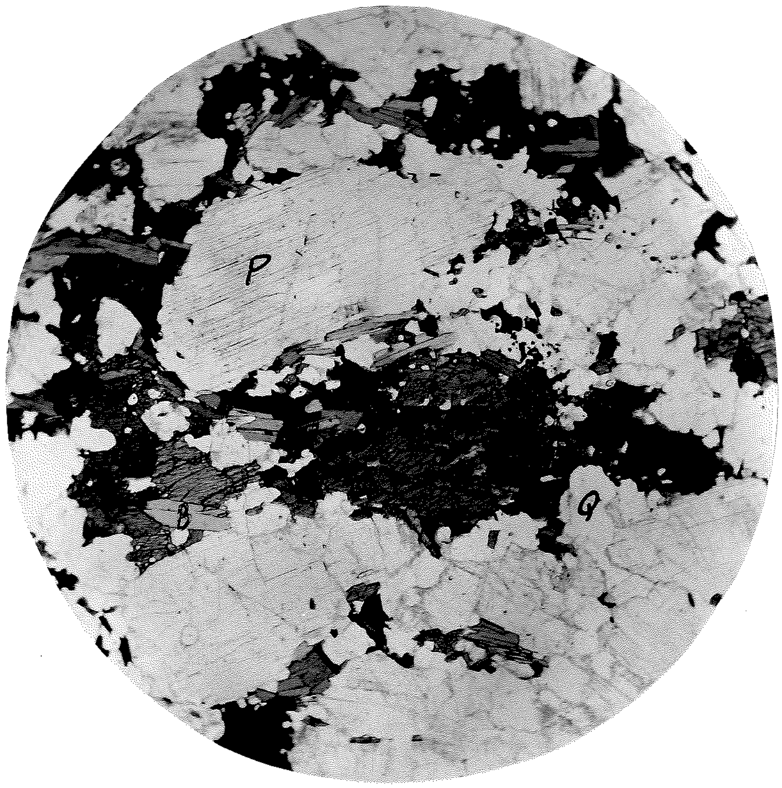
PLATE XXIX

A. Sinlahekin quartz-dioritic gneiss. Crystalloblastic texture. Hornblende (H), quartz (Q), plagioclase (P), biotite (B). Near head of Sinlahekin Creek (10.23.48.14g). Plane polarized light, x 17.

B. Different portion of same thin section, crossed nicols. Late quartz (Q) replacing plagioclase (P). x 17.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Q

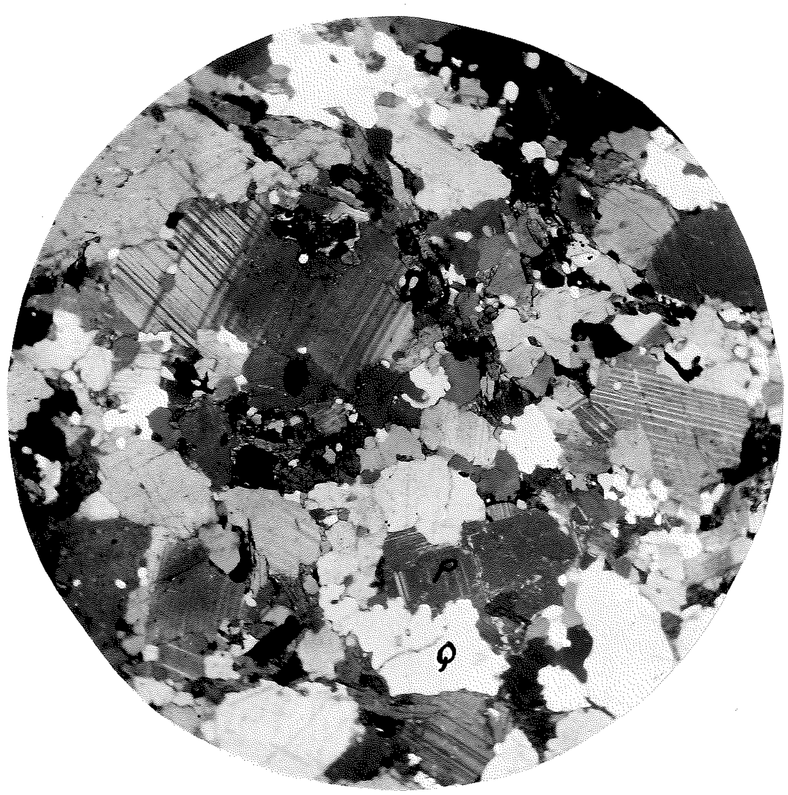
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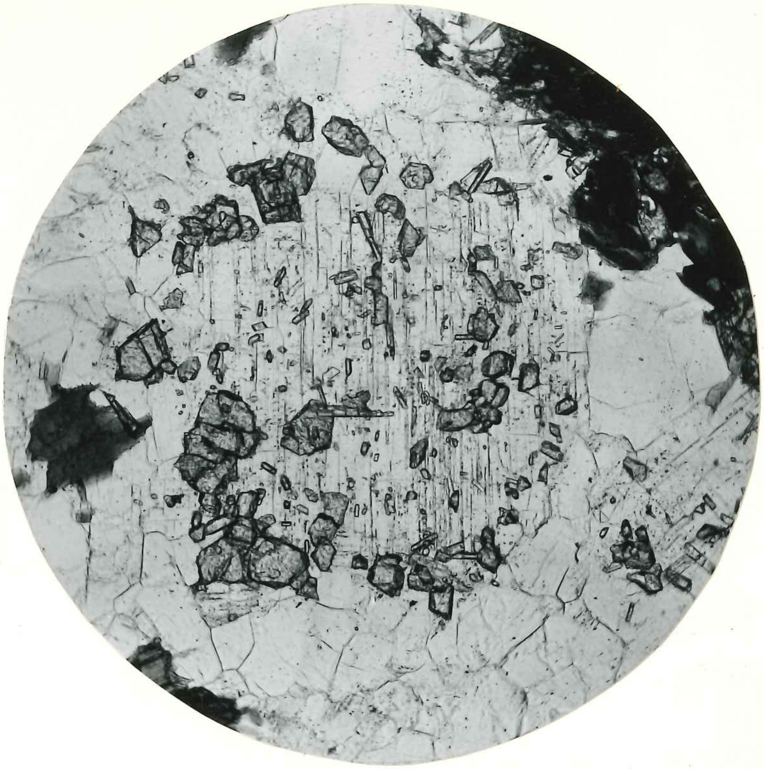
PLATE XXX

A. Early epidote and apatite grains in and near small plagioclase porphyroblast. Epidote-bearing variety of Sinlahekin gneiss (Plate XXVIII, B). Plane polarized light; x 60.

B. Same. Crossed nicols. Note complete lack of alteration of plagioclase, which excludes a secondary origin for epidote. Epidote occurs outside of as well as in small plagioclase porphyroblast.



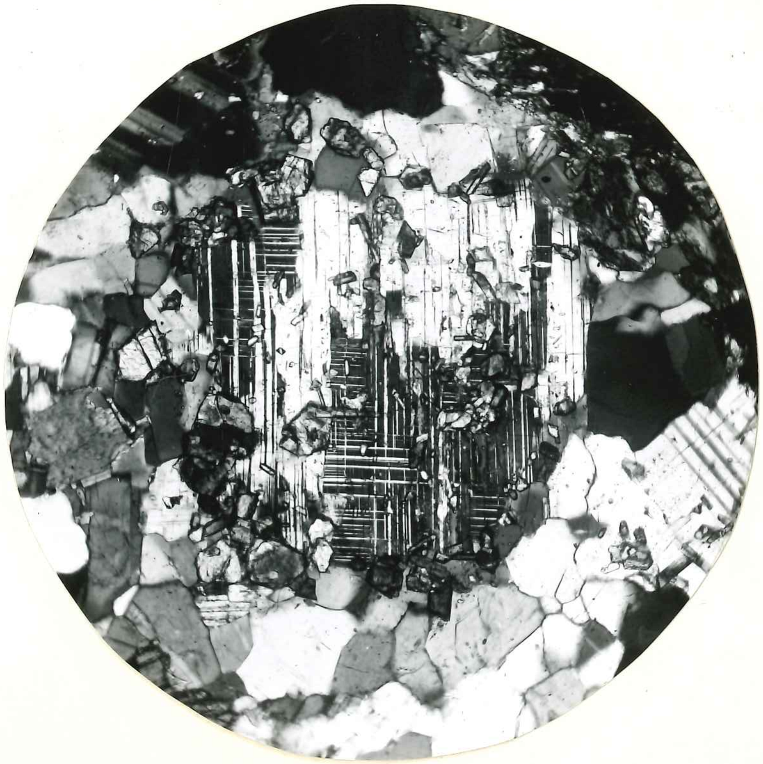


PLATE XXXI

Contemporaneous epidote and biotite in epidote-bearing variety of Sinlahekin gneiss. Epidote (E), biotite (B). Inclusions of sphene in large biotite grain. West of Blue Lake (6.22.49.6g). Plane polarized light, x 60.


E

Biotitic Gneisses

Migmatitic gneisses derived from the purer argillaceous rocks with biotite as their predominant ferromagnesian mineral are subordinate in the area. Such biotitic gneisses occur mostly in the southeastern sector of the Salmon Creek migmatitic zone intercalated and gradational with micaschists, fine grained paragneisses, and hornblendic gneisses.

The metamorphic history of these migmatitic biotitic gneisses roughly parallels that of the hornblendic gneisses described above. Since many of their textural and structural features are similar to those of the hornblendic gneisses, only a brief description of the biotitic gneisses is given. These rocks are usually characterized by the fine grain size of the dark minerals in contrast to the more coarse grain size of the dark minerals in the hornblendic gneisses. Granitization begins in the aluminum rich bands of the micaschists and paragneisses with the development of small oligoclase porphyroblasts. As these porphyroblasts become more numerous, bands of feldspar porphyroblasts schist are formed. With a development of abundant, more coarse grained plagioclase, the schistose structure is gradually lost, the mafics become relegated to intergranular positions, and the rock becomes as a whole more coarse grained. The end product is a rock of trondhjemitic, or if potash feldspar has formed, of granodioritic composition. As the feldspars develop well defined crystal faces, the rock approaches a "hypidiomorphic granular" texture. If feldspathisation has been associated with deformation synkinematic flasergneisses and augengneisses are produced. As in the hornblendic gneisses, postkinematic recrystallisation has over-shadowed or obliterated evidence of a synkinematic stage in many of the biotitic gneisses.

Primary differences in composition as well as structural control both contribute toward the formation of banded biotitic gneisses. Where narrow, more argillaceous layers are intercalated with layers less favorable to felds-pathization, as for example more silicious layers, the preferential development of feldspar in the argillaceous layers forms a banded gneiss. The beginning of this process was observed in the predominantly isochemically formed fine grained paragneisses described in Chapter II. However, banded gneisses are also formed from rocks of originally uniform composition where structural control must be the predominant factor in determining the layers of preferential feldspathiza-tion, rather than primary differences in composition; in other cases both controls may be combined.

Megascopically, the migmatitic biotitic gneisses are medium to coarse grained and weakly gneissose. Compared to the fine grained paragneisses they contain a relatively smaller, but variable, amount of biotite and a greater amount of feldspar per unit area. Accordingly they have light but variable colors. Lighter colored bands often alternate with darker, fine grained bands. The biotite in a few light colored rocks clearly marks the schistosity, especially near gradational contacts with biotite paragneiss, whereas in other light colored rocks the preferred orientation of minerals is so weak that the rocks are directionless except for their commonly developed banding. Some rocks contain planar patches and streaks rich in biotite parallel to the foliation in the surrounding schists. These patches and streaks are relicts of micaschist material (cf. fine grained paragneisses, Chapter II). Microscopic textures are granoblastic. Irregular grains of oligoclase, reddish-brown biotite, quartz, and often potash feldspar are the principle constituents. The finer grained types are aplitic in texture. The light colored gneissose to directionless material described above is intercalated with the folia of the micaschists and fine grained paragneisses and tapers into thin feldspathic bands and streaks and finally into stringers of individual small porphyroblasts. This type of penetration plus the conformably oriented patches and streaks of micaschist material and the variability in composition and color of different bands already described, indicate an origin for the lighter colored rock by lit-par-lit replacement (cf. P. Misch 1949a, p. 230). Some light colored acidic bands with sharper contacts, part of which parallel and part of which transect the gneissose structure, may represent material which formed during the later static phase of aplitic and pegmatitic replacement in the area and which became finally mobilized.

The migmatitic biotitic gneisses are also gradational with hornblendic gneisses. Conformable passages from quartz micaschist through dark fine-grained biotite paragneiss and through light colored, medium grained biotitic gneiss of trondhjemitic composition to hornblende-bearing gneiss often occur. A good example was observed just west of locality 8 (Plate III). Such sequences, where repeated, recall the intercalated micaschist amphibolite sequences in the non-granitized rocks. North of Funk Mountain, two-mica schist grades northward through biotite paragneiss into weakly gneissose trondhjemitic rock. The orientation of individual biotite flakes and relict biotite rich streaks in these trondhjemitic rocks is conformable with the foliation in the schist. Still further north, the largely hornblendic Fish Lake dioritic and granodioritic complex occurs. Although no continuous exposures were observed, those seen indicate that the gneissose biotite trondhjemitic rock passes into the hornblendic rocks.

Northwest of Salmon Meadows a poorly exposed zone of coarse grained, porphyroblastic, biotite-bearing rock occurs. It contains large subhedral calcic oligoclase porphyroblasts in a patchy, fine-grained matrix of hornfelsic micaschist. This rock resembles some of the porphyroblastic hornblendic flasergneisses or more fine-grained augengneisses in texture although not in composition. This rock was apparently statically formed for no evidence of earlier deformation is seen. This porphyroblastic rock probably formed in a volatile-enriched zone similar to that in which the hornblende-biotite augengneiss occurs.

Migmatitic biotitic gneisses showing more definite evidence of a synkinematic phase also occur. Belts of medium grained, light colored granodioritic and trondhjemitic biotite gneiss occur in the Mineral Hill area near part of the contact with the Mineral Hill granodiorite. The rocks have a flaser structure which has been largely obliterated by later recrystallization accompanying the growth of microcline. In some specimens small lenticles of quartz occur. Similar rocks occurring elsewhere between micaschist and granodioritic bodies have a more definite flaser structure which megascopically often looks cataclastic. Under the microscope, however, deformed plagioclase grains and areas of mortar are seen to have been partly healed by microcline and quartz so that the texture is primarily crystalloblastic rather than cataclastic. Microcline forms small porphyroblasts of haphazard orientation.

The gneiss zones described are considered as representing intermediate stages between non or partially granitized micaschist zones and zones of directionless granodioritic rock. This does not mean that the zones are necessarily intermediate in spatial position. In these intermediate zones, evidence still remains of the deformation which facilitated the feldspathisation. In the more directionless granodioritic bodies, such evidence is no longer present due to the more thorough recrystallization accompanying the metasomatism. Although flasergneiss bands may occur marginal to more directionless granodiorite, they are also seen intercalated and gradational with non-granitised rocks where no directionless granodioritic bodies are present. Also, the biotite flasergneisses described above do not occur marginal to the granodiorite bodies where the granodiorite cuts across the trend of the migmatitic gneisses, as for example at the south-east end of Mineral Hill, but only occur in belts parallel to the regional trend.

Gneissose rocks resembling the biotite flasergneisses but with more coarse grained biotite and some hornblende, sphene, and epidote are interpreted as having been derived from argillites of a more calcareous or dolomitic original composition. These rocks approach the hornblende-biotite flasergneisses in composition. Other dark, coarse to medium grained, well foliated rocks rich in biotite but containing some hornblende and calcium-bearing accessory minerals appear to have been derived from more hornblendic rocks. Differential shearing stress accompanied by potash metasomatism and perhaps local metamorphic differentiation are suggested as having produced this type of biotite-rich rock. In some other cases, coarse grained biotite-rich rocks were observed to have formed from hornblendic rocks under differential shearing stress; these rocks usually occur in narrow plates but sometimes in wider bands. It appears that stress facilitates the formation of biotite from hornblende in the presence of potassium. Epidote or other calcium-bearing minerals are often lacking which would indicate a removal of calcium from the locus of reaction.

Summary and Discussion of Migmatitic Gneisses

Relationship Between Progressive Regional Metamorphism and Granitization

The zones of progressive regional metamorphism and the degree of granitization show a simultaneous increase in the area. In the northeastern portion of the area cooler-mesozonal phyllitic schists occur which have undergone only isochemical regional metamorphism. Westward and southwestward these rocks pass into warmer mesozonal and katazonal micaschists and fine-grained paragneisses. The beginnings of granitization occur in this zone with some plagioclase formed in aluminum-rich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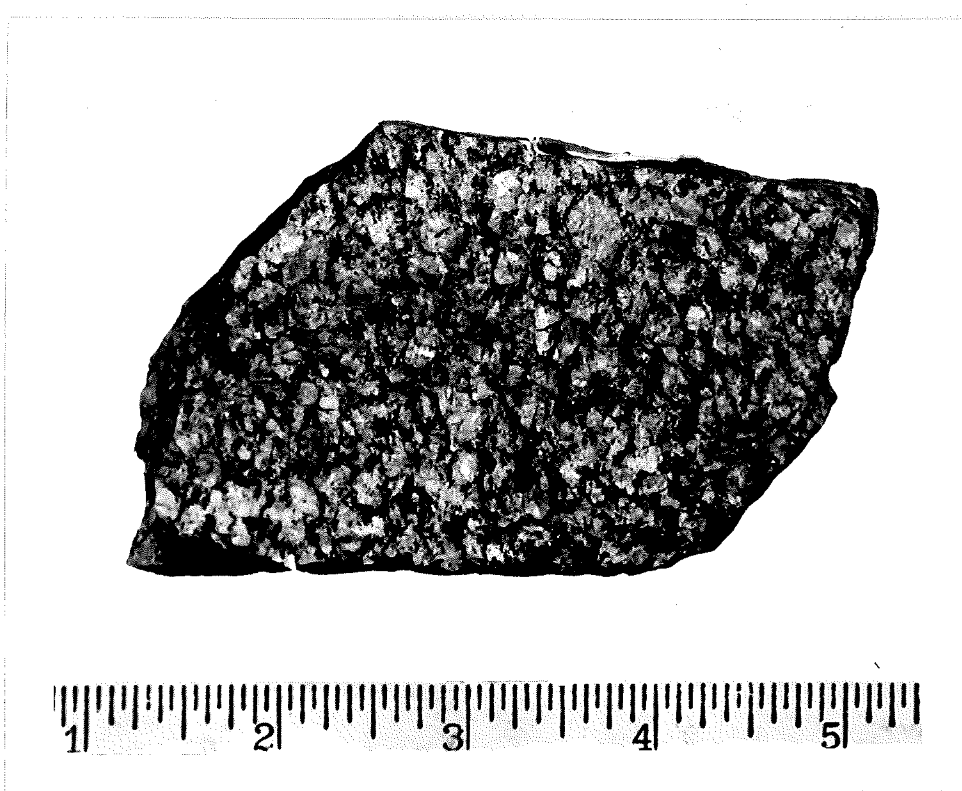
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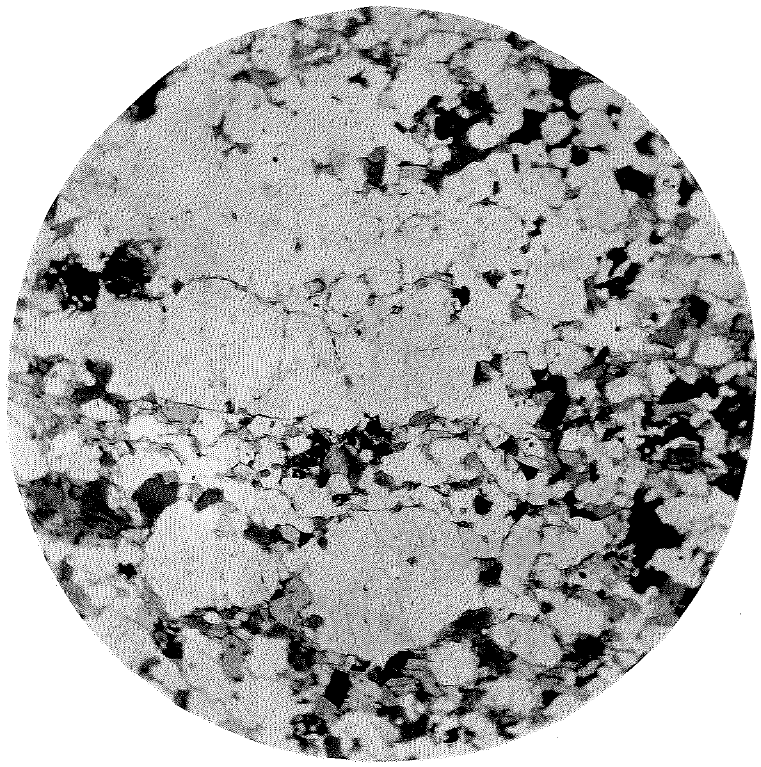


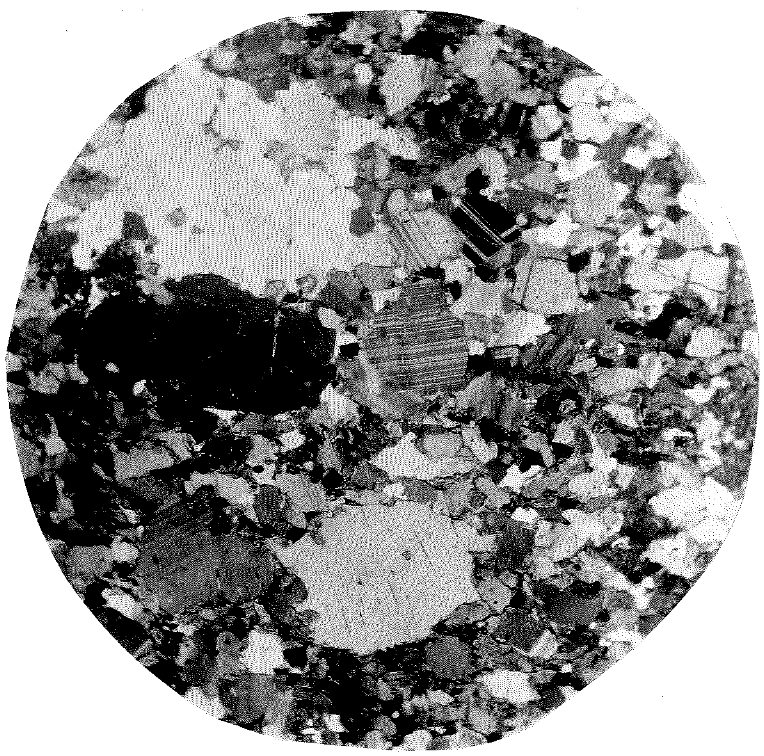
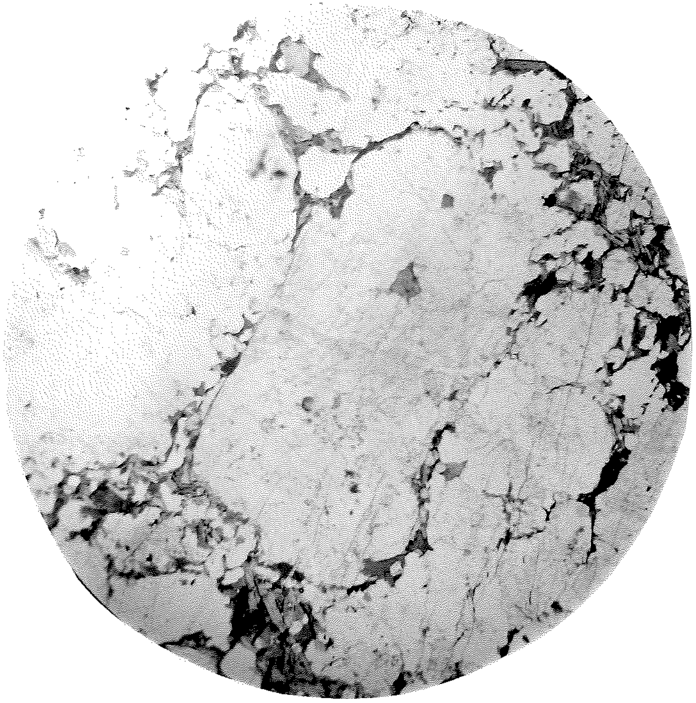
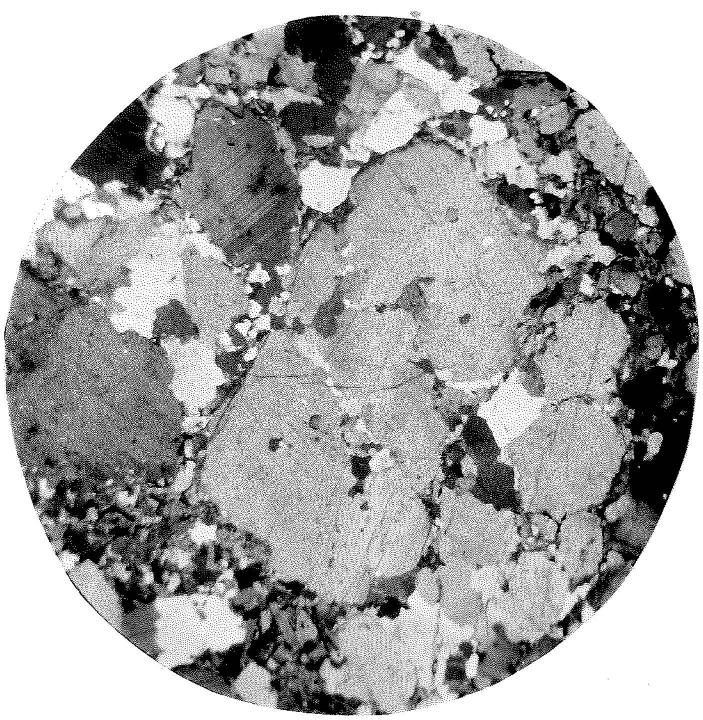


PLATE XXXIV

A. Statically formed plagioclase porphyroblast in porphyroblastic rock formed from micaschist. Intergranular patches of micaschist. Mutton Ridge (9.10.48.2g). x 15.

B. Same. Crossed nicols. Porphyroblast has coalesced from smaller individuals. Inclusions are biotite and quartz.





(possible introduction of sodium) and also some local porphyroblastic development of muscovite and potash feldspar. Aplite and pegmatite dikes and patches occur here and become increasingly abundant to the southwest. These rocks pass southwestward into metasomatically formed migmatitic gneisses which contain relict zones, bands, and streaks of isochemically metamorphosed katazonal lime-silicates and sillimanite-bearing biotite paragneisses. Still further westward and southwestward are less strongly gneissose granodioritic gneisses and more directionless granodiorites that contain little or no relict schist material and that appear to have been more profoundly transformed.

Since the increase in degree of granitization parallels an increase in temperature as shown by the increasing grade of regional metamorphism, the rise of temperature must be related to the granitization. Since the mineralogical transformations which have formed the migmatitic gneisses involve granitizing solutions, it is reasonable to assume that these solutions supplied the heat. The rise of temperature indicated by the progressive metamorphic zones is in this area not related to geologic depth as the metamorphic isograds are approximately vertical. The zonal succession, then, appears to be controlled by heat conveyed by granitizing solutions. This conclusion is similar to that reached by P. Misch (1949a, p. 241).

Metamorphic History

A number of facts indicate that the migmatitic gneisses were formed by regional orogenic metasomatic metamorphism from part of the Paleozoic geosynclinal sequence which extends into the present area from the Riverside-Conconully region where its degree of metamorphism is generally lower and where metasomatism occurs only locally. These facts are: the similarity in type of deformation throughout the area in both the isochemically metamorphosed rocks and in the migmatitic gneisses; the parallelism and continuity of the local structure with the regional orogenic trend; the mutual intercalations, and the conformable and gradational relationships of the migmatitic gneisses with the isochemically metamorphosed rocks; the undisrupted relict zones, bands, and streaks of isochemically metamorphosed rocks occurring in the gneisses parallel to the regional trend; and the progressive mineralogical transformations involved in the passages from micaschist and amphibolite to migmatitic gneiss, transformations which reflect the same general sequence of events throughout the area.

The gneissose structure, and the occasional occurrence of syncrystalline deformation, together with the mineralogical changes occurring in the sequence from amphibolite through dioritic gneiss and quartz-dioritic gneiss to trondhjemitic gneiss, indicate an earlier synkinematic stage in the formation of the gneisses. This stage was coupled with a predominant sodium and silica metasomatism. Contemporaneous deformation and recrystallization has in general been the process by which the gneissose structure was formed (crystallization foliation). The gneissose structure of the medium and coarse grained gneisses, even though in many cases greatly weakened by superimposed static recrystallization, indicates a synkinematic stage during their formation. If the recrystallization which produced the coarse grain size had been wholly static, an originally fine grained schistose rock would have probably lost its directional fabric at an early stage. This latter point is illustrated by the fairly fine grained directionless hornfelsic texture of microdiorites and diorites formed from amphibolites by static metasomatic recrystallization, and by some of the statically formed directionless aplitic patches in hornfelsized micaschists and paragneisses. The metasomatism occurring during the synkinematic stage was an integral part of synkinematic regional metamorphism in these rocks (cf. relation between metamorphic isograds and degree of granitization discussed above, p. 196).

The synkinematic stage was succeeded by a predominantly static stage of metamorphism which included a predominant potassium metasomatism as well as continued sodium and silica introduction. The continuity from predominant sodium to predominant potassium metasomatism is shown in the general progression from predominant plagioclase development to predominant potash feldspar development. This is well exemplified in the mineralogical passage from plagioclase-rich flasergneiss to potash feldspar-rich flasergneiss and augengneiss. The superposition of potassium metasomatism over predominant sodium metasomatism is well shown in the development of potash feldspar augen and spreading grantic and pegmatitic patches in the plagioclase-rich synkinematic banded gneiss of the Rock Mountain area. General re-crystallization during the static phase weakened the parallelism in the synkinematically formed rocks throughout the area by superimposing a hornfelsic texture in schists and amphibolites, and a directionless granoblastic fabric in the gneisses. During the postkinematic stage, metasomatism did not follow the older parallel structures any more, and cross cutting aplitic and pegmatitic replacement dikes and irregularly spreading replacement patches were formed. Dilational intrusive dikes were also formed under the tensional conditions during this time. Some of the migmatitic material was apparently mobilized for it is locally seen to have both replaced and intruded the surrounding rock. Dark, fine-grained, relatively basic dike material, which possibly represents basic relict material of amphibolitic derivation has been both replaced and intruded by later granodioritic and quartz-monzonitic material. Fracturing and brecciation have locally occurred both in these rocks and in portions of the country rocks. Continuing granitization in such local fractures and shear zones has led to the formation of replacement breccias. Intrusive movement of some of the material in these local shear zones has formed intrusive and "rheomorphic" breccias. Aside from the fracturing and brecciation in the gneisses, there also has occurred plastic deformation which is interpreted as a reaction to long continued stresses. This plastic reaction is observed in drag folds and other forms of mobile folds usually associated with local shearing movements. Later, dark, fine-grained, relatively basic dikes have cut all the migmatites. The latest stage of the history of the gneisses is represented by a few cross-cutting zones of low temperature hydrothermal alteration, some of which show traces of mineralization. This stage is not part of the continuous petrogenetic evolution of the gneisses but altogether later and superimposed.

The kinematic conditions during granitization vary systematically in this area. The more thoroughly granitized, gneissose and directionless granodioritic rocks occur to the southwest and west. They show evidence of an earlier synkinematic stage of granitization. The migmatitic gneisses of the Salmon Creek-Rock Mountain belt still more definitely show evidence of synkinematic granitization. In both of these regions, static granitization and recrystallization has followed the synkinematic stage, and predominant potassium metasomatism has followed predominant sodium metasomatism. To the northeast beyond the migmatitic gneiss belt, the granitization was predominantly static and potassium metasomatism prevails. Here cross-cutting and irregular aplitic and pegmatitic replacement patches and dikes and muscovite and potash feldspar porphyroblasts are present in previously not granitized schists. Postkinematic granitization then, has spread further than synkinematic granitization. Still further to the northeast occur the isochemically transformed phyllitic schists which have not been reached by granitization at all. The static phase of heating is here shown by the presence of andalusite porphyroblasts. The heat necessary to produce these porphyroblasts was probably introduced by conduction from the neighboring postkinematically granitized areas, although it may have been introduced along with a small amount of sodium-bearing solutions (Misch 1949b, p. 686-691).

Locally, however, the synkinematic and postkinematic stages are not sharply differentiated, nor is it in every case true that the synkinematic stage of metamorphism had sodium predominance and the postkinematic stage potassium predominance. Bands and areas of rock which appear to have undergone either stronger or more recent deformation occur adjacent to zones which appear to have undergone weaker deformation or in which deformation appears to have ceased at an earlier time so that its results have become largely obscured by static recrystallization. Moreover, adjacent zones may exhibit varying degrees and varying types of metasomatism. At one place sodium metasomatism may be predominant; at an adjacent place potassium metasomatism may have been superimposed on the sodium metasomatism. Such differential metasomatism may be controlled either by differences in original composition or by differences in deformation (chemical and structural control).

The variations described are on a rather local scale. An example of a variation in distribution of potassium metasomatism on a large scale is shown by a comparison of the Rock Mountain migmatitic gneisses with the Sinlahekin gneiss to the north. In the Rock Mountain gneisses, features produced by potassium introduction are abundant; in the Sinlahekin gneiss potash introduction occurs only locally and is limited to only incipient features. Both of these gneiss units were hornblende-plagioclase-quartz rocks prior to the time of potassium introduction, and therefore the great difference in the amount of potassium introduced in these two units cannot be due to compositional control.

Some small, lenticular bodies of mostly directionless dioritic, quartz-dioritic, or granodioritic rocks which are intercalated with the migmatitic gneisses and grade into them, could be interpreted in two ways: they might have been layers which escaped metasomatism during the synkinematic phase and thus never became gneisses so that post-kinematic metasomatism could much more easily eliminate their earlier parallel structure. A second interpretation appears to be much more likely. This would be that in the directionless layers in question static metasomatism and recrystallization were of greater intensity than in adjoining layers which were able to maintain their overall gneissose character.

Local deformation continued during what was, considering the area as a whole, essentially a static phase. Deformation during potassium introduction, for example, is shown in occasional bands of augengneiss in the Conconully area which contain drawn out microcline porphyroblasts. In most places the potassium metasomatism has been largely static as is shown by augengneisses in which the potash feldspar porphyroblasts are much more randomly oriented. Drag folds connected with local shearing movements were observed in the migmatites on Rock Mountain and were formed during a late stage of the evolution of the gneisses. In many rocks, notably the Sinlahekin quartz-dioritic gneiss and some of the trondhjemitic zones along the Salmon Creek migmatite belt, a fairly late, weak, cataclastic deformation has occurred; it is post-plagioclase and pre-potash feldspar or quartz. This phase of deformation apparently facilitated the introduction of the potassium and silica which was to follow. This cataclastic phase is seen mostly in bent twinning lamellae and fractured crystals of plagioclase. The plagioclase apparently was slow to readjust itself under the conditions prevailing during the later stages of the metamorphic history. The mafics seem to be able to reform more readily. In some rocks a slight post-crystalline deformation has occurred. On the whole, however, crystallization has outlasted deformation in the area.

Some cataclastic appearing areas occurring locally around potash feldspar porphyroblasts are interpreted as a replacement texture and as corresponding to the pseudo-cataclastic texture of G. H. Anderson (1934).

<u>Temperature Variations in the Migmatitic Gneisses</u>

The isochemically metamorphosed rocks have been shown to have a varied metamorphic history although it represents a single metamorphic cycle (monocyclic metamorphism). The zones of progressive metamorphism have been rendered less distinct because the geographic location of the metamorphic zones which are temperature zones, has changed from one stage of metamorphism to the next. Similar variations in the location of metamorphic zones would be expected to occur in the metasomatic rocks. However, such changes are hard to establish in the granitized rocks, for, as granitization becomes more complete index minerals of the metamorphic zones such as the lime-silicate minerals and especially the aluminum-excess minerals are eliminated through metasomatism and replacement. The exact zonal position of most of the granitized rocks can only be determined in so far as relicts of isochemically metamorphosed rocks containing critical minerals are present. Where these are lacking, only the feldspars and mafics of the granitized rocks are available for zonal classification, and these minerals in most cases do not permit differentiation between the medium and high grade zone and their subdivisions. Evidence for temperature fluctuations in the migmatitic gneisses is therefore not readily obtained. Zoned plagioclase may indicate temperature changes, but it also reflects other physico-chemical changes, such as changes in the sodium concentration and possibly in stress action. However, temperature is considered to be the primary control in such cases where in migmatitic gneisses a more sodic marginal zone of plagioclase has formed in the presence of potential excess anorthite component occurring in the form of epidote, and in the absence of simultaneous stress. Zoned plagioclase is not abundant in the migmatitic gneisses of the Rock Mountain and Salmon Creek areas, but where it occurs it always has a more sodic outer zone. The presence of this outer zone is considered as being due primarily to an increased sodium concentration in the intergranular liquid in the rock.

All that can be said about the metamorphic grade of the migmatitic gneisses is that the maximum temperatures reached corresponded to those of the warmer mesozone and katazone.

Conclusion

The metamorphic history of the migmatitic gneisses consists in general terms, of a phase of synkinematic metasomatic metamorphism followed by a phase of post-kinematic metasomatic metamorphism. This sequence of events parallels the general metamorphic history of the isochemically metamorphosed rocks. Table VI correlates the metamorphic history of these two major rock divisions.

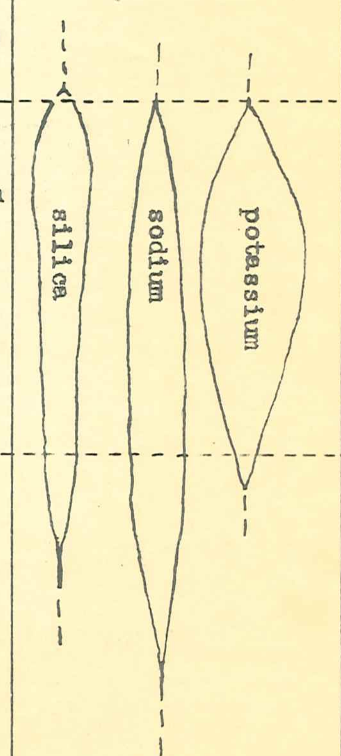
Structural Trends in the Migmatitic Gneisses

The structural trend of the migmatitic gneisses and the isochemically metamorphosed rocks in the present area conforms to the regional northwest-southeast strike. Both major and minor fold axes consistently trend northwest-southeast. Deflections from this trend occur locally; they usually reflect steep axial plunges of folds. While the regional plunge is to the northwest, individual fold axes may locally plunge to the southeast. The swirling pattern thus produced is apparent on the geologic sketch map, Plate LV.

TABLE VI

CORRELATION BETWEEN METAMORPHIC HISTORIES OF ISOCHEMICALLY METAMORPHOSED ROCKS AND MIGMATITIC GNEISSES IN THE TIFFANY - CONCONULLY AREA

General phases of metamorphic history	Isochemically metamorphosed rocks	Migmatitic gneisses	
	phases of metamorphic history	phases of metamorphic history	chemical phases of metasomatism
retrogressive phase	C. low temperature hydrothermal alteration and local deformation	low temperature hydrothermal alteration and local deformation; some mineralization	
postkinematic phase	B. development of granoblastic texture under slowly decreasing temperatures with secondary peak of recrystallization	brecciation and local shearing simultaneous with further metasomatic replacement, mobilization and intrusion recrystallization and further metasomatism; structures depart from parallelism, development of granoblastic texture, local continued deformation	
synkinematic phase	A. regional orogenic metamorphism producing schists and amphibolites A_2 less complete deformation, folding of the foliation A_1 production of the initial foliation; minerals of progressive metamorphism	regional orogenic metasomatic metamorphism producing gneisses	



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CHAPTER IV

BODIES OF DIRECTIONLESS DIORITIC TO GRANODIORITIC ROCKS

Small bodies of directionless rocks associated and at some places interlayered with the migmatitic gneisses, which have formed during the post-kinematic phase of the metamorphism of the area, have been described in the preceding chapter. In the present chapter all other bodies of directionless dioritic to granodioritic rocks will be described; for the sake of brevity, they will be referred to as "granitoid." These range from small granitoid bodies formed in previously non-granitised schists and amphibolites to large masses of directionless rocks occurring throughout the area which are in part discordant to the gneissose and schistose rocks.

Small "Granitoid" Bodies in the Predominantly Isochemically Metamorphosed Schists and Amphibolites

Introduction

In the predominantly isochemically metamorphosed schists and amphibolites local effects of static metasomatism have been observed on a microscopic scale. These have been described in Chapter II. Megascopic granitoid bodies formed in these rocks during the post-kinematic phase of metamorphism will be described now. These bodies are rich in feldspar, have light but variable colors, and occur in small patches and larger areas of irregular outlines as well as in both cross-cutting and conformable dike-like masses of aplitic and pegmatitic character. Of the latter, some represent in situ replacement, others are wholly or partly intrusive. Similar features have been described from the migmatitic gneisses, but here the formation of directionless granitoid rocks was superimposed on rocks that previously had undergone synkinematic granitization. The description of the small granitoid bodies will be divided according to the kinds of country rock in which these bodies occur.

Geographically, these granitoid bodies are concentrated in the micaschists, amphibolites and fine grained paragneisses adjacent to and northeast of the Salmon Creek belt of migmatitic gneisses. They are extremely rare in the lower grade rocks occurring in the northeastern section of the area.

<u>Small "Granitoid" Bodies in Biotitic Rocks</u>

<u>Irregular patches and areas</u>. The irregular patches and areas of granitoid composition occurring in the micaschists

and fine grained paragneisses vary in size from bodies measured in inches to those covering at least several hundred square feet. Most are granodioritic or trondhjemitic in composition. They are sometimes pegmatitic but more commonly aplitic in texture. The small, feldspathic patches tend to follow the foliation planes in the micaschist or fine grained paragneiss but also depart from these planes and extend out irregularly across the foliation. Projections from these patches pinch and swell and often appear as isolated lenticles before disappearing into the surrounding micaschist. No evidence of forcible emplacement of light colored feldspathic material is present. Occasionally the schistose structure of the micaschist continues across the feldspathic areas where it is marked by flakes of biotite in parallel orientation with the foliation in the surrounding schists. Remnants ("skialiths") (cf. Goodspeed, 1948) of undisturbed micaschist also occur in the feldspathic patches. However the feldspathic patches and areas usually have a directionless structure megascopically, and the inclusions of micaschist usually have been hornfelsized and have partly or entirely lost their schistose structure. The patches may be almost free of biotite in the center, but near the contacts, or where they disappear into the surrounding rock, or where connections between two larger patches cut across the foliation, biotite flakes are common and are frequently coarser grained than in the country rock. The latter implies a collective crystallization of biotite. The total amount of biotite contained in a unit area in the feldspathic patches may equal, but is usually less than that in an equal area in the surrounding schist.

The microscopic textures of the feldspathic patches are granoblastic. Plagioclase, potash feldspar, quartz and biotite are the predominant minerals. The contacts, passing from the micaschist into the feldspathized patches, are marked by an increase in grain size, a decrease in the number of biotite flakes, and the appearance of abundant potash feldspar. Smaller amounts of potash feldspar are present in the micaschist near the contact.

The lack of evidence for forcible injection of the granitoid material, the megascopic textural irregularities, the crystalloblastic textures, and the mineralogical changes indicate metasomatism and recrystallization, and thus demonstrate that the granitoid patches and areas were forked by replacement of schist. The irregular and cross-cutting contacts of these bodies show that they have formed statically.

Replacement locally guided by intersecting fractures has produced replacement breccias. The amount of preserved micaschist material varies widely in these breccias, and this relict material shows all degrees of recrystallization and replacement.

Larger areas of aplitic rock are similar in occurrence, texture and composition to the smaller areas and patches described above. They represent the results of the same replacement mechanism on a larger scale. Near the upper Conconully reservoir, one irregular body of directionless, aplitic, granodioritic rock formed from micaschist partly encloses an undisturbed band of isoclinally folded marble. This illustrates the selectivity of the replacement process.

Dike-like bodies. Some of the granitoid bodies are dike-like in form and may be either pegmatitic or aplitic in texture. They may parallel or transect the foliation of the schist. The discordant dike-like bodies are most common near the axes of folds; the concordant bodies are most common on the limbs.

Some of these bodies are formed by replacement which apparently has been controlled by single or parallel fractures. For example, north of Conconully, a one inch aplitic, granodioritic band transects the foliation of the surrounding fine grained paragneiss at a small angle (spec. 8.4.50.1g). The biotite flakes in the dike are oriented parallel to the foliation of the paragneiss, so that the schistosity continues across the dike undisturbed. Other light colored dike-like bodies have no uniform orientation of the biotite flakes. Most of these concordant and cross-cutting dikes have compositions and textures similar to the more homogeneous varieties among the irregularly shaped, aplitic patches and areas of replacement origin described above. Some of the dikes do not exhibit very definite criteria for replacement; but their similarity both to definite replacement dikes and replacement patches is taken as an indication of a probable similar origin.

Large pegmatite dikes are common in the Funk Mountain-Salmon Creek area. One concordant, lenticular body exceeds 500 yards in length and is 10 to 50 yards wide. The mineral composition of the pegmatites in this area is similar to that of the pegmatites occurring in the Rock Mountain area, except that muscovite takes the place of much of the potash feldspar, suggesting a somewhat lower temperature of formation.

Some of the dike-like bodies show features that indicate a dilational, intrusive mechanism of emplacement (cf. discussion of aplites, Chapter III). These features include displaced blocks of country rock in the dikes and offset of wall rock units proportional to the width of the dike and the angle of intersection. However such features are not common. Northeast of Conconully, an elongate fragment from a thin band of marble has been displaced and rotated from its former position out into an adjacent aplite dike.[1] The

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1 This feature was called to the attention of the writer during the University of Washington summer field course of 1948 on a reconnaissance trip by the group along the upper Conconully reservoir.

aplitic material intrudes the marble band and occupies the space vacated by the displaced fragment. The aplitic material can only have flowed into this space. The material however, was apparently quite viscous and of fairly low temperature because the marble fragment is suspended in the aplite close to its original position and is not fused.

The light colored, aplitic dikes interpreted as being intrusive are considered as mobilized migmatitic material; for rock of similar texture and composition is elsewhere seen to be of replacement origin and not to have moved. Localized movement of granitized material along shear zones is possibly the explanation for some darker intrusive-appearing dikes. P. Misch (1949b, p. 690) mentions a dilation dike of barely granitized micaschist intruding micaschist northeast of Conconully.

Small "Granitoid" Bodies in Amphibolitic Rocks

Fine-grained, hornfelsic, amphibolitic rocks interbedded with the micaschists and locally faulted up with them in pre-granitic time, frequently contain light but variably colored patches rich in feldspar similar in appearance and pattern to the granitoid patches and areas in the biotitic rocks. In general the description given above applies also to the hornblendic rocks, except for differences in mineral composition.

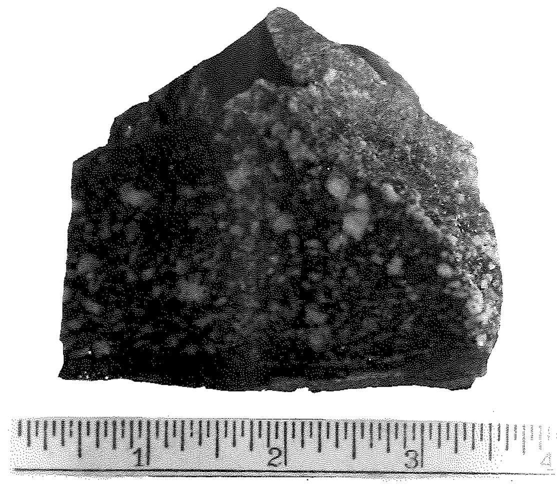
These granitoid bodies have not produced the structural disturbance of the country rock usually associated with a forcible intrusion of magma. They are usually irregular in outline and exhibit textural and compositional inhomogenieties. Some of the hornblendic rocks are traversed only by feldspathic veinlets or streaks of a discontinuous nature or by more continuous dike-like bodies. Other rocks have an irregular distribution of lighter colored, coarse grained areas and darker colored, fine-grained areas so that some patches may be dioritic and others microdioritic (cf. Plate XXXV A). These feldspathic veinlets and patches include varieties in which the proportion of feldspar (largely plagioclase) to mafics has remained about the same as in the country rock; in cases of this kind the only difference is the coarser grain size in the patches. Other varieties show an increase of plagioclase in the feldspathic patches compared to the country rock which is ascribed to sodium metasomatism. Recrystallization accompanying metasomatism is apparently responsible for the coarser grain size observed in the feldspathic patches. Some of the patches contain biotite, whereas only hornblende occurs in the country rock. Usually there also occur small amounts of potash feldspar in these light colored areas. These facts indicate that some potassium has been introduced. Pegmatitic bands rich in potash feldspar and quartz and containing coarse grained biotite occur very locally in the hornblendic rocks. The textural irregularities and the mineralogical changes described above indicate a replacement origin for these feldspathic areas.

In the more completely transformed rocks, shadowy areas (skialiths) representing incompletely recrystallized and feldspathized remnants of amphibolitic rock often occur. All stages of transformation are present.

Discussion

The examples of local postkinematic granitization described above occur in micaschists, fine-grained paragneisses, and amphibolites which during the synkinematic phase of the metamorphic history of the area had undergone only isochemical metamorphism. These rocks lie principally northeast of the belt of migmatitic gneisses along Salmon Creek. The migmatitic gneisses have undergone metasomatic metamorphism during the synkinematic as well as the postkinematic phases of the metamorphic history. Postkinematic granitization then, has advanced beyond the limits of synkinematic granitization in the present area (cf. Misch 1949b, p. 688-689).

Since the postkinematic phase of the metamorphic history is characterized by predominant potassium metasomatism, it is not surprising to find that potassium had been introduced during the formation of the small granitoid bodies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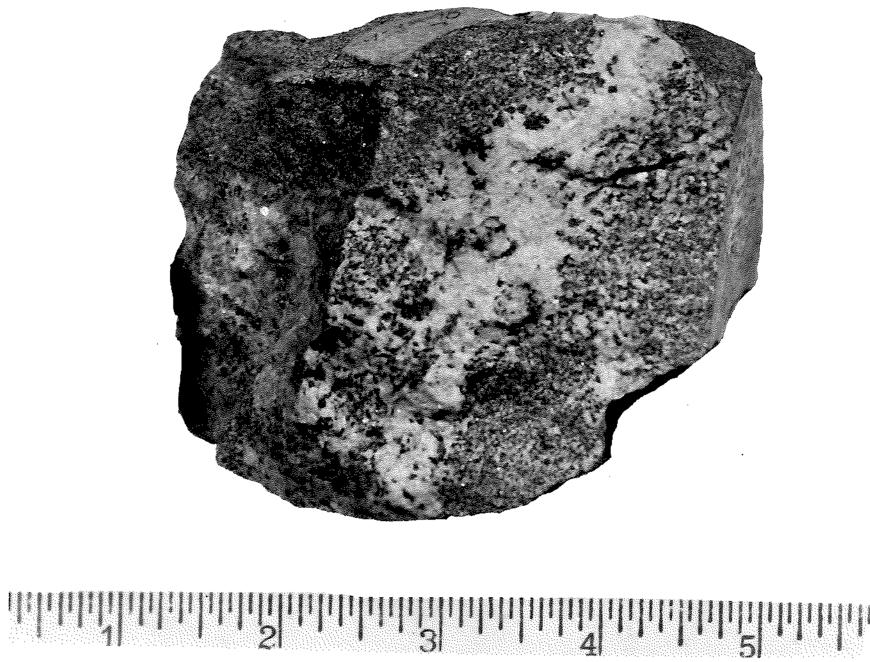
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described in this section. However, it has been shown that while potassium metasomatism was predominant in the biotitic rocks, sodium metasomatism prevailed in the hornblendic rocks. This is due to the difference in chemical composition between the two rock types. In hornblendic rocks sodium is precipitated before potassium.

Fish Lake Complex

Occurrence and Megascopic Description

Exposed along both the east and west walls of the coulee between Blue Lake and Fish Lake is a body of amphibolitic, dioritic, and granodioritic rocks which extends eastward beyond the limits of the area and westward until it merges into migmatitic gneisses of the Salmon Creek belt.

On the east side of the coulee, just north of Fish Lake, a body of amphibolite belonging to the "Anarchist Series," grades northwestward into medium and coarse grained, largely directionless, microcline-bearing dioritic, and monzonitic to quartz-monzonitic rocks. This area was mapped by part of the University of Washington 1948 field course group under the supervision of P. Misch. The writer later collected samples from this amphibolite-dioritic rock sequence and correlated it with the rocks occurring across the coulee in the present area. Still further to the northwest, in the present area, these rocks pass into a light colored, largely directionless, porphyroblastic granodioritic rock which occupies the central portion of the complex. Figure 4 illustrates the variations in mineral composition in the Fish Lake complex. On the north side of the body, near Blue Lake, the rocks revert to a medium grained quartz-dioritic rock, but the passage back to amphibolite was not observed. West of Blue Lake an east-west trending fault along Sinlahekin Creek limits the complex on the north.

The western portion of the Fish Lake complex, towards Salmon Creek, is more variable in texture and structure. Here the porphyroblastic, granodioritic variety of the Fish Lake complex blends into zones of more even granular granodioritic rock and zones of flasergneiss which contain relict bands and streaks of hornblende-rich amphibolite-derived granulite. Some of these gneissose zones appear to have been strongly sheared, others are only faintly gneissose and are poor in ferromagnesian minerals. The schistosity on these rocks parallels the trend of the isochemically metamorphosed rocks in this area which is almost east-west. These gneisses blend westward into medium grained and coarse grained hornblendic gneisses of the Salmon Creek migmatite belt.

On the southernmost part of the Fish Lake complex,

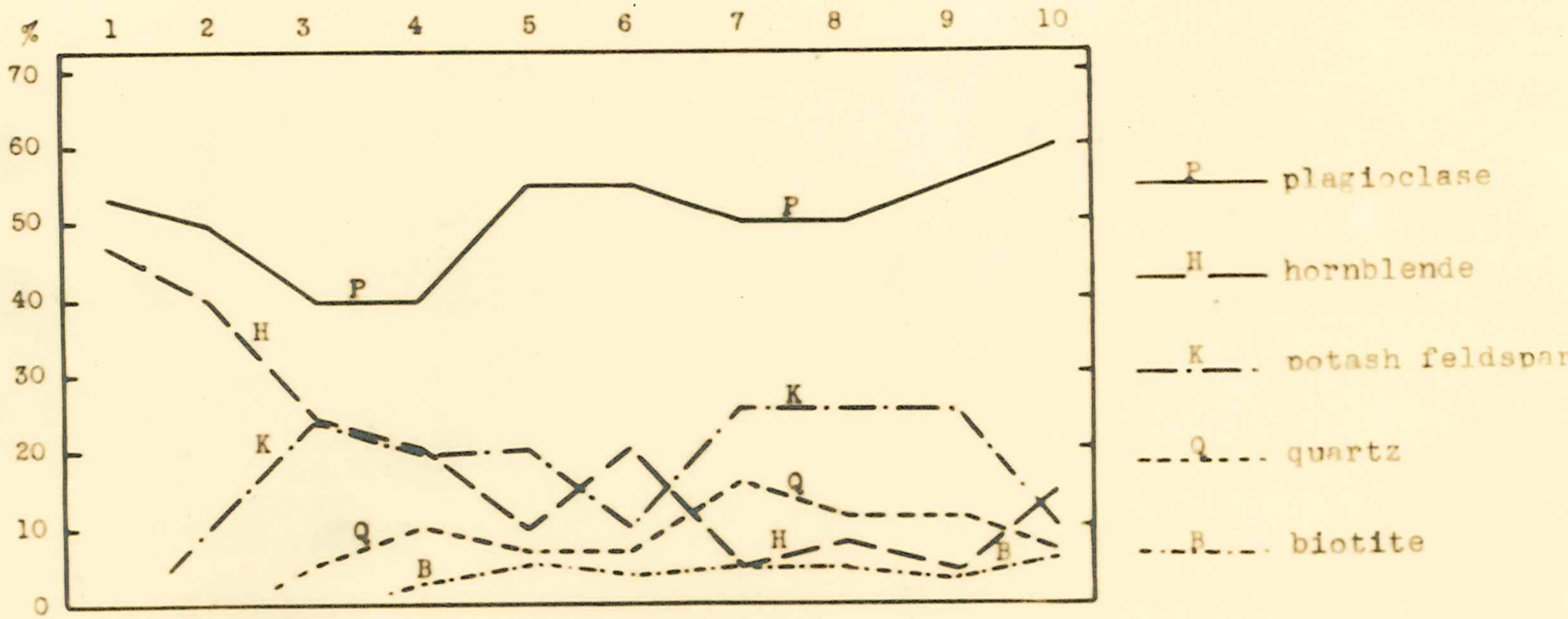

FIGURE 4

VARIATIONS IN MINERAL COMPOSITION IN THE FISH LAKE COMPLEX

Locations of specimens are indicated in figure 5. About 5 % epidote in all specimens but (1); also minor amounts of sphene, apatite, iron oxide, orthite, zircon; trace of pyroxene in specimen (3). The curves shown do not represent one linear evolution, but all typical varieties examined. There are two different types of evolutionary series, rather than one. One of these, less commonly present, exhibits an increasein potash feldspar at a fairly early stage (left side of diagram). The other, more common, shows a marked increase in potash feldspar only at a much later stage (right part of diagram).

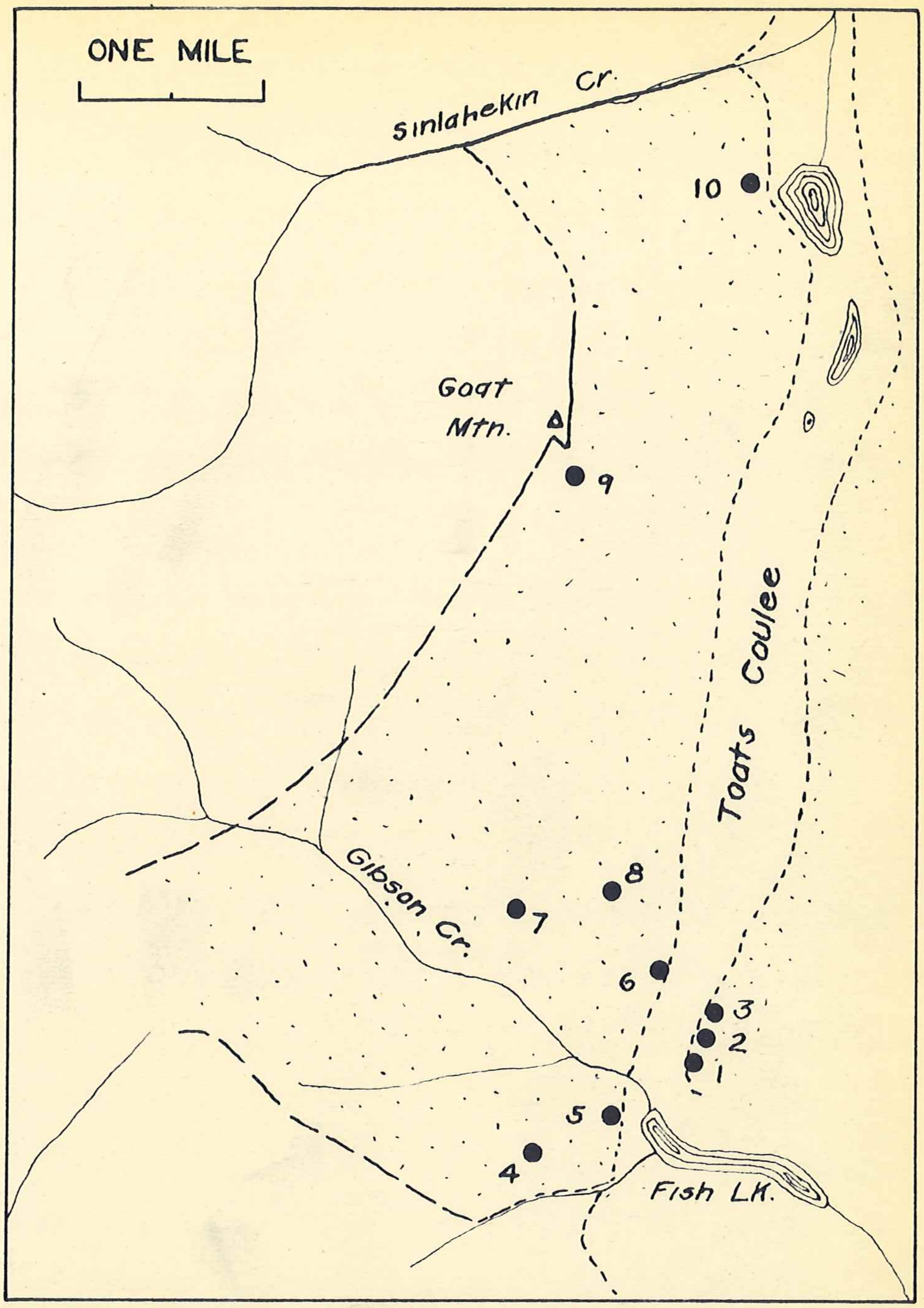

FIGURE 5. DIAGRAM OF FISH LAKE COMPLEX SHOWING LOCATIONS OF SPECIMENS SHOWN IN FIG. 4

occurs a more dark colored, dioritic variety. This is the original Fish Lake diorite as named by P. Misch during the 1948 summer field course (cf. above). To the north it grades into the granodioritic variety in the central portion of the body. On the east and south the Fish Lake diorite is in contact with micaschist. The dioritic rock contains inclusions of still more hornblende-rich diorite, amphibolite, and small clots of hornblende. It represents part of the amphibolite-diorite sequence occurring across the coulee to the east and studied by the field course group in 1948.

The central, granodioritic portion of the Fish Lake complex is a light colored, directionless to slightly gneissose rock which contains larger, almost equidimensional crystals of microcline usually about 10 to 15 mm. in size and with an observed maximum of 17 mm. These crystals have a megascopically visible sieve structure. The granodioritic rock contains inclusions of gneissose amphibolite, hornfelsic amphibolite, and dioritic rock with lathe-shaped hornblende crystals. These blocks show sharp contacts and in one instance all three types were observed together in the space of a square yard. Since three structurally and texturally varied types of inclusions appear in such a small space, it is suggested that they have been moved from previous positions into their present one. At a lower elevation in the coulee, the parallel structure within an inclusion of gneissose amphibolite is oriented at right angles to the gneissose structure here present in the enclosing granodioritic rock although the long direction of the inclusion is parallel to the structure of the enclosing rock. Like the case cited above, this structural relationship indicates that some mass movement has occurred - at least in the central portion of the Fish Lake complex.

Microscopic Description

The changes in mineral composition in the transition from amphibolite to granodioritic rock as observed along Toats Coulee north of Fish Lake are illustrated in Figure 4. Several specimens were used from the amphibolite-dioritic rock sequence northeast of Fish Lake which had been mapped by the 1948 field party (cf. above).

The textures are crystalloblastic. A pseudo-cataclastic replacement texture associated with the development of potash feldspar is widespread, and is especially prominent in the granodioritic rocks.

Plagioclase. Although the plagioclase in the amphibolite ranges from sodic andesine to oligoclase, the coarse grained rocks near and gradational with the amphibolite contain calcic andesine. The lighter colored, granodioritic rocks contain a more sodic plagioclase, generally oligoclase. The presence of a more basic plagioclase in the dioritic rocks than in the amphibolite is interpreted as due to local transfer of calcium; while the presence of a more sodic plagioclase in the granodioritic rocks is interpreted as due to the presence of greater amounts of sodium introduced from without. Plagioclase is irregularly shaped, mottled, and zoned with highly albitic rims where it is adjacent to microcline. It is frequently intergrown with quartz forming myrmekitic patches. The availability of sodium during the later part of the rocks history is not only indicated by the sodic rims on plagioclase, but by a more bluish-colored rim on hornblende which is considered here as a more soda-rich variety of hornblende.

<u>Hornblende</u>. In the more basic rocks, hornblende forms large, subhedral grains around 5.0 mm in size. It is poikiloblastic and encloses plagioclase. It is often aggregated with epidote, biotite, and sphene. It becomes more irregular in shape in the transitional rocks approaching the granodioritic variety. In the light colored rocks it occurs only in small irregular patches and in hornblende-biotite aggregates in which matted biotite predominates.

<u>Epidote</u>. About five per cent epidote occurs in all these rocks. It has a maximum observed grain size of 0.4 mm with an average grain size about 0.3 mm. It very commonly occurs with hornblende and biotite and apparently is in part a product of the reaction in which hornblende is converted

into biotite with the addition of potassium. How much of the epidote in these rocks represents a product of this reaction and how much is inherited from amphibolite was not determined. The amphibolite north of Fish Lake (spec. 1) contains no epidote. The amphibolite at the contact on Goat Mountain west of Blue Lake does, however, contain epidote. Epidote frequently occurs in plagioclase crystals and the plagioclase has apparently formed around it (cf. Sinlahekin gneiss, Chapter III, p. 179), and too, epidote and hornblende occur together without any adjacent biotite. This epidote is well formed and considered to be early, i.e. to have crystallized contemporaneously with the earlier minerals in the rock. Epidote is present in nearly constant amounts in all varieties of the Fish Lake complex. Its presence suggests a metamorphic origin for the body.[1]

<u>Sphene</u>. Sphene is a common accessory mineral and usually occurs with biotite. It generally appears to have been inherited from the amphibolite.

<u>Biotite</u>. The amphibolite and some of the dioritic rocks transitional with the amphibolite do not contain biotite; however, as the rocks become more granodioritic, biotite increases in amount and in the granodioritic rocks about five

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1 The significance of "early epidote" in granitized rocks is discussed by P. Misch in an unpublished manuscript on metamorphic minerals (1949).

per cent biotite is present. Biotite has partially replaced hornblende and often occurs aggregated with epidote or with epidote and hornblende. These groups represent the products of the completed or partially completed reaction accompanying the biotitization of hornblende. In exceptional cases biotite is absent in some rocks rich in potash feldspar and poor in plagioclase (cf. specimen 3, Figure 4).

Microcline and quartz. Microcline and quartz are the latest minerals to form. Microcline encloses all earlier minerals and replaces plagioclase. It forms porphyroblasts that appear megascopically to be euhedral, but that under the microscope show highly irregular margins. A psuedo-cataclastic texture of replacement origin occurs in many areas and especially around the margins of the porphyroblasts. A myrmekitic-appearing texture in plagioclase contains potash feldspar rather than quartz.

The passage from the granodioritic rock into one of the inclusions consists of a zone several millimeters wide in which the grain size decreases. The inclusion and the granodioritic rock contain similar minerals except that the inclusion contains much less quartz and little or no potash feldspar. It contains irregular hornblende grains, in part biotitized, and irregular biotite set in an xenoblastic plagioclase mosaic. Epidote is a constituent. The inclusion is amphibolite-derived, but has lagged behind the granodiorite in development and although recrystallized has only undergone incipient potassium metasomatism.

Goat Mountain Contact of Fish Lake Complex

On Goat Mountain, immediately west of Blue Lake, the Fish Lake complex is in sharp contact with a sequence comprising marble, quartz micaschist, and epidote-bearing amphibolite in which the epidote is not uniformly distributed but occurs in bands and lenticles. This contact cuts diagonally across the trend of these units, but the actual contact was seen only against the amphibolite. The contact is sharp, and short dilational dikes of medium grained quartz-dioritic rock which contain rotated blocks of amphibolite, project into the amphibolite. These features indicate intrusion of the quartz-dioritic material in this locality. However, no flow structure is present in the quartz-dioritic rock.

The microscopic texture of the quartz-dioritic rock at this locality is crystalloblastic. The grain size in the quartz-dioritic rock is seen to decrease slightly toward the contact. In the amphibolite, the hornblende becomes coarser grained and poikiloblastic at the contact. At the contact also, a plagioclase-hornblende granulite band several millimeters wide containing sphene but no epidote, has formed in the feldspar-poor, fine grained epidote amphibolite. This band is interpreted as a narrow reaction zone between two rock bodies of different composition brought into contact.

Discussion

The crystalloblastic and replacement textures, the presence of early epidote, the progression from amphibolite through various dioritic varieties to granodioritic rock,[1] and the presence of amphibolitic inclusions in all varieties of the complex indicate that the Fish Lake complex was formed from amphibolitic rock by sodium and potassium metasomatism. At some point during the metasomatism, apparently prior to or during the maximum of potash introduction, parts of the body became mobilized. One of the inclusions noted in the description of the central granodioritic portion of the complex was dioritic and was interpreted as having been moved into place. This would indicate that the mobilization of the body occurred after static recrystallization and metasomatism had locally produced a dioritic rock from the original amphibolitic rock. After this event, recrystallization continued to take place.

The gradational nature of some of the contacts and the textural evidence for a replacement origin for the body

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1 (cf. Misch 1949b, p. 690) Misch here makes indirect reference to this series in which granodioritic rock is produced from amphibolite.

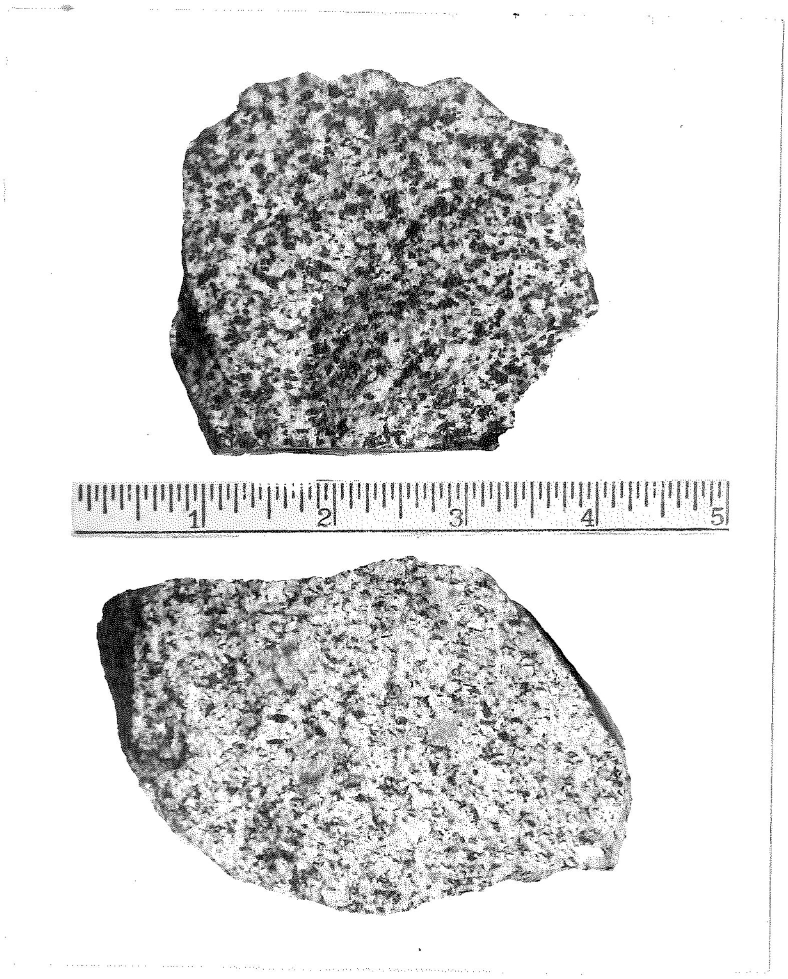
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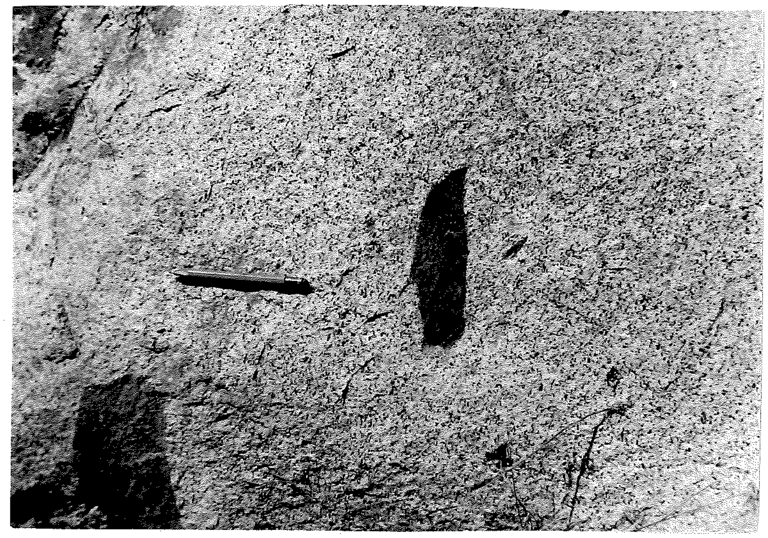
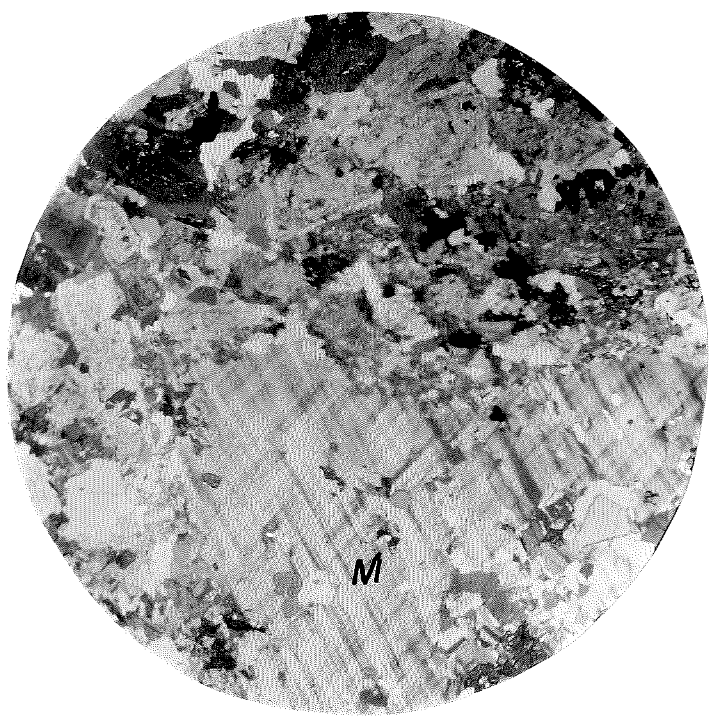
PLATE XXXVII

A. Gneissose and directionless amphibolitic inclusions in granodiorite; Fish Lake complex. Note sharp boundaries and rotation of inclusions. Northwest of Fish Lake (ph.8.17.50.1).

B. Portion of late microcline porphyroblast in granodiorite; Fish Lake complex. Microcline (M), epidote (E), plagioclase (P), quartz (Q). Goat Mountain (8.17.50.4g). Crossed nicols, x 17.

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indicate that it was already occupying approximately its present position when mobilization occurred. It is suggested that superimposed tectonic forces produced the local features demonstrating mobilization within the body and along part of its margin.

Tiffany Complex

General Statement

A mass of directionless, variably textured, largely dioritic rock occurs south and southeast of Rock Mountain along the crest and eastern slope of the range; the best exposures occur near Tiffany Mountain and Clark Peak. The body appears to be continuous with the Mutton Ridge quartz-diorite to the north and rocks resembling varieties of the Tiffany complex occur locally with the migmatites in the Rock Mountain area. To the south and west the Tiffany complex blends into the varied Boulder Creek complex. On the east, it is in sharp contact with the amphibolites and gneisses of the Salmon Creek migmatite belt. The complex differs from the Salmon Creek migmatitic gneisses in being for the most part directionless, and in that the more fine grained and generally more basic varieties which are believed to be close to the original material show non-schistose textures. The migmatitic gneisses north of Mineral Hill and south of Salmon Creek appear from the map pattern to trend into the Tiffany dioritic complex, but unfortunately, the critical area around Pelican Creek is covered by dense forest and glacial material. Pelican Creek appears to be fault-controlled, but north of the confluence of Salmon Creek and Pelican Creek, no major displacement occurs in the amphibolites and migmatitic gneisses. It is possible that the rocks forming the Tiffany complex interfinger with the gneisses of the Salmon Creek migmatite belt north of Mineral Hill. The migmatitic gneisses in this area, however, resemble the migmatites near Rock Mountain rather than the directionless Tiffany complex. The sharp northwest trending line of demarcation north of Pelican Creek that separates the belts of directionless rocks on the west from the Salmon Creek migmatite belt on the east is not exposed south of Pelican Creek until the southwest side of Mineral Hill is reached. Here the line marks the boundary between the Mineral Hill granodiorite and the migmatite belt. This line may have been displaced southwestward on the south side of Pelican Creek by the supposed Pelican Creek fault.

For purposes of description the rocks comprising the Tiffany complex are divided into three groups: (1) a northern basic variety, (2) the main body, and (3) local quartz monzonitic and granodioritic bodies scattered in the dioritic rocks. The compositions of the rocks of groups (1) and (2) vary from gabbroic to quartz-dioritic. Approximate mineral compositions are shown on Table VII.

(1) The northern basic variety occurs southeast of Rock Mountain and forms the northernmost part of what has been called here the Tiffany complex. It consists of dark, fine to coarse grained rocks that contain a more basic plagioclase than do the rocks of the main body. Although some varieties resemble the Mutton Ridge quartz-diorite to the north, the rocks in this area are more heterogeneous in composition and texture than the Mutton Ridge quartz-diorite and so have been included with the Tiffany complex.

(2) The main body of the complex is, except for the local quartz-monzonitic bodies, somewhat more homogeneous in texture and less basic in composition. To the south it gradually loses its distinctive character and blends into lighter colored rocks apparently related to both the Mineral Hill granodiorite and the Boulder Creek complex. This relationship was not studied.

(3) The zones and patches of quartz-monzonitic and granodioritic rock which, as mentioned above, occur as a superimposed element within the migmatitic gneisses near Rock Mountain, are also wide spread in the Tiffany complex where, in fact, they are much more distinct. The rock groups composing the Tiffany complex will now be discussed separately.

(1) Northern Basic Variety

Megascopic description. The northern basic variety consists of dark rocks whose texture varies irregularly from fine to coarse grained and whose composition varies from amphibolitic, with local hornblendites, through gabbroic and dioritic to quartz-dioritic. Most of the rocks contain a rather calcic plagioclase, varying predominantly from labradorite to andesine although bytownite often is present. Inclusions in the predominant dioritic rock are similar in composition to the including rock except that they are finer grained. They are directionless in structure and amphibolitic or microdioritic in composition. Locally potash-bearing material has been introduced and has formed aplitic and pegmatitic dikes and patches the same as elsewhere throughout the area.

One variety (specimen 3) is composed largely of bytownite and could be called an anorthosite. This variety was not differentiated in the field from the predominant type of massive, directionless, dark rocks forming the cirque walls in this area. Several small pods rich in talc and tremolite were observed in the general area of the anorthosite. These may represent basic aggregations or relicts of an original ultra basic igneous rock or possibly a dolomite.

Microscopic description. In the rocks of the northern basic variety, the finer grained types give perhaps the best clue to the origin of the more coarsely grained rocks, for they represent the beginning of a continuous process of recrystallization. One specimen of microdioritic rock typical of the early stage of development contains porphyroblastic andesine which encloses hornblende, biotite, apatite, and magnetite. Two distinct stages are present in both porphyroblastic and groundmass plagioclase with the cores more calcic and the rims more sodic. Groundmass plagioclase is similar in composition to the porphyroblasts. Green hornblende forms irregular aggregates which also contain small blebs of quartz and magnetite. The quartz appears only interstitially in the aggregate, while the magnetite also is included within the individual hornblende grains. These individual grains are about 0.4 mm in size, while aggregates range up to an observed maximum of 1.8 mm in size.

Other, less fine grained rocks, contain larger plagioclase porphyroblasts which also include groundmass minerals. One of these rocks contains plagioclase filled with disseminated magnetite dust. This dust is absent, however, in a zone around each inclusion of groundmass minerals in the plagioclase. The same type of rock occurs as a local variety in the Sinlahekin gneiss (cf. p. 175).

In the more coarsely grained rocks, the minerals and textures are in general similar to those described above. However, plagioclase has acquired a more idioblastic outline and has largely or entirely cleared itself of inclusions. It usually has a mottled appearance, however, and the grains exhibit complex twinning patterns. Similarly the hornblende in these rocks has passed the early stage of irregular aggregates described above, has attained a second stage in which individuals comprising the irregular aggregates have begun to coalesce and form more compact groups, and advanced to a stage where aggregates have coalesced into one single large grain which still retains a sieve texture. A similar collective postkinematic recrystallization of hornblende has been observed in the migmatitic gneisses of Salmon Creek belt (cf. p. 69), and in the statically developed dioritic patches in the amphibolitic rocks of the Conconully area (cf. p. 102).

Where quartz is present, it reveals two phases of deformation in these rocks. Most of the rocks in the northern part of this area contain plagioclase that shows bent twin lamellae or partly healed fractures which show displacement of parts of the crystal. Quartz fills these fractures in the plagioclase. Quartz envelops earlier minerals. In the rare instances where quartz is present in large amounts, mostly subhedral plagioclase grains are embedded in a quartz mosaic. The quartz commonly shows undulatory extinction. Thus two phases of deformation are recognized in these rocks: one post-plagioclase and pre-quartz characterized by fracturing of plagioclase with the filling of the fractures by quartz; and the other post-quartz, during which the quartz became strained. Some bending of twin lamellae of plagioclase may have occurred at this time. The pre-quartz post-plagioclase deformation has also been observed in some of the migmatitic gneisses of the Salmon Creek belt (cf. Chapter III). The mafics are not deformed; if they were, they have subsequently been recrystallized.

In the anorthosite, and some of the other coarse grained rocks containing highly calcic plagioclase, the texture approaches hypidiomorphic granular. In these rocks the plagioclase is usually distinctly zoned with bytownite or labradorite cores and andesine to oligoclase rims. Green hornblende is sometimes included in the outer zone of the plagioclase and projects into the core with a thin zone of sodic plagioclase around it. Inclusions in these rocks are amphibolitic, with green hornblende, zoned labradorite with rims of andesine, and sometimes minor amounts of olive-green biotite.

The crystalloblastic textures observed in the dioritic and gabbroic rocks described point to the recrystallization of an amphibolitic, or locally even of a more basic rock. The recrystallization occurred in conjunction with a slight degree of metasomatism which consisted largely of sodium and silica introduction, but with some local minor potassium introduction.

(2) Tiffany Complex - Main Body

Occurrence. The textural variations in the dioritic rocks of this group are best seen around Clark Peak and Mount Tiffany. The mineral composition is essentially uniform (cf. Table VII). The texture varies from fine grained to coarse grained. These textural varieties were not mapped separately, but very detailed work might produce some sort of a pattern in their distribution. The Tiffany complex has a much more uneven granular texture than the Mutton Ridge quartz-diorite. One characteristic peculiar to the main body of the Tiffany complex is the presence of two distinct grain sizes of ferromagnesian minerals (cf. Plate XXXVIII). This textural type is rare in the northern basic variety (1).

Locally the rocks show a weak gneissose structure, usually adjacent to contacts between different rock varieties. Uniformly oriented, lenticular inclusions and shadow areas (skialiths) of more fine grained rock occur locally.

Microscopic description. In the finer grained varieties, the texture is uneven granular; mineral grains are without crystal form. However, although the mineral grains are marginally irregular, a euhedral tendency exists. A preferred orientation of mineral grains is present in some rocks. Plagioclase forms smaller subhedral grains showing a tabular tendency and forms larger, more equidimensional grains reaching a size of 1 mm. Both are distinctly zoned. The larger grains have three distinct zones: the rim (3) and the core (1) are about An 30; the intermediate zone (2) is about An 67. The smaller plagioclase grains comprise only zones (2) and (3). The larger plagioclase grains often occur in clusters. The plagioclase contains inclusions of hornblende. Green hornblende forms irregular grains with a prismatic tendency. Some of which are about 0.8 mm in size, but most of which are about 0.3 - 0.4 mm in size. It is often twinned. Sometimes hornblende occurs in a subrounded cluster with biotite and plagioclase. The tendency toward two distinct grain sizes for hornblende is characteristic of the main body of the Tiffany complex. Biotite forms poikiloblastic grains up to 1.2 mm in size which enclose plagioclase. These have irregular margins and have formed later than the plagioclase and hornblende. Some of the hornblende has been biotitized. Quartz occurs only as a late mineral in the intergranular. Apatite needles are common as inclusions in both feldspar and quartz. The age sequence of the main rock constituents is: plagioclase and hornblende, biotite, quartz.

In the more coarse grained rocks some tendency toward tabular plagioclase remains but usually the plagioclase becomes more equidimensional and is about 2.5 mm in size. The overall texture is hypidiomorphic granular. The mafics and plagioclase sometimes show a preferred orientation. The minerals are the same as those in the fine grained varieties however the overall grain size increases. Hornblende forms large grains about 2.0 mm in size which include plagioclase. It sometimes forms clusters partly laced with biotite. Biotite reaches an observed maximum of 3.6 mm, but usually is about 1.8 mm in size. Both biotite and hornblende have irregular borders. The tendency of the hornblende to form aggregates laced with biotite suggests some biotitization of the hornblende. Biotite, however, cannot be proven in every case to be all derived from hornblende. Apatite rods are common. Some of the rocks contain much magnetite and sphene which often occur as thin seams around the edge of biotite. Magnetite also occurs as streaks in retrogressive chlorite which has formed from biotite. It has apparently been released in the chloritization of biotite. Apatite is one of the first minerals to form; quartz, excepting chlorite, is the latest.

Special varieties. One very coarse grained rock is noticeably magnetic. Magnetite occurs in distinct grains as well as in the form of finely disseminated dust in hornblende. The hornblende has a brown instead of the usual blue-green tinge, and it approaches crystal form - which is equally true for all the very coarse grained rocks. The hornblende in this rock is definitely later than the plagioclase. It forms small anhedra between tabular plagioclase as well as large crystals. Here again attention is called to the two distinct grain sizes.

Apatite forms rods over 2 mm in length. This rock evidently was formed in the presence of relatively large quantities of volatiles.

Some of the rocks have an irregular, patchy microscopic appearance. In these rocks there is little hornblende but much biotite; plagioclase varies considerably in size and includes biotite; some areas have much quartz; and rocks contain more than the usual amount of apatite.

A microdioritic inclusion in a relatively fine-grained dioritic rock contains uniformly oriented, tabular, zoned plagioclase. The preferred orientation in this inclusion suggests either relict flow structure, or relict schistosity.

Dikes. Many dike-like rocks occur in the dioritic main body of the Tiffany complex. All the dark dikes are similar to the finer grained dioritic rocks in composition and texture. The presence of tabular, zoned plagioclase, and abundant apatite needles is characteristic. Many pegmatite and aplite dikes also cut the dioritic rocks. They are similar in composition and occurrence to those dikes in the Rock Mountain migmatite area.

Discussion of the Northern Basic Variety (1) and of the Dioritic Main Body (2)

The megascopic textural inhomogeniety of these rocks and the microscopic crystalloblastic textures that show a progressive development from granoblastic and porphyroblastic to igneous appearing textures, indicate an origin by recrystallization and replacement. The mineral composition and occasional scattered remnants indicate an original amphibolitic rock. The uniformity in composition and lack of layering indicate that this material was originally massive. This suggests derivation from basic igneous material rather than from basic sediments. If the body was at all affected internally by the regional deformation, any resulting schistose structure has been eliminated by recrystallization. The preferred orientation in the inclusion noted above or in some of the more coarse grained rocks might be a relict of such deformation, or again it may indicate that the body was a former igneous extrusive or hypabyssal rock with local flow structure. Some of the gneissose structure locally present in the more coarse grained rocks appears to represent local mobilization or local shearing movements during recrystallization and metasomatism.

The following history might be reconstructed from the three zones observed in the larger plagioclase grains mentioned above: (1) The fairly sodic centers represent the plagioclase of the early amphibolitic stage. (2) The calcic medial zones represent a period of higher temperature accompanying the regional high grade metamorphism. Whether the calcium was available in the rock itself, or was contributed by transfer from the vicinity is not known; the former is considered the most likely. During this period, temperatures were high enough in the area to form labradorite in the lime silicate rocks of the Mineral Hill area. (3) The more sodic rims suggest a later addition of sodium under such conditions that the calcic centers were preserved. The more abundant smaller grains participated only in stage (2) and (3). The presence of two distinct grain sizes of hornblende in many of the rocks suggests two maxima of recrystallization which in some way may be connected with the zoning of the plagioclase.

The Tiffany dioritic complex has far too great a volume and areal extent to have formed from the impure calcareous - dolomitic members interbedded in the compositionally highly differentiated Scotch Creek-Evans Lake sedimentary sequence in the Riverside-Conconully area. This unit may represent some higher unit in the "Anarchist Series," and P. Misch suggests that it might be equivalent to the metabasalts of the Loomis area which appear to be younger than the "Anarchist" sediments in the Riverside-Conconully area.

Other rocks in the area which seem on petrographic evidence to be related to the Tiffany complex are some of the dark, fine grained, relatively basic dikes occurring in the migmatites near Rock Mountain, and inclusions in the Thunder Mountain sequence.

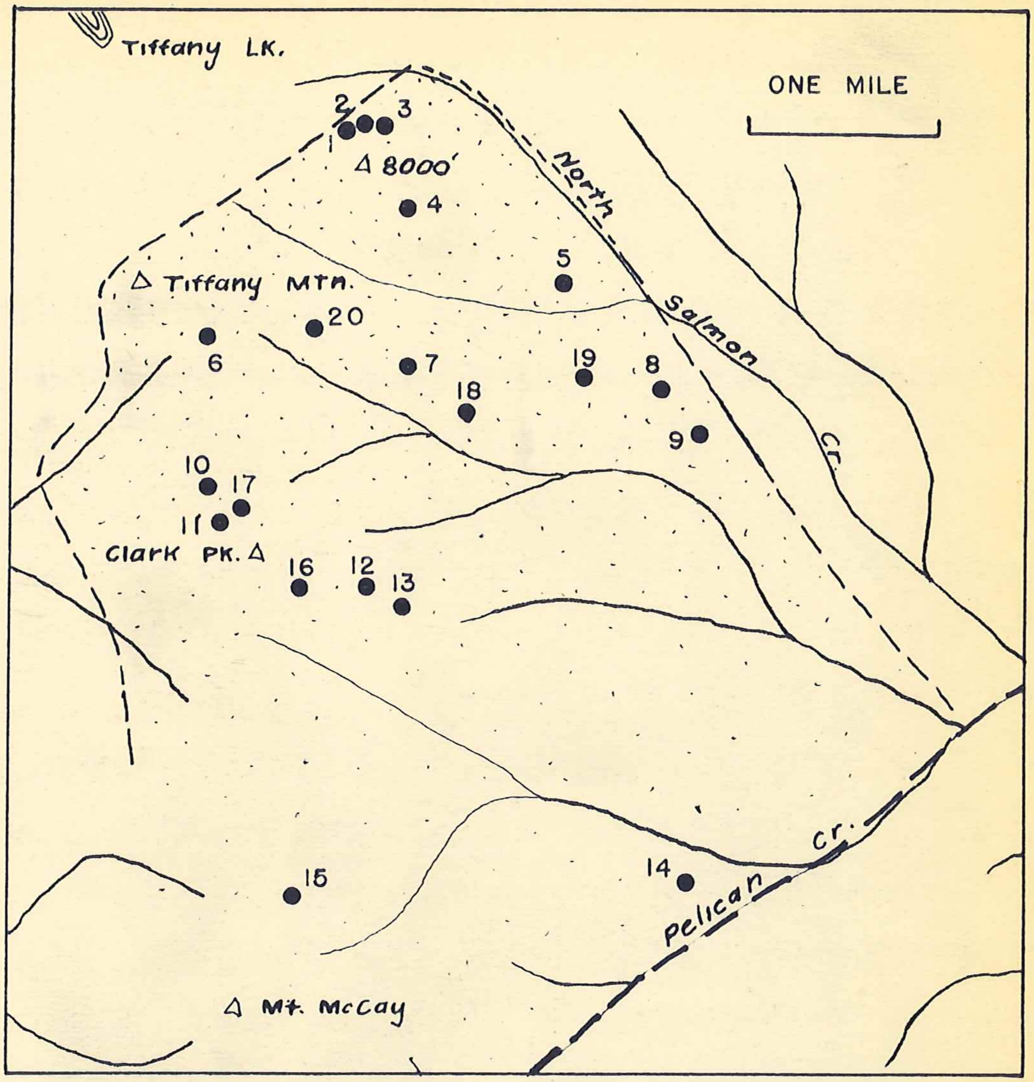


FIGURE 6 DIAGRAM OF TIFFANY COMPLEX SHOWING LOCATIONS OF THE SPECIMENS LISTED IN TABLES VII AND VIII

(3) Quartz-Monzonitic and Granodioritic Bodies

Occurrence. Small bodies of directionless granodioritic and quartz-monzonitic rock occur throughout the complex. Some of these have a dike-like form; others are irregular in shape (cf. Figure 7). Both sharp and gradational contacts with the dioritic rocks occur; Some contacts are marked by an abrupt change in color and grain size; along others, brecciated areas containing fragments of dioritic rock occur; still others are gradational and the quartz-monzonitic rock becomes darker and fades into as unevenly textured dioritic rock. Locally, thin lenticles, streaks, or bands of coarse grained quartz-monzonitic rock occur in sharp contact with dioritic rock. Sometimes thin septa of the dioritic rock cross these quartz-monzonitic bodies. This suggests that these quartz-monzonitic bodies were formed by replacement rather than by intrusion into the dioritic rock (cf. Plate XLVI). One contact between quartz-dioritic and granodioritic rock is marked not only by a change in color of the rock, but by a sharp contrast in the directions of a weak gneissose structure occurring in both rocks near the contact. That in the granodioritic rock is parallel to the contact; that in the quartz-dioritic rock is intersected by the contact at a small angle. This contact evidently represents a shear zone.

Both dark, fine grained, relatively basic dikes, and

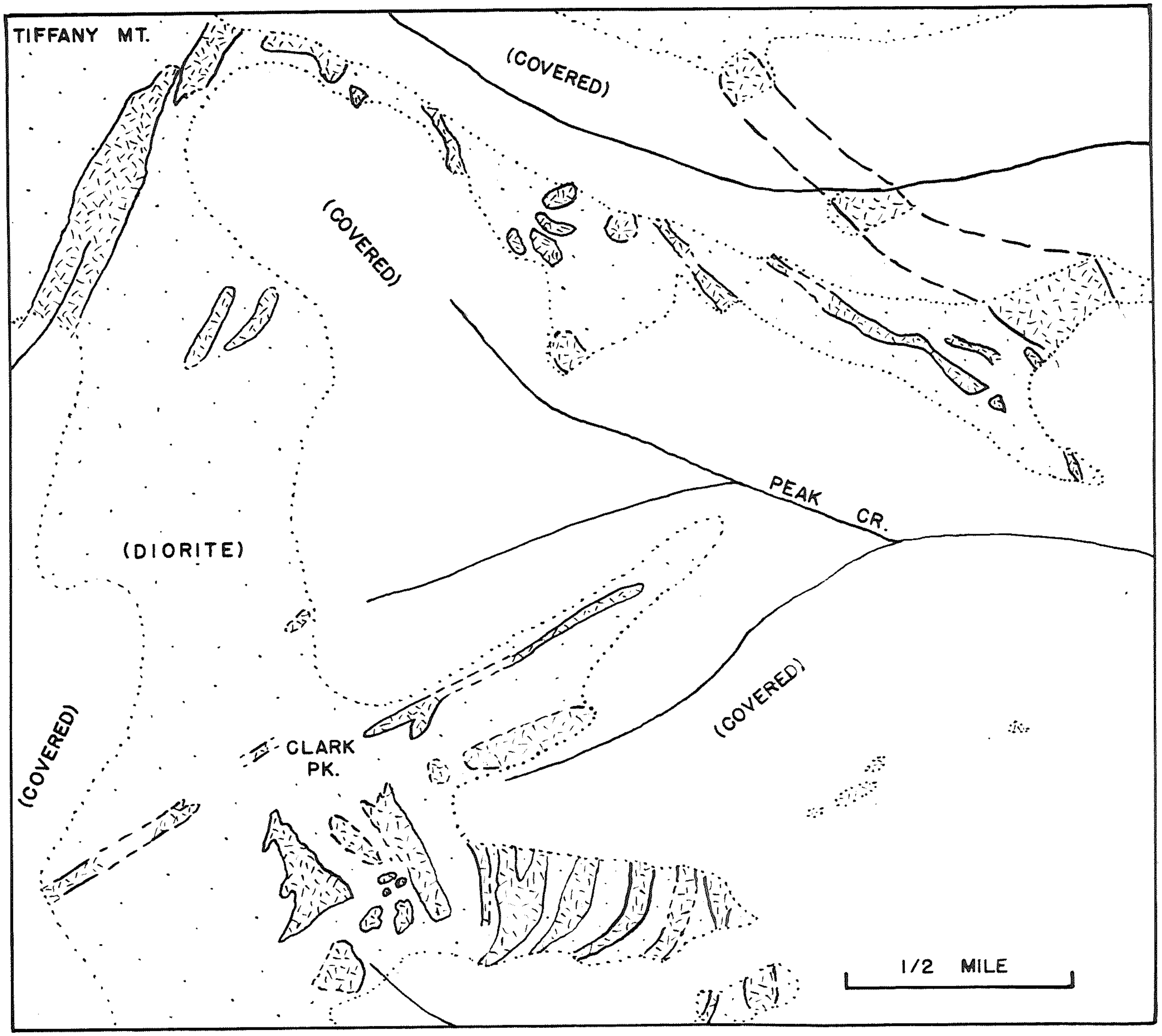


FIGURE 7. DIAGRAM OF QUARTZ-MONZONITIC BODIES WITHIN THE TIFFANY DIORITE COMPLEX OBSERVED NEAR CLARK PEAK

alaskitic aplite dikes cut the quartz-monzonitic bodies. Both types are correlated with the late dark dikes and aplitic dikes in the Rock Mountain area.

Microscopic description. The composition is usually homogeneous except in brecciated zones and in transitional contact zones. In both these zones, granodioritic rather than quartz-monzonitic rock occurs. Table VIII shows the approximate mineral compositions of some of these rocks.

The texture is crystalloblastic, but usually uniform. Mafics are not abundant except where many inclusions are present. In the quartz-monzonitic rocks, quartz and potash feldspar form irregular grains usually about 2 mm in size, but ranging up to 6 mm. Plagioclase forms anhedral to subhedral grains with a slightly smaller variation in size. It is mottled, has indistinct twinning, and is frequently antiperthitic and myrmekitic. It is being replaced by microcline and quartz. Microcline frequently has perthitic streaks, and a complete series of replacement of plagioclase by microcline can be determined in these rocks: from antiperthite, through a stage where about equal amounts of plagioclase and microcline are present, and a stage where optically continuous inclusions of plagioclase appear in the microcline, to a stage where the plagioclase appears as only perthitic patches. Quartz projects into cleavage planes of plagioclase. Biotite is the chief ferromagnesian mineral;

it is irregular in shape and often occurs in clusters. Hornblende occurs primarily near the contacts with dioritic rocks.

<u>Discussion</u>. The pattern of the quartz-monzonitic and granodioritic bodies suggests structural control of their distribution. Zones of fracturing and brecciation apparently determined the position of some of the bodies. Where thin septa of wall rock transect small quartz-monzonitic bodies, an origin for the quartz-monzonite by replacement rather than by intrusion is indicated. The local transitional contacts and the microscopic crystalloblastic textures support such an interpretation. Features suggestive of intrusion are: uniformity in composition over wide areas, regularity in width of some of the dike-like bodies, occurrence of sharp contacts, sharpness of borders of fragments in some brecciated areas. However, these features mean little in the absence of evidence for a forcible emplacement or injection for the bodies, for similar features occur in replacement bodies elsewhere in the area (cf. Rock Mountain migmatites). Some intrusive movement of mobilized quartz-monzonitic material appears to have occurred locally.

The quartz-monzonitic bodies were formed during a late part of the recrystallization of the dioritic rocks of the Tiffany complex, but before the still later aplitic and relatively basic dikes were formed.

Specimen	2	13	14
Plagioclase	0	65	70
Per Cent Anorth	36	57-30	36-29
quartz	r	-5	-5
potash feldspar			
hornblende	0	10	10
biotite	5	15	10
apatite	r	tr	tr
sphene	r		
iron oxide		tr	tr
orthite			
epidote	r	tr	tr
chlorite	5		tr

Figures are in
tr indicates tr

Locations of sp

TABLE VIII

APPROXIMATE MINERAL COMPOSITIONS OF SPECIMENS FROM QUARTZ-MONZONITIC - GRANODIORITIC BODIES OF TIFFANY COMPLEX

Specimen	15	16	17	18	19	20
plagioclase	30	35	55	45	30	30
per cent anorthite	(20)		(31-22)	(27)		
quartz	30	25	25	15	30	30
potash feldspar	30	25	15	25	30	35
biotite	-5	10	-5	10	5	tr
hornblende				tr		
apatite	tr	tr		tr	tr	tr
sphene	tr	tr		tr	tr	
orthite	tr			tr		
iron oxide	tr	tr	tr	tr	tr	tr
epidote	tr	tr	tr	tr	tr	
muscovite						tr
chlorite		tr	tr			

Figures are in percentages.
-5 means less than five per cent.
tr equals trace.


1
2
3
4
5


1
2
3
4
5
6

PLATE XXXIX

A. "Pegmatitic" variety of diorite; more coarsely re-crystallized due to presence of more abundant volatiles. Northwest arm Tiffany Mountain (9.9.50.2g).

B. Potash feldspar porphyroblasts with sieve texture in dark swirled granodioritic rock derived from finer grained, more basic dioritic rock (lower left and inclusion) typical of Tiffany complex. Local gneissosity ascribed to plastic flow (see near top left of hammer) which occurred prior to final development of the porphyroblasts. Old Baldy Mountain (ph. 9.23.50.1).

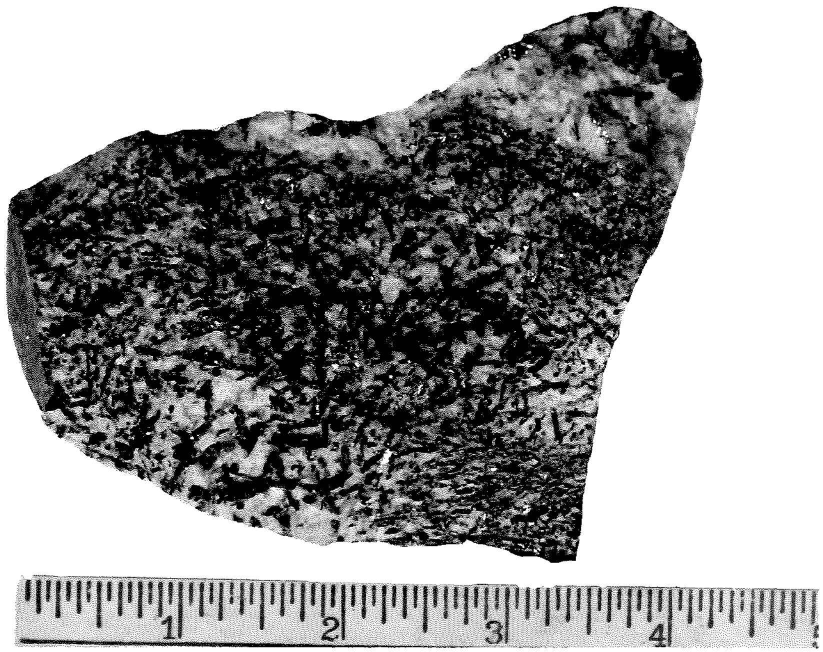
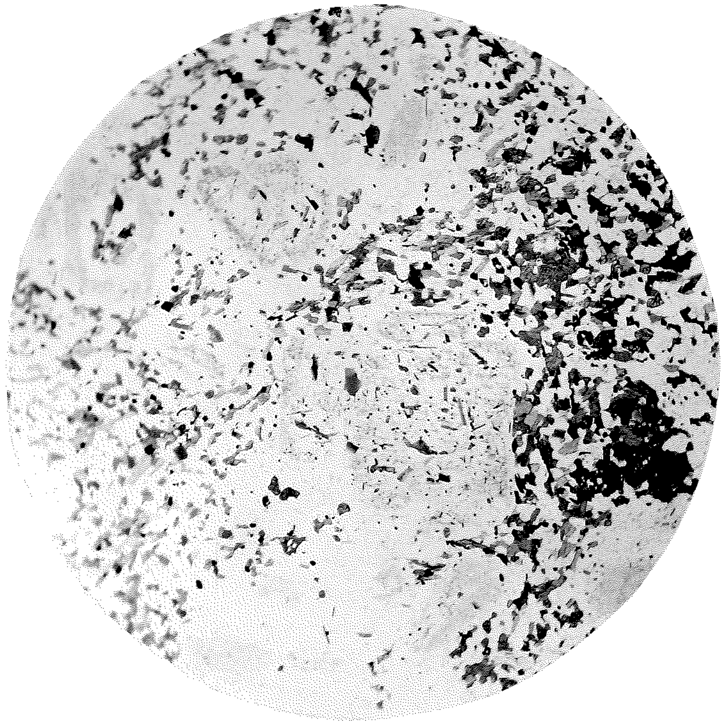

1
2
3
4

PLATE XL

A. Porphyroblastic development of plagioclase in microdioritic rock. Randomly oriented inclusions of groundmass minerals. Tiffany complex. Middle Tiffany Mountain (9.20.48.8ag). x 18

B. Same. Crossed nicols.



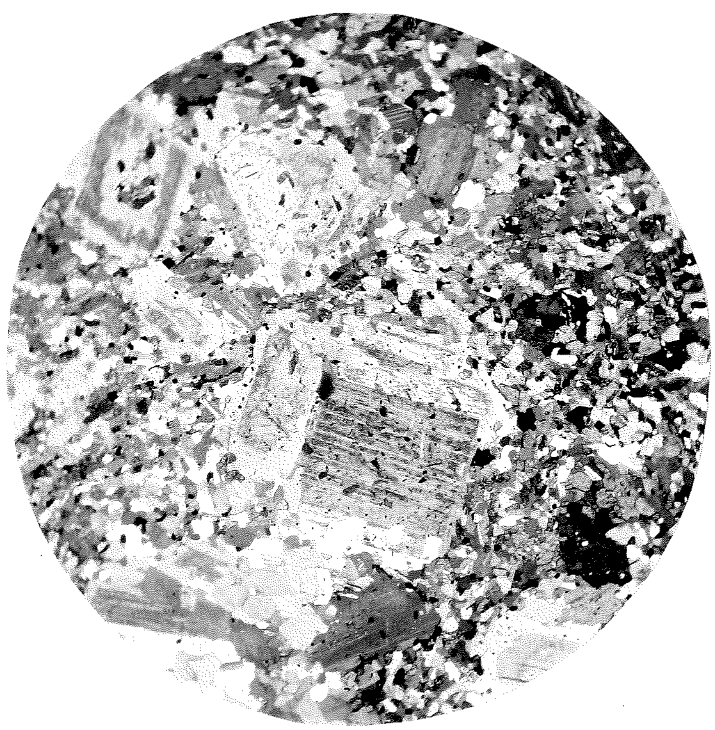


PLATE XLI

Clusters of hornblende forming in dioritic rock near contact with microdioritic rock. Hornblende partly biotitized. Plagioclase porphyroblasts (P) include small hornblende grains. Tiffany complex; Middle Tiffany Mountain (7.31.49.5g). Plane polarized light, x 18.

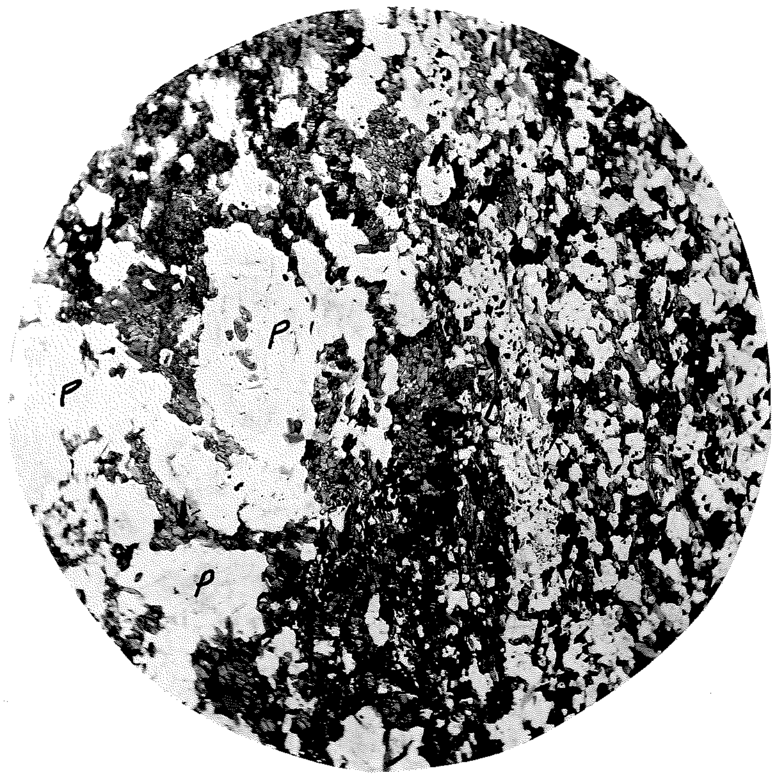
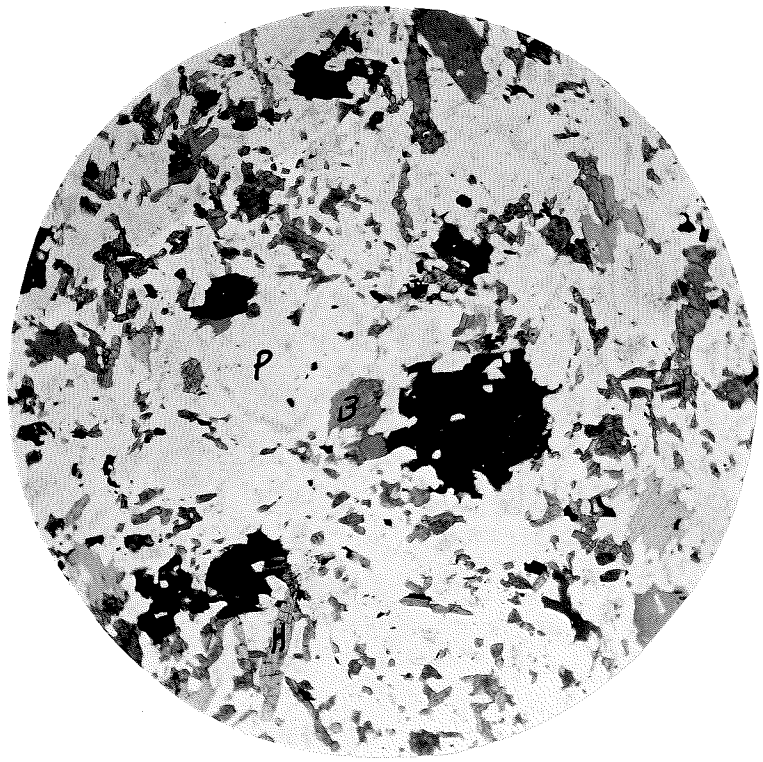

P
P
P

PLATE XLII

A. Medium grained dioritic rock, Tiffany Complex, main body. Plagioclase (P), biotite (B), hornblende (H). Crystalloblastic texture approaching an igneous character. East of Clark Peak (9.4.50.1g). Plane polarised light, x 17.

B. Same, crossed nicols.


P
B
H

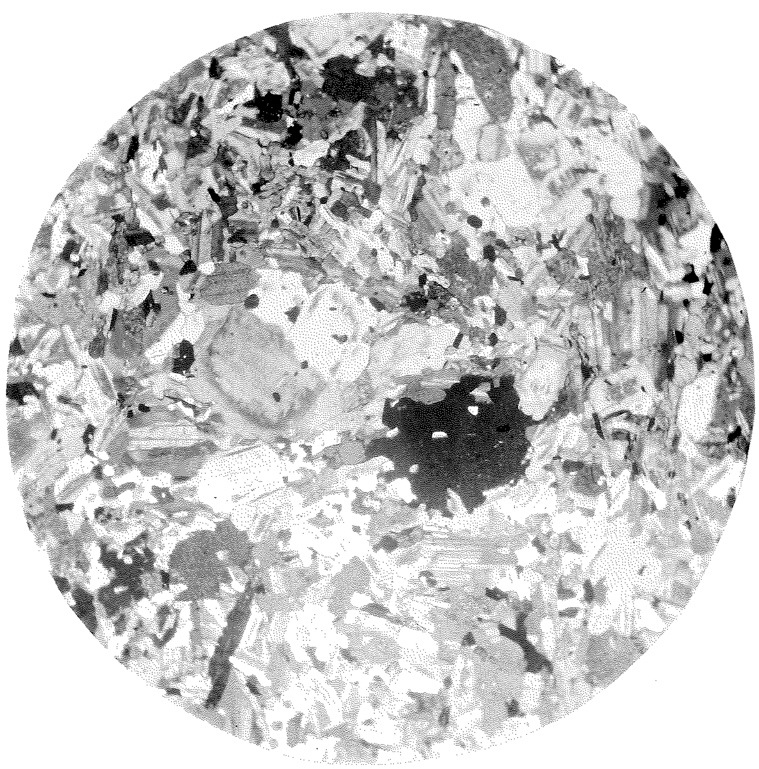
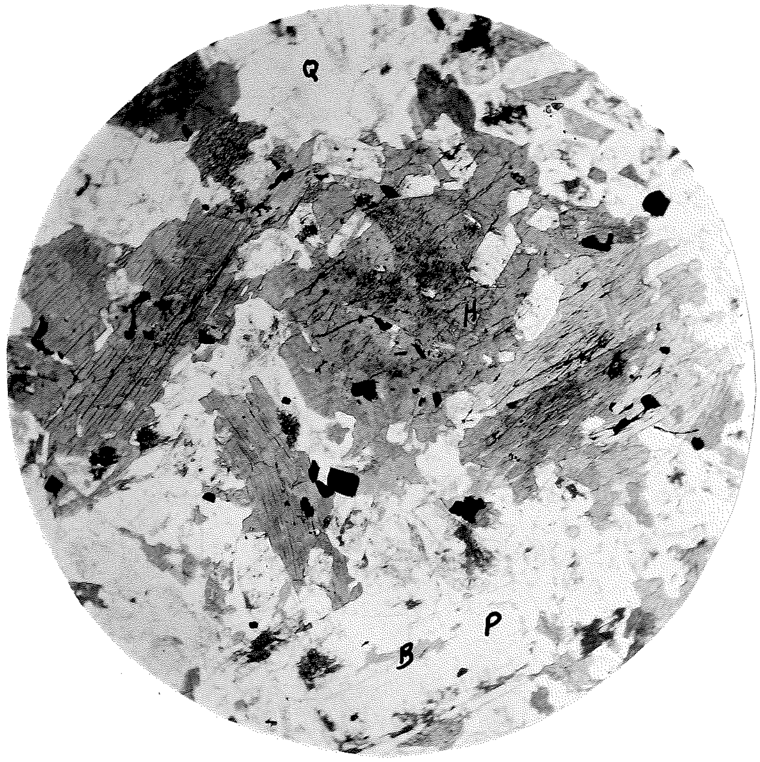


PLATE XLIII

A. Coarse grained dioritic rock; Tiffany complex, main body. Hornblende (H), plagioclase (P), biotite (B), quartz (Q), iron oxide. Crystalloblastic texture approaching an igneous character. South side Middle Tiffany Mountain (9.7.50.5g). Plane polarized light, x 17.

B. Same; crossed nicols.


Q
H
B
P

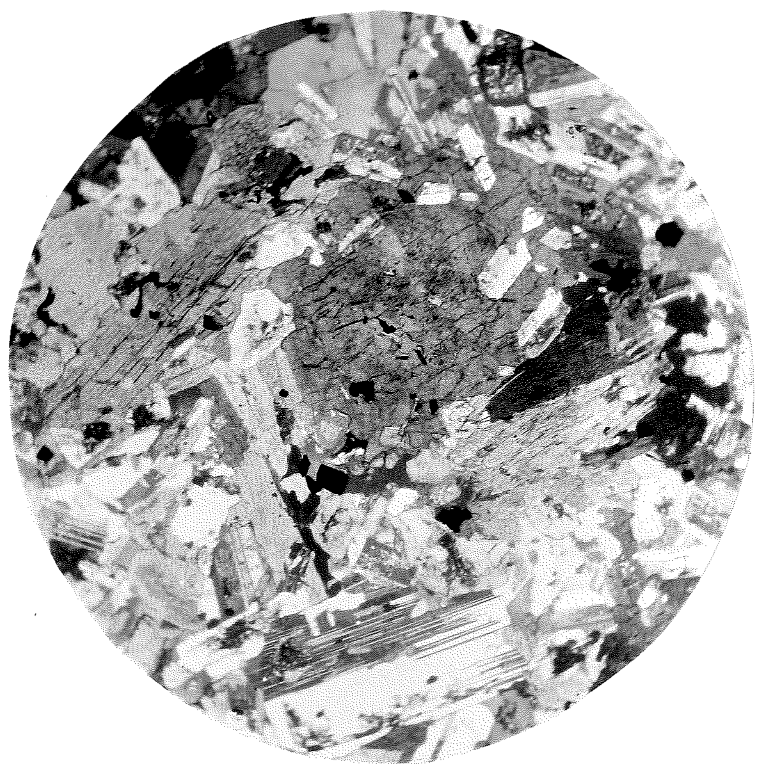
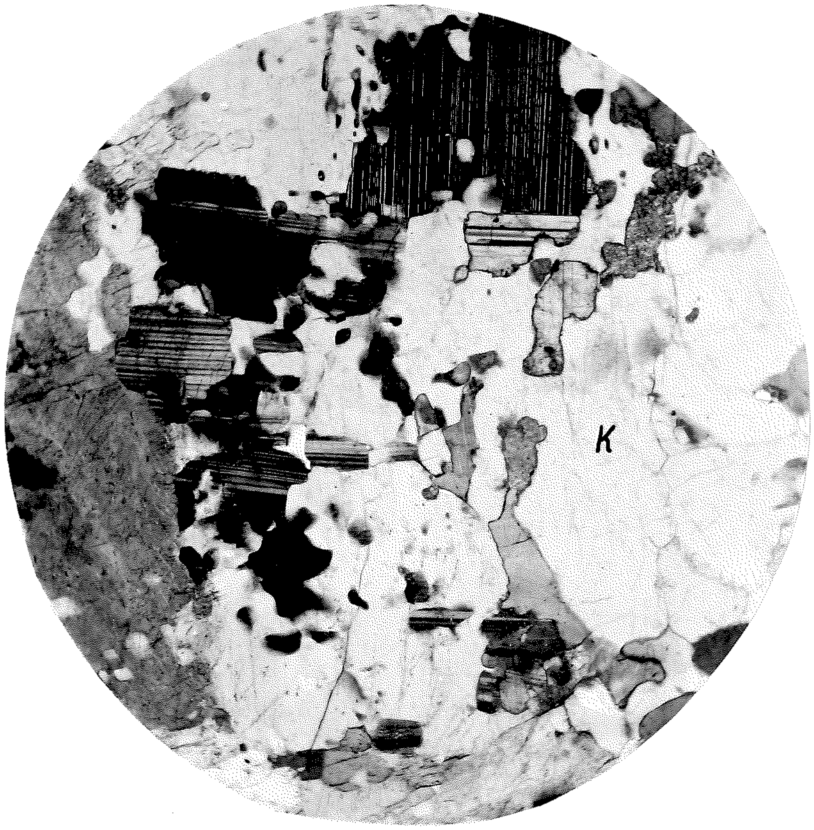


PLATE XLIV

Quartz-monzonitic streaks in microdioritic rock, Tiffany complex. Thin undisturbed septa of microdiorite cross the quartz-monzonite suggesting a replacement origin for the quartz-monzonite. Contacts, however, are generally sharp. East of Clark Peak (ph. 10.12.51.2).

PLATE XLV

Potash feldspar (K) replacing plagioclase in replacement breccia composed of quartz-monzonitic material and dioritic country rock. East of Tiffany Mountain (7.4.49.4g). Crossed nicols, x 30.


K

Mutton Ridge Quartz-Diorite

__Occurrence__

A body of coarse grained, almost completely directionless hornblende-biotite-quartz-dioritic rock occurs east of Rock Mountain. It is partly concordant and partly discordant with the surrounding rocks. On the northwestern margin, a narrow, sharp, recrystallized shear zone forms the contact with a slightly finer grained biotite quartz-dioritic variety of the Thunder Mountain complex. This contact strikes N5E and dips 65° E near locality 5 (cf. Figure 8). On the northeastern margin, the hornblende quartz-diorite is in contact with amphibolite and gneiss of the Sinlahekin quartz-dioritic gneiss unit. In the gneiss along this contact a breccia occurs which is about six feet in width and which consists of jumbled fragments of amphibolite in a light, but variably colored tondhjemitic matrix. In some places the fragments of amphibolite are so closely spaced that the rock resembles tile. The fragments range up to an observed maximum of eight inches in size. A weak "s" occurs within the Mutton Ridge quartz-dioritic rock near the contact. This gneissose structure, the contact, and the structure of the adjacent gneiss are all parallel in this area. On the eastern margin a mylonitic zone less than a foot wide, striking north-south and dipping 65° W, occurs between the quartz-dioritic rock and biotite paragneiss. Its attitude conforms to that of the paragneiss in this area. The southern limit of the body is concealed by heavy forest and glacial material. On the western margin the quartz-diorite becomes gneissose parallel to its margins and blends into quartz-dioritic banded gneisses of the Rock Mountain migmatite zone. Specimen 7 (Table IX) is taken from a quartz-dioritic layer in the gneisses and is included in the table to show the similarity in composition.

The petrologic relationship of the Mutton Ridge quartz-diorite with the dioritic and amphibolitic complex occurring to the southwest in the Tiffany Mountain area is not clear. If the quartz-diorite follows the trend of the gneisses, it should pass into the Tiffany Mountain complex. However, even though there is a similarity in composition between the Mutton Ridge quartz-diorite and some of the Tiffany Mountain rocks, the Mutton Ridge quartz-diorite is treated as a separate unit because of its textural and mineralogical homogeneity as contrasted with the heterogeneity of the Tiffany complex.

Petrography

Megascopic description. The rock is coarse grained with about 30 per cent ferromagnesian minerals. Approximate mineral compositions are given in Table IX. It is homogeneous in texture throughout except that small clots of mafics or small feldspathic patches sometimes occur. Larger, dark gray, sugary textured inclusions occur locally, but at only one locality are they numerous. In this swarm they are lenticular in shape and oriented parallel to the regional trend of the rocks in the area. At one locality the quartz-dioritic rock is cut by a gently dipping, dark, fine-grained dike which extends out into rocks of more acidic composition.

Microscopic description. Microscopically, the texture is granoblastic but resembles a hypidiomorphic granular texture. Plagioclase is the only mineral to show straight crystal boundaries, but these are not always crystallographic faces. The plagioclase is twinned according to the carlsbad, pericline, and albite laws. The crystals are free of inclusions. Plagioclase is zoned, but the zoning is partly irregular producing a mottled appearance. However, the cores are labradorite and the rims andesine. Bent twin lamellae are common and some grains are fractured and partly healed by quartz.

Bluish-green hornblende occurs in irregularly shaped grains, often twinned; or it occurs in clusters of individual grains. Some of the hornblende has cores of colorless diopsidic pyroxene which has an extinction angle c/Z about 34°. The boundary between the diopsidic core and the hornblende shell has an irregular replacement pattern. The hornblende includes small, subhedral plagioclase grains and occasionally encloses larger plagioclase grains. It also often has mutually irregular contacts with plagioclase. The foregoing facts indicate that while part of the hornblende formed later than the plagioclase, the two are in general contemporaneous. Sometimes a fine sieve texture occurs in hornblende in which the included mineral is quartz.

Olive-green biotite forms large irregular grains that often include plagioclase crystals. It does not appear to have formed from hornblende.

Quartz is intergranular to the other minerals and in part replaces plagioclase, hornblende, and biotite. Potash feldspar is very rare and always late. One large spreading potash feldspar grain was observed replacing plagioclase. Magnetite, apatite, and retrogressive chlorite are common accessory minerals. Sphene and retrogressive epidote are less common.

<u>Inclusions</u>. The fine grained inclusions have a granoblastic texture. Plagioclase, hornblende, and biotite form a mosaic of irregular grains. The plagioclase varies in size and includes hornblende. Some of the larger grains of plagioclase have labradoritic medial zones, while the centers and rims are andesine to oligoclase similar to some plagioclase in the Tiffany complex (cf. above, p. 248). Biotite forms individual grains or clusters with hornblende. Little quartz

is present; otherwise the proportion of minerals is about the same as in the quartz-dioritic rock surrounding the inclusions. The passage from the inclusions to the quartz-dioritic rock is marked by a sudden increase in grain size and an increase in the amount of quartz.

The inclusions are closely related in composition to the enclosing rock, and they are similar in texture and composition to some of the recrystallized and partly metasomatized amphibolites occurring with the migmatitic gneisses (cf. Chapter III).

Contact with the Thunder Mountain complex. The contact between the Mutton Ridge quartz-diorite and the biotite quartz-dioritic variety of the Thunder Mountain complex to the northwest is sharp. It was observed in one good exposure to consist of a band about three inches in width, similar in texture to the Mutton Ridge hornblende quartz-diorite, but with a smaller grain size. Mafics are roughly aligned parallel to the walls. The passage into the biotite quartz-diorite is marked by an abrupt decrease in the amount of mafics. The minerals in the contact band are similar to those in the Mutton Ridge quartz-diorite with the addition of pyrite and calcite. Larger amounts of subhedral magnetite and quartz occur in the contact band than occur in the quartz-diorite. Sphene is common and sometimes occurs as a dendritic network in plagioclase. Mafics are partly altered to chlorite, and plagioclase is partly altered to sericite. None of the minerals are deformed.

This contact is interpreted as a shear zone modified by subsequent recrystallization and hydrothermal action. About a quarter of a mile to the west of this contact an isolated pod of hornblende biotite quartz-diorite grades into the surrounding biotite quartz-dioritic variety of the Thunder Mountain complex. It would appear, then, that the transitional rocks which apparently should occur between the Mutton Ridge quartz-diorite and the Thunder Mountain complex have been cut out by faulting at the sharp contact described above. Locke, Billingsley, and Mayo (1940, p. 531) have observed similar phenomena in plutonic rocks of the Sierra Nevada.

Breccia along the northeastern margin. A large thin section (3 1/4 x 4 inches) of the contact breccia occurring on the northeastern margin of the Mutton Ridge quartz-diorite shows some textures and mineralogical relationships recalling those seen in the main Mutton Ridge quartz-diorite body. The fragments of amphibolite contained in this breccia belong to those amphibolites of the Salmon Creek belt that contain layers rich in diopsidic-augite. The fragments have a hornfelsic texture superimposed on a gneissose structure. The surrounding lighter colored rock has a granoblastic texture. The minerals are plagioclase, hornblende, biotite, diopsidic-augite, and quartz. Plagioclase and diopsidic-augite are subhedral, the other minerals are anhedral.

The contacts of the fragments are distinct and marked by a change in structure and in grain size. At the contact hornblende forms large grains with an almost skeletal sieve texture. This hornblende is interpreted as having been formed by the collective crystallization of smaller hornblende grains in the amphibolite. The pyroxene occurs in small grains in the amphibolite, but at the contacts and in the lighter colored rock, it too, forms larger grains. These, however, are more compact than the recrystallized hornblende grains described above. These larger grains are interpreted as having formed, like the hornblende, by collective crystallization. Its more perfect crystal form is attributed to greater force of crystallization. Some of the large subhedral pyroxene grains in the light colored rock are rimmed with hornblende. In some of these grains the uralitization has just begun, in others only relict patches of pyroxene remain in the centers of the hornblende. Biotite does not appear in the fragments except marginally. In the light colored rock, biotite occurs on the margins of hornblende or forms large individual grains. Quartz is absent in the fragments, but is abundant in the light colored rock. The plagioclase in the amphibolite is andesine; it shows only a slight increase in size at the contacts. In the light colored portion, the plagioclase is zoned with centers of sodic andesine and rims of calcic oligoclase. It varies considerably in size and forms grains up to 3.6 mm in size which may occur immediately adjacent to the fragments. Occasionally plagioclase exhibits bent twinning lamellae. Potash feldspar is present only as a thin film in the intergranular.

The breccia is believed not to be connected with the emplacement of the quartz-diorite, but to have formed at a later period of time, although at a time when alkalic and silicic material were still available for introduction into the zone of deformation. The following reasons are given for this interpretation: (1) the brecciation occurs in an amphibolite band outside of the quartz-diorite body; (2) the brecciation represents a different type of reaction to stress than that represented by the weak gneissosity in the quartz-diorite near the contact; (3) the light colored material is more silicic and alkalic than the quartz-diorite; (4) the same type of breccia continues along the strike of the breccia band to the northwest beyond the limits of the Mutton Ridge quartz-diorite.

Discussion

A replacement origin for the Mutton Ridge quartz-diorite is indicated primarily by the transition of the quartz-diorite into the migmatitic gneisses of the Rock Mountain area along the western border. The migmatitic gneisses have been shown to be produced from amphibolitic rocks by sodium, silica, and potash metasomatism (cf. banded gneisses Chapter III). The texture of the Mutton Ridge quartz-diorite is crystalloblastic although it approaches the hypidiomorphic granular texture of igneous rocks.

The uniformity in overall composition and texture taken alone might possibly be considered as evidence of an igneous origin, however, it could also be explained as the result of uniform recrystallization of a rock of originally uniform composition. The mineral composition of the rocks indicates that the original material was amphibolitic. Possibly the Mutton Ridge quartz-diorite has formed from the same material from which the Tiffany complex to the south was supposedly formed (cf. p. 253), namely from a body of basic igneous rock. The pyroxene cores of the hornblende may represent, then, relicts of original pyrogenic pyroxene, or more likely, they merely indicate that an earlier period of higher temperatures occurred corresponding to the maximum rise of temperatures in the area. Another possible explanation would be that the original material was of sedimentary origin, perhaps an impure dolomitic sediment. However, the considerable degree of uniformity in the composition of the Mutton Ridge quartz-diorite and the lack of banding or layering or any other signs of original differences in composition which would have to be expected in an impure sediment, all would make this interpretation appear rather improbable.

How much alkalic material was originally present in the rocks from which the Mutton Ridge quartz-diorite was formed, and how much has been added is not known. Judging from the type of zoning of the plagioclase it may be suggested that some sodium has been added to that originally present. The presence of biotite and quartz indicates some addition of potassium and silica respectively during re-crystallization of the original amphibolitic rock.

The contacts on the northwest, northeast, and east sides of the Mutton Ridge quartz-diorite were formed at different times during the history of the body. The narrow, recrystallized shear zone on the northwest side was formed after the formation of the body, or at best during a late stage. The narrow mylonitic zone on the east side was formed after the end of recrystallization within the body. The gneissose structure in the quartz-diorite along the north-eastern margin could have been formed by tectonic movements at any time prior to the end of recrystallization. It may be relict structure inherited from pre-dioritic amphibolite, but it may also have formed during a later stage as a result of a differential movement of this portion of the dioritic body; in the latter case, this particular marginal portion of the Mutton Ridge quartz-diorite would in a sense be intrusive. This northeastern contact occurs along a continuous northwestward trending line that separates the Sinlahekin gneiss on the northeast from the Thunder Mountain sequence on the southwest. This fact suggests that the contact has been formed by tectonic movements of regional extent.

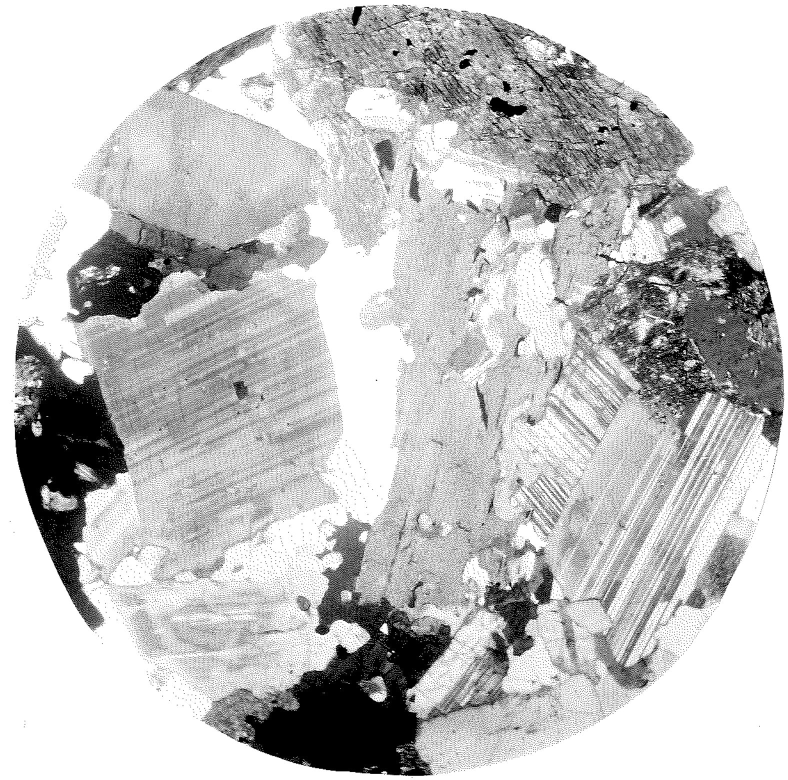
It is concluded that the Hutton Ridge quartz-diorite was formed by static recrystallization and partial metasomatism of amphibolitic rock, and that its contacts on the north, northeast, and east sides were determined by tectonic movements at various stages in its history. The possibility exists that some mobilization has occurred.

TABLE IX

APPROXIMATE MINERAL COMPOSITIONS OF SPECIMENS FROM THE HUTTON RIDGE QUARTZ-DIORITE

Specimen Number	1	2	3	4	5	6	7	(8)
plagioclase	55	60	55	65	60	55	65	70
per cent anorthite	(32)	(43-35)	(43)	(54-37)	(43)	(43)		(36)
quartz	20	10	5	5	10	10	5	tr
potash feldspar		tr	tr					
biotite	10	10	10	10	10	15	10	10
hornblende	10	15	25	15	15	15	15	20
pyroxene	tr	tr	tr				tr	
sphene	tr	tr	tr				tr	
iron oxide	tr	tr		tr	tr	tr	-5	tr
apatite	tr	tr	tr	tr	tr	tr	tr	tr

Also retrogressive chlorite and epidote.
tr - trace, -5 - less than 5 per cent, figures are in percentages. (8) is an inclusion.
Locations of specimens are shown in Figure 8.



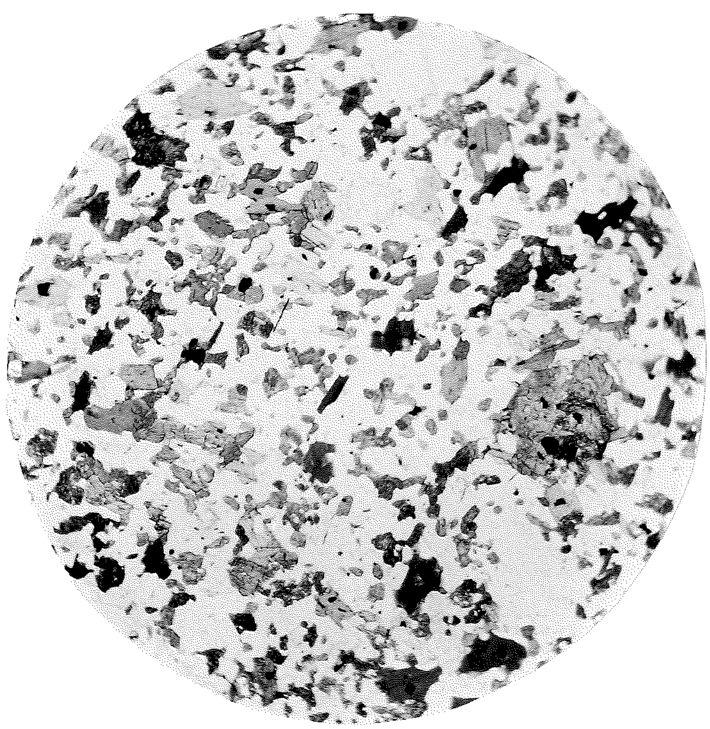


PLATE XLVIII

A. Biotite quartz-diorite, Thunder Mountain complex. Lone Frank Pass (9.25.48.3g).

B. Mutton Ridge quartz-diorite. Northeast of Lone Frank Pass (10.23.48.10g).

C. Granodiorite, Thunder Mountain complex. West of Bottle Springs Camp (9.18.50.11g).

D. Quartz-monzonite, Thunder Mountain complex. Thirty-mile Meadows (9.16.50.2g).


A
B

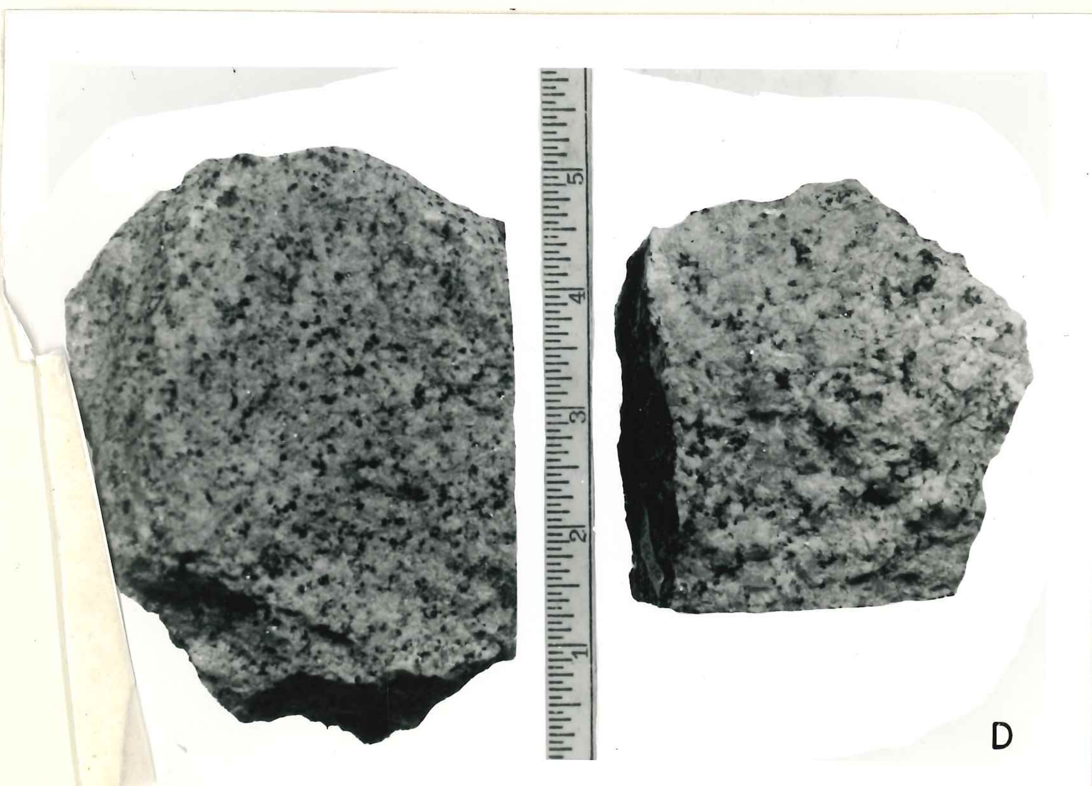
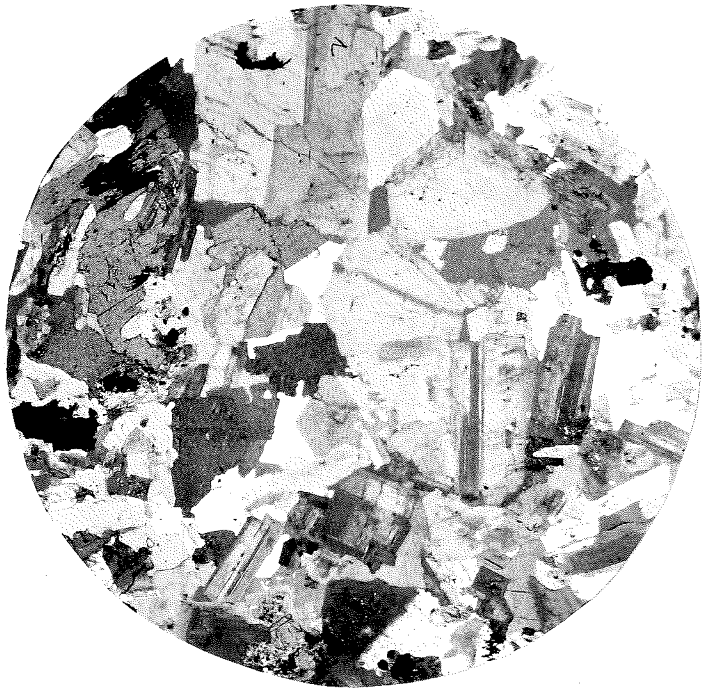

D

PLATE XLIX

A. Biotite quartz-diorite, Thunder Mountain complex. Plagioclase, quartz, potash feldspar, biotite. Approaching igneous texture, still some subordinate crystalloblastic features. Lone Frank Pass (9.25.48.3g). Crossed nicols, x 17.

B. Granodiorite, Thunder Mountain complex. Plagioclase, quartz, potash feldspar, biotite. Igneous texture. Thunder Mountain (7.22.49.2g). Crossed nicols, x 17.



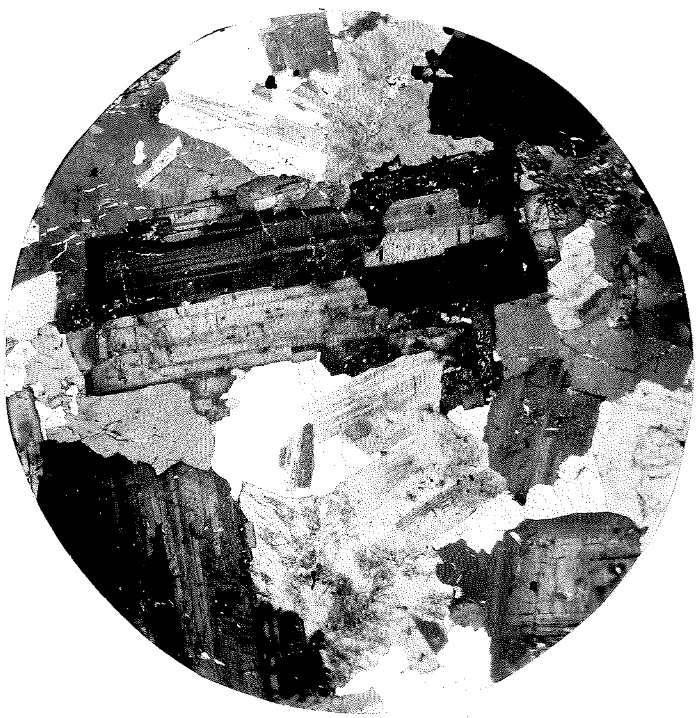


PLATE L

More fine grained and slightly more basic inclusion in biotite quartz-diorite, Thunder Mountain complex. Plagioclase, hornblende. Lath-shaped feldspars with irregular margins. Head of Siulahekin Creek (7.20.49.1g). Crossed nicols, x 60.

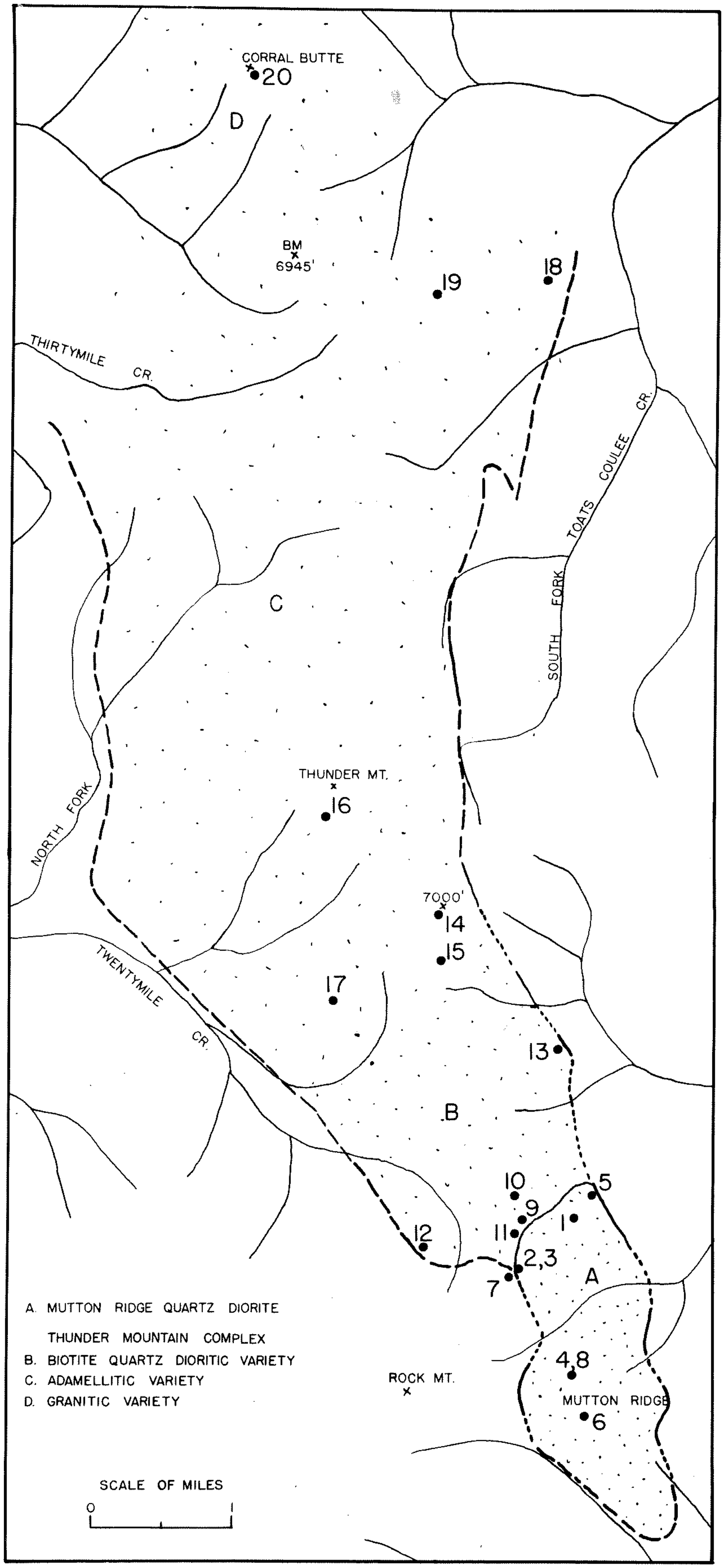


FIGURE 8 DIAGRAM OF THE MUTTON RIDGE QUARTZ DIORITE AND THE THUNDER MOUNTAIN COMPLEX SHOWING LOCATIONS OF SPECIMENS LISTED IN TABLES IX, X, AND XI

Thunder Mountain Complex

Introduction

The medium grained biotite quartz-diorite that occurs northwest of the Mutton Ridge hornblende biotite quartz-diorite described above forms part of a geographically continuous area of directionless rocks of northward increasing potash feldspar content. These rocks extend in a belt along the crest of the range north of Rock Mountain. They grade from biotite quartz-diorite through granodiorite and quartz-monzonite to granite. This progression is shown diagramatically in Figure 9. Representative hand specimens are illustrated in Plate XLVIII. The Mutton Ridge quartz-diorite might be considered a basic end member to this sequence; however the Mutton Ridge quartz-diorite is not considered a part of the Thunder Mountain sequence because its texture and that of its inclusions differ from the textures of the adjacent biotite quartz-dioritic variety of the Thunder Mountain complex and its inclusions. The fact that a knob of hornblende quartz-diorite occurs in the biotite quartz-diorite about three-quarters of a mile northwest of the faulted contact between the Mutton Ridge quartz-diorite and the biotite quartz-diorite might appear to indicate that these two bodies are parts of one unit. However, it is

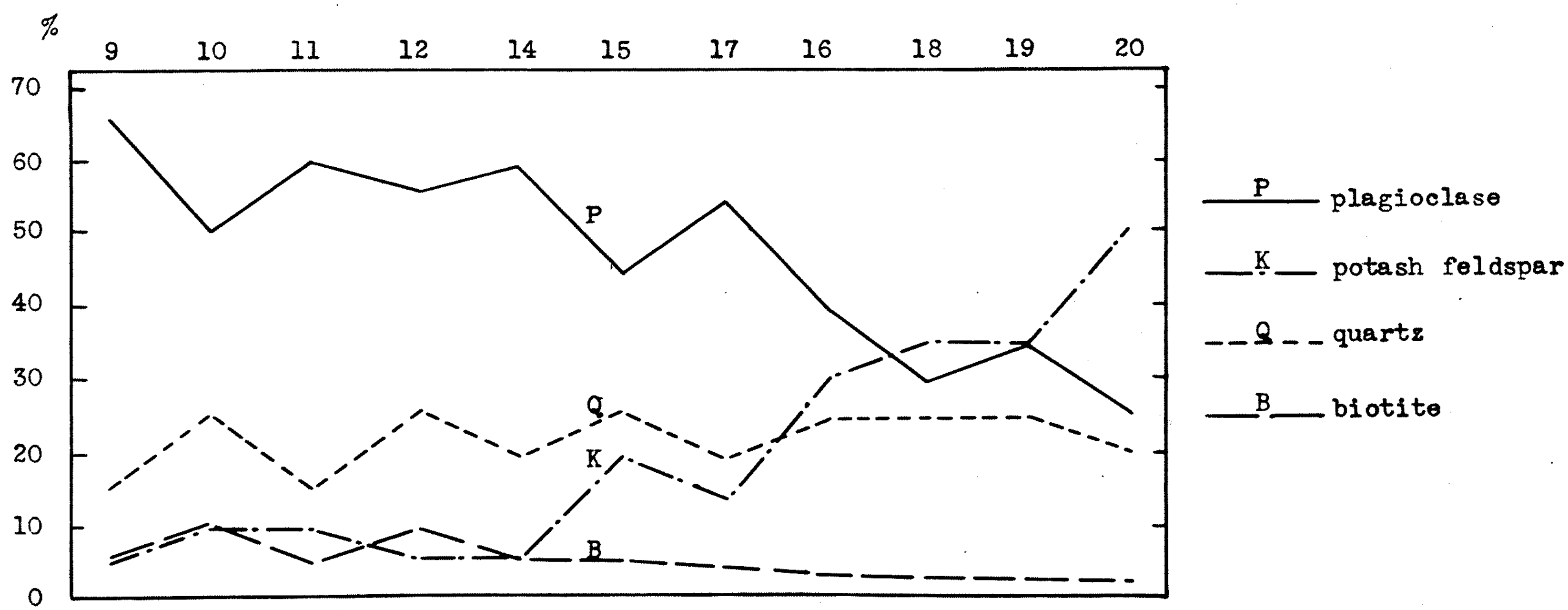


FIGURE 9

CHANGES IN MINERAL COMPOSITION IN THE THUNDER MOUNTAIN COMPLEX ILLUSTRATING THE TRANSITION FROM BIOTITE QUARTZ-DIORITE TO GRANITE

Locations of specimens are indicated in figure 8. Approximate mineral compositions taken from tables X and XI.

probable that the original material from which the Mutton Ridge quartz-diorite was made had a different composition from the original material which has been transformed into the Thunder Mountain complex. This seems more likely than that the Mutton Ridge quartz-diorite and the Thunder Mountain complex could have formed from the same original material and represent only different stages of transformation. What has just been said does, of course, imply that both the Mutton Ridge quartz-diorite and the Thunder Mountain complex are the results of transformation of earlier more basic country rock; this mode of origin has been discussed above for the Mutton Ridge quartz-diorite, and there will be offered some evidence below that the Thunder Mountain complex is likewise a product of transformation although its evolution has proceeded to a point where at least partial liquefication has occurred. If this evidence should be considered inconclusive in the Thunder Mountain complex, the question of the nature of the "original material" would not arise.

The contact of the Thunder Mountain complex with the Sinlahekin quartz-dioritic gneiss to the east is a narrow migmatite zone of variously feldspathized hornblendic gneiss and directionless granitoid rock. In some places these migmatitic hornblendic gneisses show some contortion. The contact between the Thunder Mountain complex and the Sinlahekin gneiss does not everywhere display such a migmatite zone, but is in part quite sharp without visible mechanical disturbance. The contact in part parallels and in part transects the adjacent Sinlahekin gneiss. Near Windy Peak directionless granite of the Thunder Mountain complex sharply truncates the trend of hornblendic gneiss at the margin of the Sinlahekin gneiss area. No chilling effects were observed at this granite contact. Neither were chilled margins observed elsewhere along the contact of the Thunder Mountain complex with the Sinlahekin gneiss. This indicates that both rock bodies were at more or less similar temperatures whatever their mode of origin.

The contact of the Thunder Mountain complex with the Boulder Creek gneiss complex to the west was not determined.

Description of the Rocks Comprising the Thunder Mountain Complex

(1) Biotite quartz-dioritic variety. This rock is finer grained than the Mutton Ridge quartz-diorite. It is directionless, even near its margins. Dark gray, sugary textured inclusions are common near the margins and are much more abundant than are inclusions in the Mutton Ridge quartz-diorite.

On the east side this quartz-diorite is in sharp contact with a narrow band of amphibolite belonging to the Sinlahekin quartz-dioritic gneiss. Near the contact, in the Sinlahekin gneiss, a breccia occurs similar to that occurring along the northern margin of the Mutton Ridge quartz-diorite. The breccia contains jumbled blocks of amphibolite in a swirled, gneissose quartz-dioritic matrix. To the north the biotite quartz-diorite passes into light colored trondhjemite and granodiorite. The contact with the Rock Mountain migmatitic gneisses on the west side is everywhere concealed except that a southeastward projecting tongue of the quartz-dioritic rock appears to be concordant with the migmatitic gneisses just to the northeast of Rock Mountain.

The texture of the biotite quartz-diorite is hypidiomorphic granular. Sharply zoned, tabular, subhedral, plagioclase and irregularly-shaped biotite grains are set in quartz, potash feldspar, and minor amounts of anhedral hornblende. The larger biotite grains and the plagioclase are about 1.8 mm in size. Quartz and potash feldspar are the latest minerals to form and appear as filling between the plagioclase crystals, thus producing an igneous appearing texture. This texture strongly suggests crystallization from a silicate melt. Some varieties of the biotite quartz-diorite have a finer grain size than others, in these the plagioclase is more lath shaped. Approximate mineral compositions are given in Table X. Some of these specimens contain enough potash fledspar to be called granodiorite under some petrographic classifications; however the classification used here is that of Whalstrom (1941).

Microscopically, the inclusions in the biotite quartz-diorite blend into the surrounding rock, and their texture is quite similar to that of the surrounding rock except that in the inclusions the grain size is finer and the plagioclase grains more elongate in shape. The inclusions are not similar in texture to the inclusions in the Mutton Ridge quartz-diorite, nor are the compositions similar, particularly insofar as the inclusions in the Thunder Mountain biotite quartz-diorite contain potash feldspar which is absent in the inclusions in the Mutton Ridge quartz-diorite. However, the inclusions in the Thunder Mountain quartz-diorite are similar to some of the dark, fine grained, relatively basic dikes occurring in the migmatitic gneisses of Rock Mountain and to dark dikes and other fine grained, relatively basic rocks of the Tiffany complex. In detail, the plagioclase is lath-shaped and zoned, but the margins are irregular and enclose hornblende and apatite. Carlsbad twins are prominent in the centers of the plagioclase, but no twinning is visible on the albitic marginal area of the grains. Occasional larger metacrysts occur in the inclusions. The plagioclase ranges in composition from sodic andesine to sodic oligoclase. Some of the plagioclase shows oscillatory zoning with a sodic core and rim and a more calcic medial zone. Some of the centers of the plagioclase grains contain hornblende and matted apatite needles. Hornblende forms small, irregular grains which sometimes exhibit light-green to colorless cores of a pale amphibole ($c/Z = 21^{o}$). Some biotite has formed on the margins of hornblende, but biotite also occurs as individual, anhedral grains. Potash feldspar forms small irregular grains that enclose hornblende, plagioclase, and apatite. Fine needles of apatite are abundant in the inclusions.

(2) Granodioritic variety. The contact relations between the Thunder Mountain complex and the Similkameen gneiss to the east have been described in the introduction to this section. Within the Thunder Mountain complex, the granodiorite is continuous with the biotite quartz-dioritic variety of the Thunder Mountain complex to the south, and with its quartz-monzonitic and granitic varieties to the north. Approximate mineral compositions for the granodioritic, quartz-monzonitic, and granitic varieties are given in Table XI.

The rock is coarse grained, light colored, and like the other rocks of the complex, uniform in texture.

Microscopically, the texture is hypidiomorphic granular. Irregularly shaped biotite is the main ferromagnesian mineral. Plagioclase is subhedral, zoned, and often exhibits complex twinning patterns. Its maximum observed grain size is 4 mm; its average grain size is about 3 mm. It is enclosed by usually larger anhedral quartz and potash feldspar grains. Potash feldspar encloses all the other minerals except quartz, with which it is evidently contemporaneous. The potash feldspar is perthitic with albitic threads.

(3) Quartz-monzonitic and granitic varieties. The quartz-monzonitic and granitic varieties are still more coarse grained than the granodioritic variety. They have a pink rather than a gray tinge, and they weather readily to gruss.

Microscopically, the texture is similar to that of the granodiorite except that the greater amounts of anhedral potash feldspar and quartz produce a more xenomorphic texture. Plagioclase shares in the general increase in grain size shown by these rocks, but potash feldspar shows the greatest increase in size. The potash feldspar is perthitic and partly replaces plagioclase. Twinned quartz is common. Hornblende is no longer present, but sphene and magnetite are sometimes present in association with biotite.

Inclusions are rare. They are more coarse grained than the inclusions in the biotite quartz-dioritic variety, and their textures show a greater degree of recrystallization. One typical inclusion in quartz-monzonite contains some large metacrysts of plagioclase, the number of which increase toward the contact. Although the contact is sharp, the large grains project from the inclusion into the surrounding quartz-monzonite producing a crenulated border. Slender apatite prisms are common in the inclusions. Such an elongate, prismatic habit of apatite is characteristic of inclusions throughout this sequence.

Discussion

An intrusive origin for the Thunder Mountain complex is suggested by the following features: the general textural and compositional homogeneity which varies only over a wide area; the nature of the contacts, which are in part discordant to the gneisses, locally sharp, and locally have a narrow migmatite zone in the wall rock along the contact; and the igneous-appearing textures.

Only one type of inclusion was observed in the complex. Yet the emplacement of the mass by stoping should be expected to have produced xenoliths of some of the varied rock types that comprise the migmatitic gneisses in the area. If the mass is intrusive then, the mechanism must be that of dilational injection of either liquid or hot plastic mobile material, or forcible emplacement of a solid crystalline mass. The lack of protoclastic or cataclastic post-crystalline deformation along the contacts rules out the latter possibility. The lack of flow structure might be used as an argument against the former; however, a long continued "stewing" in place could eliminate any earlier flow structures.

However, it might be suggested that the Thunder Mountain complex is a migmatitic mass that was already occupying, or approximately occupying its present position; that it therefore had to move only a relatively short distance to produce intrusive contacts; and that it might have partially or even in large part liquified. The inclusions, in this case, would represent relicts of original material. However, since the inclusions resemble some of the fine grained, relatively basic dikes occurring in the migmatitic gneisses and the Tiffany complex, it could be argued that the inclusions are relicts of dikes which had cut the original material, although these dikes may actually be a late feature representing more basic relict material which became mobilized and intrusive (cf. p. 330). The original material may have been already discordant to the Salmon Creek-Sinlahekin gneisses to the east, or it may have become discordant through tectonic movements before or during metamorphism. Faulting along the contact between the Thunder Mountain complex and the Sinlahekin gneiss could form a barrier to replacement that would account for the sharp contacts. The line of discontinuity between the migmatitic gneisses to the east and the directionless bodies to the west and southwest is of regional extent. It can be traced across the entire area and forms part of the border of many rock units. This fact suggests that the eastern contact of the Thunder Mountain complex was produced by regional pre-granitic or early granitic tectonic movements rather than by local magmatic intrusion, although, on the other hand, such movements could have controlled the rise and emplacement of magma or migma.

Assuming a migmatitic descent for the Thunder Mountain complex, the nature of the original material is not known. A probable petrogenetic relationship to the Tiffany complex, primarily its main body, appears to be suggested by the textural similarity of the biotite quartz-dioritic variety of the Thunder Mountain complex and of its inclusions, which in turn are similar to dark dikes and other fine grained, relatively basic rocks of the Tiffany complex. The Thunder Mountain complex may have been formed from the same original amphibolitic material as the Tiffany complex, but in the Thunder Mountain complex the transformation from amphibolitic rock to a granitic rock was much more thorough, and apparently reached the stage of partial liquification. The presence of hornblende and sphene as accessories suggest an earlier more basic phase, although this is not conclusive.

The origin of the Thunder Mountain complex, then, is not definitely determined. It appears to be an intrusive body, but whether the material is of magmatic or migmatitic origin is not proven. Criteria that apply to intrusive bodies occurring in a non-metamorphic environment and at higher levels in the crust, need to be re-evaluated when applied to relatively deep-seated intrusive appearing plutonic bodies occurring in areas of high grade regional metamorphism.

TABLE X

APPROXIMATE MINERAL COMPOSITIONS OF BIOTITE QUARTZ-DIORITIC VARIETY OF THE THUNDER MOUNTAIN COMPLEX

Specimen	9	10	11	12	Inclusions 12a	13
plagioclase	65	50	60	55	55	60
per cent anorthite	(36-32)	(32-25)				
quartz	15	25	15	25	5	tr
potash feldspar	5	10	10	5	5	10
biotite	5	10	5	10	tr	10
hornblende	-5	-5	-5	tr	25	15
sphene	tr	tr	tr	tr		
apatite	tr	tr	tr	tr	tr	-5
iron oxide	tr	-5	-5	tr	tr	-5
pyroxene				tr		

Also retrogressive chlorite and epidote; tr - trace, -5 - between 1 and 5 per cent. Locations of specimens shown in Figure 8.

TABLE XI

APPROXIMATE MINERAL COMPOSITIONS OF THUNDER MOUNTAIN COMPLEX OTHER THAN THE BIOTITE QUARTZ-DIORITE VARIETY

Specimen	14	15	16	17	18	19	20	Inclusions 17a	19a
plagioclase	60	45	40	55	30	35	25	65	60
per cent anorthite	(44-21)	(32-2?)	(36-2?)		(2?)	(22)	(2?)	(35-21)	(35-22)
quartz	20	25	25	20	25	25	20	15	20
potash feldspar	10	20	30	15	35	35	50	tr	tr
biotite	5	5	5	5	-5	-5	-5	5	5
hornblende	tr		tr	tr				15	10
sphene	tr	tr	tr		tr		tr	tr	-5
apatite	tr	tr	tr	tr		tr		tr	tr
iron oxide	tr	tr	tr	tr	tr	tr	tr	tr	tr
muscovite					tr				

Also epidote, chlorite, calcite, zircon.
tr - trace, -5 - less than 5 per cent.
Locations of specimens are shown in Figure 8.

Mineral Hill Granodiorite

Occurrence and Megascopic Description

A body of directionless granodioritic rock lies southwest and west of Conconully in the area drained by the west and south forks of Salmon Creek. It is in contact with the isochemically metamorphosed rocks and the migmatitic gneisses along a line running from Peacock Mountain, south of Conconully, to Mineral Hill and thence along the south side of the ridge leading northwestward from Mineral Hill. One major break occurs in this line: on the southeast slope of Mineral Hill, the granodiorite projects to the northeast to Salmon Creek across the trend of the migmatitic gneisses. To the west and southwest, the granodiorite appears to have considerable areal extent, but this region was not mapped.

Granodioritic rock occurs again on Funk Mountain, but this occurrence is not uniform and includes an augen gneiss-like variety and an aplitic variety passing into biotitic gneisses and micaschists. This granodioritic rock is considered a separate unit from the Mineral Hill granodiorite, and as belonging to the group of granitoid replacement bodies occurring in the micaschists. The northwestern contact of this granodioritic body on Funk Mountain is sharp and apparently represents pre-granitic or early-granitic faulting.

This sharp contact is aligned with the northeasterly trending cross-cutting portion of the contact of the Mineral Hill granodiorite mentioned in the preceding paragraph.

The contacts of the Mineral Hill granodiorite are mostly concealed, but they are sharp where they can be seen. On Mineral Hill, the granodiorite cuts across the trend of the metamorphic rocks, and dike-like bodies with sharp contacts project from the granodiorite into the country rock. At one locality, the granodiorite is in contact with thin bedded quartzite succeeded by marble. No chilled border is present, but the granodiorite contains fewer mafics near its contact with the quartzite. This is interpreted as a reaction zone between two rock bodies of dissimilar composition which have been brought into contact.

Although directionless, the granodiorite is variable in character. West of Conconully near the contact with the Salmon Creek hornblendic flasergneisses and augengneisses, it is a hornblende granodiorite; elsewhere it is a biotite granodiorite. On the south arm of Mineral Hill, in a belt extending southeastward to the south fork of Salmon Creek, it is a porphyritic granodiorite with large (about 3 cm.) potash feldspar crystals which contain megascopically visible, crystallographically oriented inclusions of mafics. Near Mineral Hill, some of the rocks show hydrothermal alteration with leaching of mafics and some sulfide deposition along joints.

Microscopic Description

Textures are hypidiomorphic granular and locally porphyritic. In the hornblendic varieties the texture becomes more xenomorphic. Plagioclase and frequently biotite form subhedral grains; other minerals are anhedral except for some of the minor constituents such as apatite, sphene, and orthite. Plagioclase is usually about 4 mm in size, while quartz and especially microcline form much larger grains. The large microcline grains reach an observed maximum of 3 cm. Although the microcline appears to be euhedral megascopically, its margins are actually crenulated. It includes hornblende, biotite, plagioclase, and quartz. Plagioclase is zoned, with cores of sodic andesine and rims of oligoclase. In the hydrothermally altered rocks, plagioclase has been partly sericitized, and some of the biotite has been converted to muscovite or chlorite with a release of iron. Some pyrite is present in these rocks and is apparently related to the late mineralization in the area. Some approximate mineral compositions are given in Table XII.

Discussion

Although the Mineral Hill granodiorite was only examined along its northeastern margin, its cross-cutting relationship to the migmatitic gneisses, and the occasional sharp bordered apophyses, suggest that it is intrusive.

However, the variable composition of the body as a whole repeats some of the compositional variation of the migmatitic gneisses. For example, the hornblendic variety of the Mineral Hill granodiorite corresponds to hornblendic flasergneisses, the porphyritic variety corresponds to the augengneisses, and the biotitic variety corresponds to the biotitic flasergneisses. This suggests that the Mineral Hill granodiorite may be of migmatitic origin. It may have had a history comparable to that of the Fish Lake complex, but may have attained a higher grade resulting in partial mobilization of the migmatitic material, after more thorough metasomatism and at higher temperatures than occurred in the Fish Lake complex. The cross-cutting contacts may represent pre-granitic faulting. The late, large microcline grains that include all earlier minerals suggest a late addition of potassium into the rocks, but whether this is deuteric, or whether the added material has been derived from elsewhere is not known. This body has not been studied sufficiently to state definitely whether it is a migmatitic or magmatic intrusive.

TABLE XII

APPROXIMATE MINERAL COMPOSITIONS OF THE MINERAL HILL GRANODIORITE

Specimen	1	2	3	4	5
plagioclase	40	40	45	50	60
per cent anorthite	(32-23)		(27)		(33-25)
potash feldspar	20	30	25	10	15
quartz	30	20	25	30	15
biotite	-5	-5	tr	-5	-5
hornblende	tr	tr	5		-5
sphene	tr	tr	tr		tr
epidote	tr	tr	tr		tr
apatite	tr			tr	
orthite			tr		
iron oxide	tr	tr		tr	

Figures are in percentages. Also zircon, chlorite, and sericite. tr - trace, -5 means less than 5 per cent.

Dark, Fine Grained, Relatively Basic Dikes, Occurring in the Migmatitic Gneisses

Occurrence

Numerous dark gray to black, fine grained, relatively basic dikes occur throughout the Salmon Creek migmatite belt and in the migmatitic gneisses near Rock Mountain. They also occur in the Boulder Creek complex, the Sinlahekin gneiss, and the Tiffany complex. Superficially the dark dikes resemble some of the andesite dikes accompanying the Tertiary volcanics in the area. However, megascopically the dark dikes have a more hornfelsic, even granular texture than the Tertiary dikes, and generally they are flat rather than near vertical. Microscopically, the dark dikes lack the igneous textures, and hydrothermal alteration of the Tertiary dikes. The dark dikes apparently follow the horizontal jointing in the gneisses. Some of the aplite and pegmatite dikes follow the same direction.

In the Rock Mountain area, where the dikes are best exposed, early and later dark dikes have been recognized. The early dikes sharply truncate the foliation of the gneisses and yet have been partly replaced as well as intruded by aplitic and medium grained, granodioritic and quartz-monzonitic material. The contacts of these earlier dikes with the light colored aplitic rock are usually sharp although some transitional areas representing replacement occur. Intrusive and replacement breccias in which the fragments are derived from the basic dikes are common (cf. Plates XXII, XXIII, and XXIV). These early basic dikes are not discontinuous remnants of possible pre-orogenic dikes, but are continuous and undisturbed for considerable distances; one is continuously exposed for 150 yards. They are not schistose. These dikes were definitely emplaced after the formation of the synkinematic migmatitic gneisses and are therefore post-kinematic. The later dark dikes cut the breccias mentioned above which consist of fragments of the earlier dikes and light colored aplitic material. The later dikes often have finer grained chilled borders and always have sharp contacts with the country rock. Some medium grained, deuterically altered, dioritic dikes and sills occur in the Fish Lake and Blue Lake areas, but little work was done on them.

Microscopic Description

A variety of names could be applied to the dark dikes on the basis of their composition. Most of the rocks comprising both the older and the younger group of dikes are essentially similar in composition to the amphibolitic, dioritic, and quartz-dioritic rocks in the area (cf. Table XIII). As lamprophyres, they would be classified as gladkaites or spessartites. Flow structure is sometimes seen. It is less obvious in those early dikes which after their emplacement have undergone static recrystallization and metasomatism near contacts with granodioritic aplite. Other dikes are structureless.

The dark dikes vary from granoblastic to igneous-appearing in texture. The former texture is more common in the earlier group of dikes, whereas the latter texture is more often seen in the later dikes. One early dike examined consists of a mosaic of irregular plagioclase grains through which shreddy green hornblende is evenly distributed. Another, a late dike, has an igneous-appearing texture and contains larger grains of euhedral brown hornblende (c/Z - 17°) and euhedral plagioclase in a groundmass composed of the same minerals less well crystallized. The brown hornblende has a margin of more greenish hornblende. The plagioclase has clear rims, but has a sieve texture in the cores which contain hornblende similar to the finer grained hornblende in the groundmass. Most of the dikes however, contain lath-shaped or tabular grains of zoned plagioclase with irregular margins, and subhedral to anhedral mafics. Intergranular quartz and less often potash feldspar may be present and needles of apatite are usually abundant. These dikes are usually even grained megascopically; however, microscopically, occasional larger grains of plagioclase or hornblende occur. Hornblende, sometimes with biotite, may occur in clusters of small grains.

Little textural differences between the early and later dikes exist. The early dikes have a more granoblastic texture resulting from the recrystallization and partial metasomatism which they have undergone, and in general contain more biotite and quartz. The later dikes commonly contain xenocrysts and xenoliths of country rock, and intergranular alkali feldspar is common.

The lath-shaped plagioclase characteristic of the predominant type of dike is strongly zoned with cores of calcic andesine or sodic labradorite and rims of oligoclase. Although the crystals are lath-shaped, they have irregular borders, and the rims, in contrast to the cores, are usually untwinned. In those early dark dikes that occur as fragments in breccias, or are otherwise associated with aplite, the plagioclase is more equidimensional, although the lath-shaped cores can still be recognised. Such change in form of growth indicates a later static recrystallization.

The principle ferro-magnesian minerals in the dark dikes are hornblende and biotite, and these two minerals vary in all proportions. The amount of biotite increases with the amount of quartz and intergranular potash feldspar. Green hornblende forms irregular individual grains, irregular matted clusters, or pale needles in the groundmass, but occasionally it forms larger, elongate grains with irregular margins. Sometimes the hornblende contains dark areas which may cover the whole grain except for the rim, and are rich in magnetite dust. Anhedral patches of magnetite sometimes occur with clusters of hornblende grains. Biotite replaces hornblende in varying degrees in most of the rocks. Sphene is present in the rocks containing biotite.

TABLE XIII

APPROXIMATE MINERAL COMPOSITIONS OF SOME DARK, FINE GRAINED RELATIVELY BASIC DIKES

Specimen	1	2	3	4	5	6	7	8C	9C	10C
plagioclase	65	65	65	65	50	55	65	45	60	50
quartz	5	-5	10	-5		10	5	30	20	20
hornblende	15	16	5	25	45	15	15	10	5	
biotite	10	10	15	tr		10	10	10	15	25
potash feldspar	5		tr	tr						
aptite	1	tr	1	tr	1	tr	tr	tr	tr	1
sphene		tr	1			tr	tr	tr	tr	
iron oxide		tr		tr	-5		tr		tr	

Also orthite, epidote, chlorite, zircon.
C - fragment of early dike in aplite or near contact with aplite.
tr means trace, -5 means less than five per cent.

Quartz occurs as irregular, intergranular grains. Less than five per cent is usually present, but it becomes more abundant in those early dikes which are associated with aplite. Some of the dikes, usually the late ones, contain large rounded quartz grains or aggregates which are rimmed with small hornblende grains. These may occur in a rock which has no intergranular quartz and are considered to be xenocrysts. Plagioclase sometimes may occur with quartz in an xenolith.

One of the most characteristic features of the dikes is the presence of innumerable, hair-like apatite needles in the groundmass. This recalls the occurrence of apatite in the Tiffany complex. Some of the dikes, especially the later ones, have much intergranular potash feldspar. Other accessory minerals are magnetite, orthite, and epidote.

<u>Discussion</u>

A brief summary of the early and later, dark, fine grained, relatively basic dikes occurring in the migmatitic gneisses, and of the dikes associated with the Tertiary volcanics, is given below:

Early dikes (Ae) -	Transect gneiss, intruded and replaced by granitoid material, locally recrystallized and metasomatized. Gently dipping. Apatite needles characteristic. Composition dioritic to quartz-dioritic.
Later dikes (Al) -	Transect gneiss and breccias formed from earlier dark dike rock and granitic material. Gently dipping. Texture largely similar to (A_e), but not recrystallized. Apatite needles characteristic. Intergranular alkali feldspars common. Composition dioritic to quartz-dioritic.
Dikes associated - with Tertiary	Transect all other rocks. Steeply dipping. Usually porphyritic.

volcanics	Usually show hydrothermal alteration. Typically andesitic to basaltic rocks.

The early and later dark dikes fall into one group which is distinct from the dikes associated with the Tertiary volcanics. The early and later dark dikes are considered to be similar in origin although their time of emplacement differs.

Several possible explanations for the origin of the dikes will be advanced and each, in turn, discussed. The dikes might be:

A. Basic igneous dikes derived from great depth (sima derived). This calls for a "simatic interval."[1]

B. Basic differentiates from an acidic magmatic body (classical lamprophyres).

C. Of migmatitic derivation.

(1) Mobilized and partially liquified basic relict material of metamorphic origin that became intrusive.

(2) Formed by localized movement of not or incompletely granitized country rock material

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1 According to H. H. Read (oral communication) a "simatic interval" represents a period of intrusion of basic dikes drawing on the sima and emplaced under tensional conditions into cold rocks at high levels in the crust so that chilled margins are produced.

along shear zones with subsequent recrystallization.

In any case, the early dark dikes are relict dikes with respect to the following granodioritic aplite invasion.

The various possibilities mentioned above will be discussed now:

A. It is considered unlikely that the early dark dikes which cut the migmatitic gneisses represent a "simatic interval." Such an interval would mean that the rocks undergoing metamorphism and granitisation well within the crust were brought to shallow levels, intruded by simatic material, and then again covered deeply enough to undergo further metasomatism and mobilisation (late replacement and intrusive aplites mentioned above). If the interpretation of the metamorphic history for the present area is correct, such an interval has not occurred. It has been shown that postkinematic metasomatic metamorphism follows synkinematic metasomatic metamorphism as a continuous process concomitant with a single rise and fall of temperature although minor temperature fluctuations occurred. The emplacement of the early and later dark dikes and the intervening replacement and intrusion by light colored aplitic rock appear to belong to a single episode since the early and later dark dikes appear to be so closely related. Moreover, neither the chemical nor the mineral composition of the dark dikes is at all similar to that of true basic intrusive dikes derived from great depths, supposedly from the sima. On the contrary, mineralogically and chemically these dikes are identical with many of the country rocks.

B. The dark dikes might be considered differentiates (lamprophyres) from some nearby acidic magmatitic body. These dikes when combined with the light colored aplite and pegmatite dikes would complete the suite of dikes usually ascribed to a granitic magmatic body. Several bodies of apparently intrusive granitoid rock occur in the area, for example the Thunder Mountain complex and the Mineral Hill granodiorite, but it has been suggested above that these bodies may be of migmatitic rather than magmatic derivation. The smaller light colored aplitic and pegmatitic bodies, including dikes and irregular patches, that occur in the area have been shown to consist of replacement as well as intrusive types. Rocks representing both types of emplacement may have identical compositions and similar granoblastic textures. The intrusive types are considered to be mobilized migmatitic material (cf. Chapter III). For these reasons, an origin for the dark, fine grained, relatively basic dikes by differentiation from a magmatic body, while possible, is considered less likely than the following mode of origin.

C. H. G. Smith (1946) visualizes "lamprophyres" as mobilised upward extensions of an early solidified shell of magma under the influence of residual volatile constituents. With little difficulty the emplacement of the dark dikes in the present area could just as easily be visualized as mobilization of basic relict material of metamorphic origin under the influence of the volatile constituents available during regional metasomatic metamorphism. The basic relict material could easily be derived from the widespread amphibolitic rocks of the area. The similarity in composition of the dark dikes with the amphibolites and amphibolite-derived migmatitic dioritic to quartz-dioritic rocks in the area is striking. The resemblance of the dark dikes to fine grained rocks of the Tiffany complex and to inclusions in the Thunder Mountain complex has been mentioned above. The abundance of apatite, and the considerable amount of late introduced intergranular alkali feldspar (mostly in the later dikes) might be considered as suggesting considerable action of volatiles which would have been important in mobilization of the dikes. Once the material has become softened and mobilized, there is no reason why igneous-appearing textures should not be formed, especially if partial liquification has taken place.

The emplacement of early and later dark dikes might possibly be correlated with the sequence of events during the postkinematic phase of metamorphism in the area. The early dark dikes may reflect the change from the synkinematic to the postkinematic phase of metamorphism. In this change the mechanical conditions pass from the confinement of differential compressive stresses to the loosening conditions accompanying post-orogenic uplift of the geosynclinal belt. With the opening of channelways, the upward migration of materials is facilitated. The later dark dikes might be correlated with the period of mobilization and intrusion of granitoid rock characterizing the later post-kinematic stage when potassium metasomatism was predominant (cf. Table VI). The presence of intergranular potash feldspar in the later dikes suggests such a relationship. It may be recalled that a secondary peak of recrystallization during the post-kinematic phase of the metamorphic history was observed in the predominantly isochemically metamorphosed rocks. This secondary peak of recrystallisation may be a reflection of the period of mobilisation and intrusion.

The foregoing discussion was concerned with the movement of mobilized material over considerable distances; however, some of the dikes may have been derived locally. Localized movement of partly granitised country rock material along shear zones could have produced some of the dark dikes. The mylonitisation of a coarse or medium grained rock of a dioritic or quartz-dioritic composition would produce a darker-appearing rock although the composition may not be changed. Since in many cases the dikes are largely similar to the wall rocks in composition such an explanation should not be difficult to accept. However if very much feldspathic material is involved in this process, the resulting dikes would be lighter in color and would be expected to look like the dike in Plate XXV B.

An origin for the dark dikes by shearing and re-crystallization of country rock material would not seem to apply to some of the later dikes which cut granitoid rocks poor in mafics. Some of the dikes too, have finer grained margins, which implies that they were at least partially liquified and were at temperatures higher than those of the intruded rocks. The textures, structures, and contact relationships indicate that most of the dike material was derived from more distant sources than the above explanation implies.

Conclusion

The majority of the dark, fine grained, relatively basic dikes occurring in the migmatitic gneisses and in the Tiffany complex most likely represent mobilization of relict basic material of metamorphic origin. Local mobilization of partly granitized material along shear zones may account for some of the dark dikes. This process, of course, is merely an incipient stage of the more complete mobilization implied above. However, more detailed work on the occurrence and petrography of individual dikes in the whole area might produce more definite evidense as to their origin than has been presented here.


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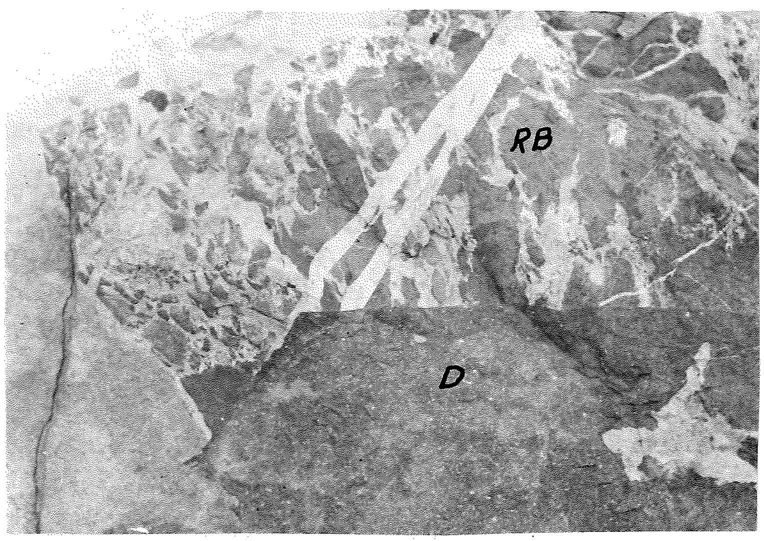
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PLATE LII

A. Typical dark, fine grained, relatively basic dike. Hornblende, biotite, plagioclase, apatite. Approaches igneous texture. Rock Mountain (10.23.48.1g). Plane polarized light, x 60.

B. Same, crossed nicols.

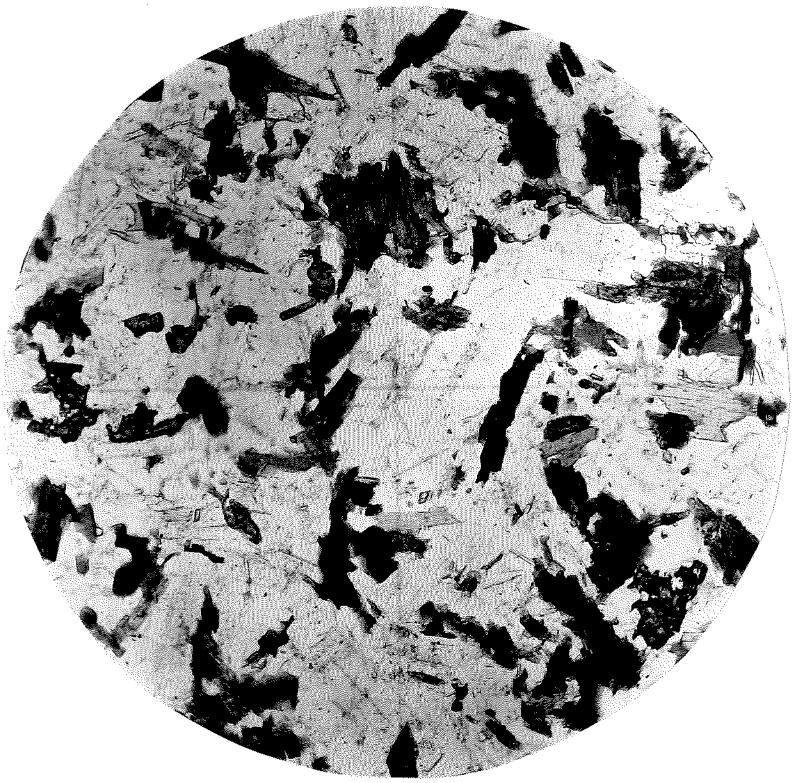
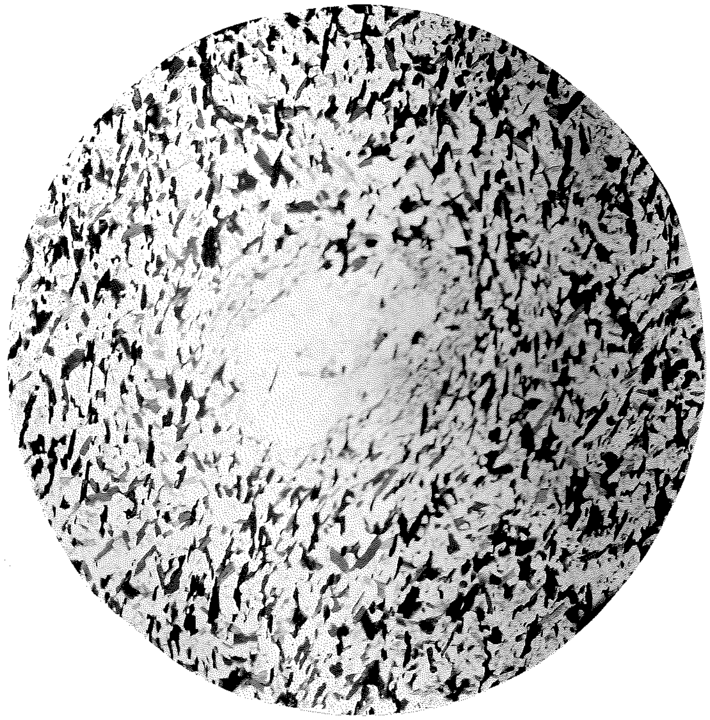


PLATE LIII

A. Dark, fine grained, relatively basic dike; typical example of those early dikes associated with aplite. Biotite, hornblende, plagioclase, quartz. Flow structure. Plagioclase porphyroblasts not common. Rock Mountain (8.30.48.8g). Plane polarized light, x 17.

B. Same, crossed nicols. Note hornfelsic texture, and inclusions of groundmass grains in plagioclase porphyroblast.



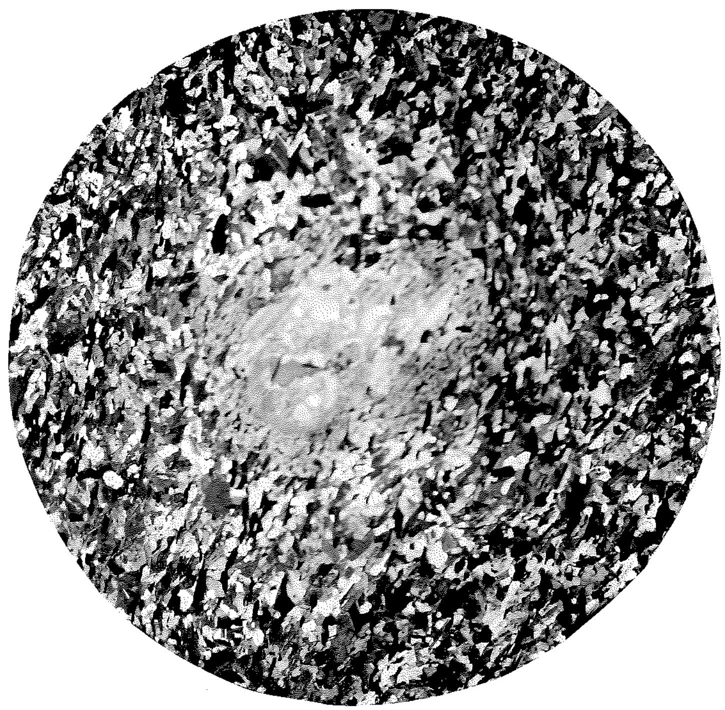
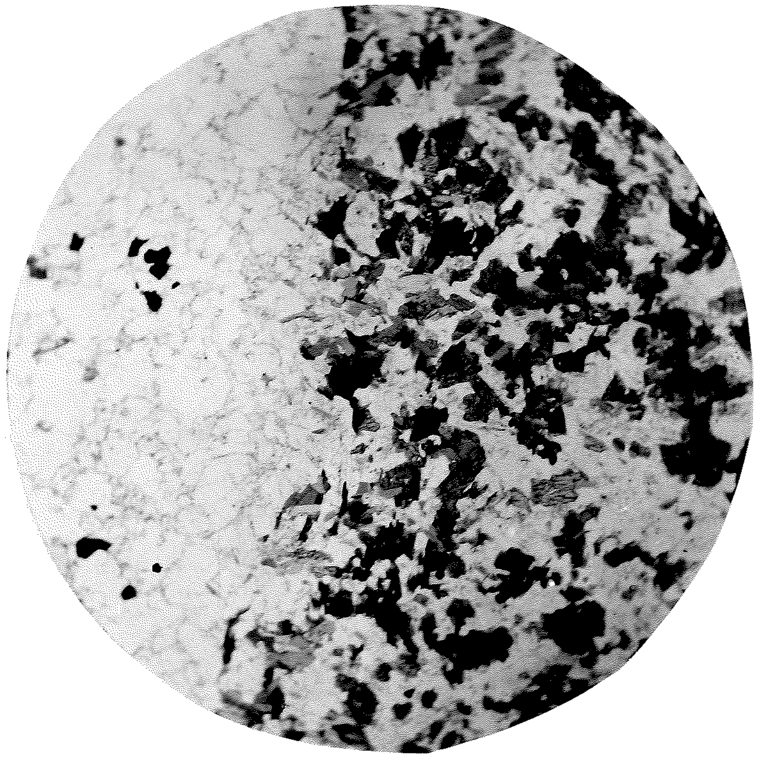
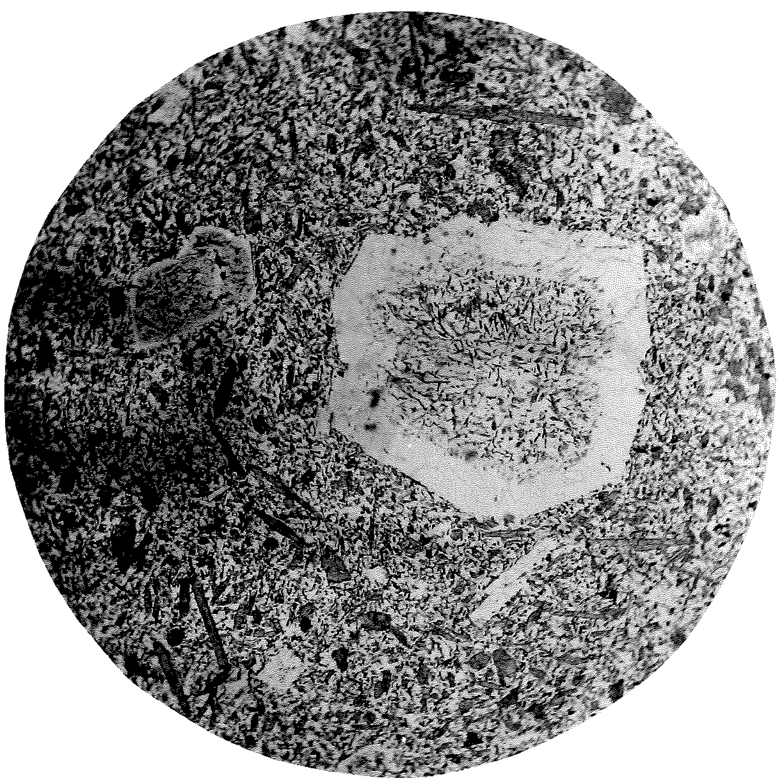


PLATE LIV

A. Contact of aplite with early dark, fine grained, relatively basic dike. Note granoblastic texture in dark, dike rock. Rock Mountain (9.2.48.6g). Plane polarized light, x 17.

B. Late fine grained, basic dike. Not typical of either the earlier or later dark dikes, probably related to the Tertiary volcanics. Plagioclase and hornblende. Rock Mountain (7.18.49.2g). Plane polarized light, x 17.





CHAPTER V

TERTIARY VOLCANICS

Occurrence and Composition

A sequence of andesitic tuffs, flows, and breccias lies unconformably on the gneisses in the north central part of the area. These rocks cover approximately 40 square miles. The volcanics have gentle dips - observed attitudes were usually less than 5°. The basal layers contain pebbles and cobbles of the underlying granitic and metamorphic rocks. Younger units of the volcanics have a wider distribution than older ones.

Study of these volcanics was only in the nature of reconnaissance but a suggested sequence is given below: On both sides of upper Sinlahekin Creek near the junction with Coxit Creek occurs a thick bedded, massive, greenish-gray, white-weathering, waterlain, arkosic tuff containing occasional pebbles of quartzite, phyllite, and greenschist. This unit has about a 200 foot minimum thickness. The top part consists of coarse conglomeratic arkosic tuff containing stream rounded phyllite and granite pebbles and a few larger less rounded fragments of cobble and boulder size, chiefly phyllite, were observed. The same conglomeratic member occurs on the north side of the creek, but here it directly overlies the metamorphic rocks. Above this unit is a columnar-jointed greenish, aphanitic andesite with a slightly different attitude than the tuff and conglomerate beds. This andesite is the lower part of a sequence of undetermined thickness which consists largely of mottled porphyritic purple and green andesitic breccias, with some green and red tuffs. The volcanic breccias are much more extensive than the flows. Near the base of the mottled rocks, thin lenticular red tuff and grit beds occur locally. These range from inches to several feet in thickness. A local small angular unconformity was observed in the upper sequence, and some intermediate layers contain fragments of metamorphic rocks.

Other volcanic rocks observed in the area include a small, poorly exposed patch of dacite which occurs on the west bank of Salmon Creek about eight miles northwest of Conconully and black, gre enish, and gray porphyritic and aphanitic dikes which occur in both the volcanics and metamorphics; some porphyries occur in small stock-like bodies. The trend of the dikes is almost universally north-south, and they dip steeply. One dike is about 100 feet wide.

Most of the volcanics are highly altered. Mafics have been replaced predominantly by chlorite (green rocks) or predominantly by hematite (purple rocks). However, the shape of the chlorite or hematite pseudomorphs and occasional unaltered crystals show that the chief ferro-magnesian mineral is hornblende, although augite is present in some specimens. Plagioclase has been largely saussuratized, but a sufficient number of unaltered grains remain to indicate that andesine predominates, but that labradorite is present in some rocks. The texture is usually pilotaxitic or hyalopilitic. One unaltered basalt dike containing xenoliths of granite was observed cutting granitic rock at Corral Butte.

Age and Correlation

No possible age determination could be made of the volcanic sequence in this area except that it is younger than the metamorphics. However rocks similar in lithology occurring northeast and east of the present area have been dated by Waters and Krauskopf (1941) as Tertiary on the basis of fossil plants. Some of the rocks they describe occur only about fourteen miles to the east in Pine Creek Valley, and further northeast near Whitestone Mountain. The lithology and the observed sequence of the volcanics in the present area, is also similar to part of that described by Barksdale (1948) in the Methow Valley, although both thickness and degree of disturbance are apparently considerably less in the present area. The arkosic tuff described above is possibly an equivalent of the upper tuffaceous arkose portion of Barksdale's Winthrop sandstone, and the overlying volcanics of the present area are possibly equivalent to his Midnight Peak formation. The latter is tentatively assigned by Barksdale to the Upper Cretaceous because of its conformable position above the Winthrop sandstone which he assigns to the Upper Cretaceous from the dating of fossil plants. However, the volcanics of the Methow Valley are at quite some distance from those of the present area, and a correlation of the latter with those of the Pine Creek-Whitestone Mountain region (cf. above) might appear more likely.

CHAPTER VI

ECONOMIC GEOLOGY

In the late 1800's the area around Conconully formed the most active center of mining in Washington. After the collapse of the silver market in 1893, production was sporadic, and at the present time there is no producing mine in operation, although some small scale development work is going on.

Most of the production came from Ruby Hill southeast of the present area. However, development work was done on Mineral Hill, the area immediately north of Conconully, and in the vicinity of Blue Lake. A small prospect located high on the eastern slope of Clark Peak has produced silver. Most of the mineralized zones occur in granodioritic or quartz-monzonitic rocks.

General economic reports on the district were made by E. Jones (1916), and M. H. Patty (1921). A detailed study of the economic geology of Peacock Mountain, south of Conconully was made by Griffith (1949). According to Griffith, the deposits are of low grade. The principle value of the ore shoots is in lead, silver, and copper. The economic minerals are galena, tetrahedrite, chalcopyrite, bournite, pyrite, and sphalerite. Some pyhrrotite contains gold; most of the silver is in tetrahedrite and galena.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary of Petrogenetic History of the Tiffany - Conconully Area

Original Materials

A strongly folded, variously metamorphosed, and partially granitised thick Paleozoic geosynclinal succession occurs east and southeast of the area mapped. Where no metasomatism occurs, the upper part of this succession consists of late Paleozoic thick argillites transformed to phyllites and biotite schists with intercalated actinolite-tremolite granulite and schist members in the lower part. The actinolite-tremolite rocks pass laterally into amphibolites and are mostly derived from impure dolomitic sediments. Thin bands of carbonates and quartzites are also present. Since the regional folding trends northwest, these sediments and their associated migmatitic rocks pass into the area mapped. Meta-volcanics, including meta-basalt, and meta-sediments higher in the late Paleozoic sequence occurring northeast and east of the area mapped are probably also represented in the present area.

I. Synkinematic Phase of Metamorphic History

A. Isochemical metamorphism - regional orogenic metamorphism producing schists and amphibolites, comprising two phases. Rocks increase in metamorphic grade from northeast to southwest and west.

(1) Early synkinematic phase - production of the initial foliation. Strong deformation. Minerals of progressive metamorphism.

(a) lime silicate rocks - lime silicate granulites of the high grade zone containing diopside, wollastonite, grossularite and vesuvianite; and lime silicate granulites of the cooler portion of the high grade zone and the warmer portion of the medium grade zone, i.e. of the katazonal-mesozonal passage interval, containing calcite, quartz, diopside, scapolite, and labradorite.

(b) amphibolites - amphibolites of the high and medium grade zones containing green hornblende, diopsidic augite, and labradorite to andesine. In cooler portion of medium grade zone, the plagioclase is andesine to oligoclase.

(c) argillites - micaschists and fine grained paragneisses. Essential minerals are biotite, garnet, and sillimanite in the high grade zone.

(2) Late synkinematic phase - Less intense deformation, folding of the earlier foliation. Partial deformation of garnet, development of fibrolite from biotite in micaschists (c) at slightly lower temperatures than existed at the time of (1).

B. Allochemical metamorphism - regional orogenic metasomatic metamorphism producing gneisses. The increase in metamorphic grade from the northeast to the southwest and west is paralleled by the increase in metasomatic transformation in the same direction, the former being dependant on the latter. The early (1) and late (2) phases are not readily separable. Sodium and silica metasomatism were predominant during most of the synkinematic phase while potassium was added in appreciable amounts only during the latest part of this phase.

(a) lime silicate rocks not noticeably affected. The presence of sodic plagioclase in high grade lime silicate rocks suggests addition of sodium; however this may have occurred during the post-kinematic phase (II).

(b) amphibolites - transformed, chiefly by the addition of sodium and silica, into hornblendic gneisses (b_g) comprising banded gneisses, flasergneisses, and augengneisses of dioritic, quartz-dioritic, and trondhjemitic composition. Where potassium has been added late in this stage, the gneisses become granodioritic in composition. Undisturbed relicts of original amphibolitic material often are preserved.

(c) argillites - transformed into biotitic gneisses (c_g) comprising biotite flasergneisses and gneissose trondhjemitic and granodioritic rocks. Undisturbed relicts of original micaschist material are locally preserved.

Most of these various migmatitic gneisses did undergo further changes during the postkinematic phase of metamorphism (II).

II Postkinematic Phase of Metamorphic History

The postkinematic phase was continuous with the synkinematic phase (I). It is characterized by the development of superimposed hornfelsic or granoblastic textures, and the departure of structures from the strict parallelism of the synkinematic phase. Weak recurrent deformation occurred locally during phase II.

A. Isochemical metamorphism

(1) Development of granoblastic fabric under slowly decreasing temperatures.

(a) lime silicate rocks - little change.

(b) amphibolites - static recrystallization.

(c) argillites - static recrystallization shown by mimetically recrystallized folds, helesitic structure, superimposed hornfelsic texture. Non-oriented staurolite, slightly later andalusite and oligoclase all later than fibrolite. Formation of andalusite in rocks which during the synkinematic phase had been in the cooler portion of the medium grade zone, shows that temperatures had become more nearly equal throughout the area.

(2) Temperatures decrease but a secondary peak of recrystallization occurs. Partly hydrothermal.

(a) lime silicate rocks - local porphyroblastic growth of epidote; hornblende forms from pyroxene.

(b) amphibolites - chlorite porphyroblasts in the lower grade amphibolites.

(c) argillites - first, sericite formed from andalusite and other minerals, then well crystallized muscovite formed during secondary peak of crystallization.

B. Allochemical metamorphism

(1) Earlier phase - Recrystallization and metasomatism under static conditions continuous with above (IB). Structures depart from parallelism. Development of granoblastic textures. Local recurrent weak deformation. Potassium introduction becomes dominant locally and its occurrence is controlled both by composition and structure. Metasomatic metamorphism during this period spread beyond the area affected by synkinematic metasomatism and reached rocks hitherto only isochemically metamorphosed.

(1') Transformation of previously not metasomatised rocks.

(a) lime silicate rocks were not affected.

(b) amphibolites - local introduction of sodium with minor amounts of potassium produced irregular replacement patches and streaks of dioritic and quartz-dioritic rock. In areas of abundant volatiles, coarse grained "pegmatitic" gabbroic and dioritic rocks were formed. Larger bodies of massive amphibolite which appear not to have undergone metasomatic metamorphism during the synkinematic phase were transformed by recrystallization and partial metasomatism into gabbroic, dioritic, and quartz-dioritic rocks (Tiffany complex) or where abundant potassium introduction has followed sodium introduction, granodioritic rock was formed (Fish Lake complex).

(c) argillites - Formation of oligoclase in mica-rich bands and streaks. Local development of irregular and cross-cutting replacement streaks and patches of trondhjemitic and granodioritic composition in micaschists and fine grained paragneisses. Local porphyroblastic growth of potash feldspar and muscovite. Local development of replacement pegmatite and aplite dikes.

(1') Further transformation of migmatitic gneisses.

(a) hornblendic gneisses (b_g, cf. above) - static recrystallization combined with continued metasomatism superimposed a granoblastic texture on the synkinematic hornblendic gneisses, weakening or in some cases almost obliterating the earlier gneissose structure. This was an unevenly selective process and in the migmatitic gneisses, bands of relatively more directionless dioritic, quartz-dioritic or even granodioritic rock are interbedded with bands of more gneissose rock. More profoundly transformed gneisses occur in the southwestern and western portion of the area. Development of irregular and cross-cutting features of replacement origin connected with potassium metasomatism; spread of potash feldspar porphyroblasts; formation of pegmatite and aplite patches and dikes. Early, dark, fine grained relatively basic dikes emplaced during this stage. Recurrent local differential deformation followed by the introduction of silica (Sinlahekin gneiss) or silica and potassium.

(b) argillite-derived gneisses (cg, cf. above) - superimposed static recrystallization and continued metasomatism producing more directionless trondhjemitic to granodioritic rocks. Subordinate in the area.

(2) Late static phase - continuous with II (1) and not readily distinguishable from it, but chiefly characterized by a more mobile behaviour of the rocks. Local brecciation and shearing simultaneous with further metasomatic replacement, as well as mobilization and intrusion of migmatitic materials of granodioritic and quartz-monzonitic composition. Final stage of formation and emplacement of large bodies of directionless granitoid rock (Fish Lake

complex, Thunder Mountain complex, and the Mineral Hill granodiorite) by continued metasomatism, mobilization and intrusion. Plastic reactions to long continued and brittle reactions to sudden stresses. Later dark, relatively basic dike invasion occurred during this stage.

III. Retrogressive Phase of Metamorphic History

Discontinuous with Phase II. Local post-crystalline deformation. Local low temperature hydrothermal alteration in all rocks. Some mineralization.

Conclusions

The principle purpose of the investigation was to determine the relationship of the late Paleozoic sequence in the Riverside-Conconully area with the batholithic-plutonic complex comprising the Okanogan Range in the Tiffany Mountain area. It has been shown that an extensive belt of migmatitic gneisses trending along Salmon Creek into the central portion of the range was formed from the Paleozoic geosynclinal rocks by synkinematic and postkinematic metasomatic metamorphism.

In the north and northwest part of the Salmon Creek belt, the migmatitic gneisses are predominantly hornblendic with inter-layered relict bands of amphibolite. A large body of quartz-dioritic gneiss (Sinlahekin gneiss) in the northern part of the area has formed from similar amphibolitic rocks.

A somewhat irregular line of discontinuity passes through the area in a northwest-southeast direction and separate the migmatitic gneisses comprising the Salmon Creek belt and the Sinlahekin gneiss to the east and northeast from a belt of directionless granitoid bodies of less certain derivation to the west and southwest. Some of these granitoid bodies have formed through recrystallization, partial metasomatism, and possible mobilization from massive amphibolitic rocks which may be stratigraphically equivalent to metavolcanics higher in the late Paleozoic sequence; others represent intrusive bodies of either magmatic or migmatitic derivation.

The line of discontinuity bordering these directionless rocks on the east and northeast appears to play a significant part in controlling the position of the large bodies of directionless granitoid rock in the area. This line appears to be structurally controlled, and probably was originally a major pre-granitic to early-granitic cross-cutting fault zone. Secondary pre-granitic faults at right angles to this line appear to be locally important in determining the boundaries of some of the directionless granitoid bodies, as for example, in the Mineral Hill, Funk Mountain, Fish Lake areas. The structural control of small granitoid replacement and intrusive bodies in the migmatitic gneisses and the micaschists is thus duplicated on a regional scale.

In the western and southwestern portion of the area, an extensive complex of gneissose and directionless granitoid rocks displays structural and petrographic features indicating a migmatitic origin. It appears to be in large part derived from amphibolitic rocks.

The Okanogan Range in the Tiffany Mountain area, has been shown to comprise a highly heterogeneous batholithic-plutonic complex composed of rocks in large part of metamorphic-migmatitic derivation.

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