ETROLOGY AND RECONNAISSANCE GEOLOGY OF THE SNOWKING AREA, NORTHERN CASCADES, WASHINGTON

by

BRUCE HAZELTON BRYANT

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ABSTRACT

The Snowking area is located in the western marginal portion of the metamorphic-plutonic belt occupying most of the northern Cascades which belong in the western part of the Cordilleran eugeosyncline.

The area consists of a central core of gneissose and directionless granitic rock bordered on three sides by schistose metamorphic rocks. To the south of the core is a discontinuous band of migmatites. South of the migmatites occur mica schists and amphibolites. West of the granitic core is a belt of greenschists, glaucophane and crossite schists, and phyllites separated from the core and the migmatites, mica schists, and amphibolites by a fault. North of the core occurs a narrow band of amphibolites, quartzitic schists, and mesozonally metamorphosed quartz diorite. This band widens eastward. Farther north is a band of epizonally metamorphosed quartz diorite, greenschists, and phyllites, which extends as a tongue from the west almost to the northeastern corner of the area. The northern and western belts of greenschists and phyllites are contiguous.

The pre-metamorphic sediments consisted of shales, greywackes, calcareous and dolomitic greywackes, and their mixtures. Pure argillites, carbonate rocks and quartzites were rare. Intermediate and basic volcanics occurred both as flows and pyroclastic deposits. Mixtures between pyroclastic rock and sedimentary rock were common. Quartz diorite and possibly ultrabasic bodies intruded the rocks of the geosyncline before metamorphism.

In the epizone intermediate and basic volcanic rocks have been metamorphosed to greenschists, greenstones, crossite schists, and glaucophane schists. Greenstone and greenschist contain the minerals assemblage

albite, epidote, chlorite, actinolite and quartz. The crossite and glaucophane schists have the same minerals with the addition of crossite, glaucophane, and sodic actinolite. Argillites and silt-sized greywackes have been metamorphosed to phyllites containing chlorite, sericite, albite, quartz, and stilpnomelane. These assemblages are characteristic of the greenschist facies and the chlorite zone.

Metamorphism of the earlier quartz diorite has produced the following new mineral assemblages: andesine to sodic oligoclase, hornblende, biotite, and epidote in the mesozone; albite, epidote, sericite, and chlorite in the epizone.

Ultrabasic intrusive bodies occurring in both the epizonal and mesozonal rocks were partially altered to serpentine and talc. These minerals indicate the ultrabasic bodies were only epizonally metamorphosed. Therefore, those intrusives occurring in the mesozonal rocks must have been emplaced or altered in late-metamorphic time.

In the region of mesozonal metamorphism shales were altered to garnet-biotite schists containing rare kyanite and staurolite, and where the shales were calcareous, the biotite schists contain zoisite, clinozoisite or epidote. Dolomitic shales, partly with tuffaceous or greywacke components were altered to hornblende-biotite schists and para-amphibolites, usually with zoisite and epidote. More strongly dolomitic-calcareous layers became lime silicate bands, partly containing diopside with contemporaneous epidote. Volcanics were metamorphosed to plagioclase-rich ortho-amphibolites, many with epidote or clinozoisite. Nearly all these rocks contain sodic andesine. With regard to metamorphic grade, the occurrence of contemporaneous diopside and epidote, as well as the association epidote-zoisite and andesine are critical, indicating the upper limit of the epidote amphibolite facies or the warmer part of the kyanite zone. (P. Misch, unpublished MS; 1954).

In a narrow schist zone within the granitic massif, argillite-derived mica schists contain sillimanite, which is indicative of metamorphism at katazonal temperatures.

A discontinuous band of migmatitic schist and gneiss occurs between the mesozonally metamorphosed rocks occurring in the southern part of the area and granitic rocks comprising the Snowking massif. Patches of migmatite are found outside this band also. The migmatites consist mostly of hornblende quartz dioritic gneiss with lesser amounts of biotite quartz dioritic and granodioritic gneiss. They contain numerous intercalcations of amphibolite and a few of quartzite.

The central portion of the area is occupied by a complex plutonic body of hypersthene diorite, diorite, quartz diorite, trondhjemite, granodiorite and quartz monzonite. In these rocks plagioclase varies in composition from oligoclase to labradorite. Potash feldspar is usually microcline. Mafics are biotite and hornblende. The distribution of rock types in the massif is not systematic. Some areas contain relatively homogeneous rocks; others contain highly heterogeneous rocks.

Structurally the rocks of the Snowking Mountain include gneiss, directionless granitic rock, and breccia. Texturally they comprise granoblastic cataclastic, and igneous varieties. No correlation exists between mineral composition and textures or structures.

The hypersthene diorite is a pre-orogenic intrusion which has locally escaped metamorphism.

The granitic rocks are interpreted as having been formed at least in part by allochemical metamorphism of the country rocks. In some areas complicated plutonic processes, such as cataclasis, liquefaction, mobilization, and recrystallization have obscured the early history of the granitic rocks.

The northwestern portion of the Snowking massif has intruded the adjacent valley schist zone.

The marginal part of a post-metamorphic intrusive trondhjemite body was mapped in the southeastern corner of the area.

Basalt, andesite, microdiorite, and dacitic porphyry intrusive dikes occur in the schists south of the Snowking massif. Basalt, andesite, and microdiorite dikes are found in portions of the Snowking massif, and they may in part by syn-metamorphic.

Glacial erosion has been the dominant process shaping the landforms of the area. A few small glaciers are still active.

PETROLOGY AND RECONNAISSANCE GEOLOGY

OF THE SNOWKING AREA,

NORTHERN CASCADES, WASHINGTON

INTRODUCTION

Location and Access

The Snowking area is located west of the Cascade crest seventy miles northeast of Seattle, Washington. It lies east of the Sauk River and between the Cascade and Skagit Rivers on the north and the Suiattle River on the south.

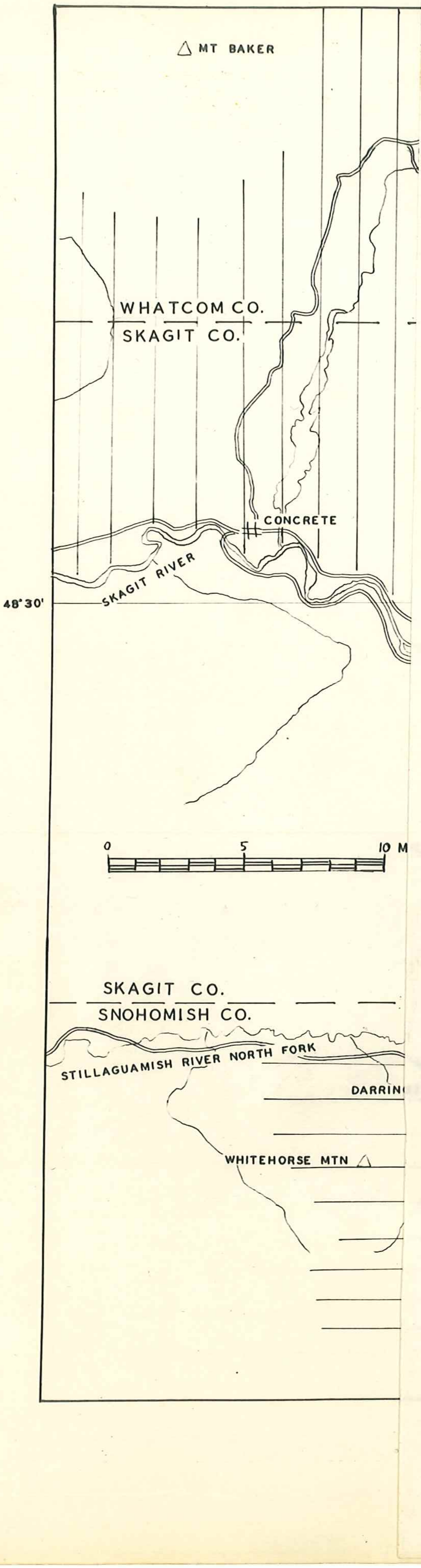
The Snowking area covers about 280 square miles and includes the northwestern third of the old (1901) United States Geological Survey Glacier Peak 30 minute quadrangle, a small area along the southern margin of the Marblemount 15 minute quadrangle, and a small area in the northeastern portion of the Stillaguamish 30 minute quadrangle. It lies in the Skagit and Suiattle districts of the Mt. Baker National Forest and is covered by more recent maps, which show more lakes and roads than the old quadrangles. However, in many places the Forest Service maps are less accurate with regard to minor drainage than the quadrangles. Aerial photographs cover a narrow strip along the northern border of the area, and some poor aerial photographs taken in June 1949, a year of heavy snowfall, are available for the area west of Illabot Lake. For several years the Forest Service has been planning to photograph the rest of the area.

State highway 17a furnishes access to the northern part of the area through the villages of Rockport and Marblemount on the Skagit River. Marblemount is 110 miles from Seattle by road. From Marblemount a road extends up the north side of the Cascade River valley to within a mile and a half of Cascade Pass. The Cascade River may be crossed by a bridge at Marblemount and by footlogs at Marble Creek and Kindy Creek. At Rockport, which is 8 miles west of Marblemount, a ferry crosses the Skagit River.

The southern portion of the Snowking area is approached from Darrington via a road along the east side of the Sauk River and up the Suiattle River valley. The road up the Suiattle River valley extends to opposite Milk Creek, which is beyond the eastern margin of the area. A road follows the east bank of the Sauk River.

Within the area virgin timber is being logged in the mountain valleys and on the adjacent slopes, and in the future logging roads will provide better access to the high country. At present logging roads extend up to about 3500 feet elevation on the south side of Suiattle Mountain, the Illabot Creek-Sauk River divide, the Illabot Creek-Jordan Creek ridge, and the north side of Razor Back Mountain. Old logging roads reach the falls at 3000 feet elevation on Jordan Creek and up to 1500 feet elevation on Boulder Creek. Logging is in progress at about 2000 feet elevation on Grade Creek. An extensive area from the Skagit River up to 2500 feet elevation in the northwestern part of the area has been logged. Besides furnishing access and outcrop, logging roads help one locate outcrops in the forested country, providing recent aerial photographs are available.

No roads or trails pass through the area. Several trails built during the 1930's have been abandoned, though they are still shown on the Forest Service map. In some places they are still usable. Trails up Razor Back, Green, and Huckleberry Mountains give access to the high country. Fishermen's trails lead to Illabot and Jordan Lakes. The first two miles of Irene way and four miles of Kindy way have been maintained. A good trail extends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WHITEHORSE MTN

seven miles up the Downey Creek valley, and from its end a fishermen's trail leads to Bench Lake.

Topography and Exposures

Altitudes in the Snowking area range from 240 feet at the Skagit River near Rockport to 7385 feet on the summit of Snowking Mountain. The Cascade and Suiattle Rivers lie in very deep troughs. At Kindy Creek at the northeastern corner of the area, the Cascade River is at only 1200 feet elevation, and at Downey Creek near the southeastern margin of the area the Suiattle River is 1400 feet above sea level. The larger creeks lie in deep glacial troughs which head in cirques at between 2500 and 3000 feet elevation directly below the highest ridges. The ridges tend to be quite continuous and have a maximum relief of 2000 feet along their crests. Slopes are steep to very steep except in the northwestern portion of the area, in which they are moderate. Cliffs are numerous, both on the ridges, which in many places are aretes, and the sides of the glacial troughs.

Exposures on the high ridges are good, especially on their north sides where, in a few localities, they have been recently glaciated. However, some rather high, forested ridges, even above 5000 feet elevation, have amazingly few outcrops, and the same applies to steep, densely wooded valley sides.

Previous Work

No geologic work has been done in the Snowking area except for a few early reconnaissance surveys that touched the margins of the area.

In 1898 I. C. Russell came down the Sauk River from White Pass, went up the Cascade River to Cascade Pass and back, and went up the Skagit River

PLATE II

Fig. 1 View looking northwest from the southernmost peak of Buckindy. Mt. Chaval on the left; Snowking on the right; Mt. Baker in the right background.

Fig. 2 View from a 6400 foot summit between Irene and Found Creeks. Mt. Chaval on the left; the 6375 foot peak at the head of Boulder Creek on the right.

to Hart's Pass. His reconnaissance map shows greenstone along the Sauk River in the Snowking area, schists in the valley of the Cascade River all the way to Cascade Pass, and a patch of granite in the vicinity of Jordan Lakes.

In 1901 G. O. Smith and F. C. Calkins made a traverse from Windy Pass on the Cascade crest two miles north of the present settlement of Barron down Canyon Creek and Ruby Creek, an eastern tributary of the Skagit River, and down the Skagit River. They described some altered pyroxene andesites from Sauk Mountain across the Skagit valley from the northwestern corner of the area, and some specimens of glaucophane schist from the south side of the Skagit valley and farther west (opposite Hamilton).

In 1936 the State of Washington published a preliminary geologic map of the state. The picture of the geology of the Snowking area given in that map is highly generalized and far from correct. No sources for this mapping are given in the bibliography in the bulletin published with the map.

During the past few seasons a United States Geological Survey party has been mapping the Holden 15 minute quadrangle, which is adjacent to the southeastern quarter of the 30 minute Glacier Peak quadrangle and some distance southeast of the present area.

Since 1949 Peter Misch has been studying the geology from the Cascade and Skagit Rivers north to the Canadian border. This area is immediately adjacent to the one described in this report. A preliminary report on the area appeared as a popular article in the "Mountaineer" in 1952. A paper presented at the meeting of the Cordilleran section of the Geological Society of America treated the evolution of the granitic rocks (1952b).

South of the Suiattle River west of Lime Creek Joseph A. Vance has

PLATE III

Fig. 1 The north face of Buckindy from east of Kindy Creek.

Fig. 2 Snowking Mountain from the north-east. Mt. Chaval in the right background.

been mapping the geology for a University of Washington PhD thesis. The results of his study of the glaucophane schists in that area were presented at the 1954 meeting of the Cordilleran section of the Geological Society of America.

At the same meeting the author presented a preliminary report on metamorphism in the Snowking area (1954).

Statement of Purpose

This investigation is part of a project to map the geology of the northern Cascades started in 1949 by Peter Misch. The Snowking area fills a gap between the areas being studied by Misch to the north and Vance to the south.

The specific purpose of this investigation was to map the geology of an unknown area and through field observations and petrographic study to determine the origin of and relations between the metamorphic and granitic rocks occurring there.

Two specific regional structural problems were posed. The first was to find out what happens to the Straight Creek fault, which has first been observed by Joseph A. Vance south of the Snowking area, but which Peter Misch has found to be absent north of the Skagit River. The second was to determine the relationship of the Snowking granitic massif and the adjacent mesozonal metamorphic rocks to the epizonal and non-metamorphic rocks which occur to the northwest along the regional structural trend along the Skagit valley, and to the lower grade metamorphic rocks which occur to the north along the Cascade River.

PLATE IV

Fig. 1 The Cascade River valley, a glacial trough along the northern margin of the Snowking area.

Fig. 2 Typical upper part of a larger creek valley in the Snowking area. (The upper Illabot Creek valley from the ridge east of Arrow Creek.)

Field and Laboratory Work

Field work was done during the summers of 1952 and 1953 and in September 1954. A total of about 14 weeks was spent in the field. The topographic and Forest Service maps were used for location and plotting in the field. Where aerial photographic coverage was available, the photographs were found useful, especially where numerous logging roads occurred. Each attitude was plotted in the office on a Forest Service map enlarged to a scale of 1:31,000. Most of the ridges were traversed. Since even under the best conditions, so much time was spent just traveling, no effort was made to visit the inaccessible valley heads. It was deemed best to concentrate on the ridges where a maximum of information is available for the amount of back packing and brush fighting involved.

About 730 thin sections were made and studied at the University of Washington laboratory.

Acknowledgments

The writer would like to thank Richard C. Hubley, Anton W. Engle, and A. Robert Grant, who each accompanied him in the field for about a week.

The writer is indebted to Dr. Peter Misch of the Geology Department of the University of Washington, who introduced him to the problem in the field and gave generously of his time in supervising the petrographic study and writing of this thesis. The writer also thanks Dr. Howard A. Coombs, Professor G. E. Goodspeed, and Dr. J. Hoover Mackin for reading the manuscript and offering their suggestions.

The author was helped greatly by discussions on mutual geologic problems with Peter Misch, who is mapping north of the Snowking area, and Joseph A. Vance, who is mapping the area to the south.

For typing the last two drafts of this thesis, the author is grateful to his wife, Sandy.

OUTLINE OF REGIONAL AND LOCAL GEOLOGY

Regional Geologic Setting

The Snowking area is located in a belt of metamorphic and plutonic rocks which occupy a portion of the Cordilleran eugeosyncline. This belt extends in width all the way from the western Cascades to the eastern boundary of Washington. The western part of this belt makes up the northern high Cascades (Misch, 1952a). The Snowking area lies on the western margin of the zone of medium and high grade metamorphism and associated granitization which occupies the northern high Cascades west of Pasayten Creek. To the west all the known pre-orogenic rocks have been subjected to only epizonal metamorphism, and in some places they have not been metamorphosed at all. The western portion of the zone of granitic and high grade metamorphic rocks extends to the Canadian border to the north. It is covered by younger rocks in the vicinity of Snoqualmie Pass 60 miles to the south (Smith and Calkins, 1906; Smith, 1904). This zone of metamorphic rocks continues for 60 miles to the southeast, beyond which it is overlain by the Columbia River basalts. About 40 miles to the northeast of the Snowking area it is interrupted by generally unmetamorphosed Cretaceous sediments which extend northward into Canada. (Daly, 1912; Rice, 1947; Barksdale, 1948; Misch, 1952).

Outline of Geology in the Areas Adjacent to the Snowking Area on the North and South

North of the Snowking area Peter Misch has found migmatitic gneiss on the east (Skagit gneiss) that grades into directionless granodiorite on the west (Chilliwack granodiorite) (1952a, pp 13-16). The Chilliwack granodiorite moved upward and westward and intruded epizonally metamorphosed rocks along its western margin. To the south near the Snowking area, the Chilliwack intruded mesozonal rocks. Texturally the rock of this granitic zone grades from metamorphic in the Skagit gneiss and the eastern portion of the Chilliwack granodiorite to igneous in the western portion of the Chilliwack granodiorite (Misch, 1952a, pp 15-16). In places the Chilliwack occurs as small igneous intrusions west of the main body (Misch, 1952a, p. 16).

Peter Misch has also mapped a zone of epizonal and mesozonal schist in the Cascade River valley directly adjacent to the Snowking area. Northeast and east of the village of Marblemount at the mouth of the Cascade River he has found a pre-orogenic quartz diorite (Marblemount quartz diorite) in this zone (1952a, p. 12). At Marblemount the north side of the Skagit valley is in greenschists, crossite schists, glaucophane schists, and phyllites, whereas to the west the northern side of the valley is in unmetamorphosed volcanics associated with partly metamorphosed sediments (immediately west of Marblemount, Sauk Mountain, Concrete) (1952a, map p.4; personal communication).

South of the Snowking area and west of Lime Creek, a southern tributary of the Suiattle River, Joseph A. Vance has found migmatitic schist and gneiss east of Straight Creek, and epizonally metamorphosed volcanics with some sedimentary intercalations (Whitechuck unit), epizonally metamorphosed sediments (Gold Hill phyllite), and a sequence of only slightly metamorphosed volcanics and sediments (Whitehorse unit) west of Straight Creek (personal communication). A reverse fault (the Straight Creek fault) separates the low grade rocks from the migmatites. On the northern ridge of Prairie Mountain just south of the Snowking area preliminary field observations indicate that the Whitechuck unit and the Gold Hill phyllites are thrust over the Whitehorse unit (Vance, personal communication).

Outline of the Geology of the Snowking Area

In the Snowking area unmetamorphosed or only very slightly metamorphosed rocks are almost absent. They occur at only a few places at the western margin of the area, namely along the eastern Sauk River road south of the bridge across the lower Sauk River. These rocks can probably be correlated with Vance's Whitehorse unit.

Epizonally metamorphosed rocks occupy a belt in the western part of the area and another belt in its northern part. These two belts join south of Marblemount. Epizonal rocks crop out west of Grade and Bluebell Creeks (Whitechuck unit) and in a long tongue extending up the Cascade River valley almost to Kindy Creek (epizonal portion of the Cascade valley schist zone). These units consist mainly of greenschist, greenstone, crossite schist, glaucophane schist, and phyllite.

Mesozonally metamorphosed, but not granitized, rocks occur in a belt in the southern portion of the area along the Suiattle River and the ridges to the north (Green Mountain unit). They are also found along the northern margin of a granitic massif south of the Cascade River in a band 1/4 mile wide, which broadens east of the head of Irene Creek (mesozonal portion of the Cascade valley schist zone). Another zone of mesozonally metamorphosed rocks occurs in the northwestern part of the area in the Illabot Creek valley between two portions of the granitic massif. The mesozonal rocks consist of mica schists, ortho-amphibolites, para-amphibolites, hornblende-biotite schists, and various other rock types.

Several pre-orogenic intrusive bodies occur in the epizonally and mesozonally metamorphosed rocks. The Marblemount quartz diorite mentioned above extends into the Snowking area and is found in both the epizonal and mesozonal portions of the Cascade valley schist zone. An ultrabasic body also occurs in the Cascade valley schist zone (Jordan ridge serpentine).

Other smaller ultrabasic intrusives are found in both the Cascade valley schist zone and the Green Mountain unit. Some of them may be late-orogenic rather than pre-orogenic intrusions.

Katazonally metamorphosed rocks occur in a zone a few hundred yards wide on the ridge between Snowking Mountain and Mt. Chaval.

Typically heterogeneous migmatites occur between the Green Mountain unit and a granitic complex (the Snowking massif) to the north. However, they do not form a completely continuous belt.

The Snowking massif, a complex plutonic body, occupies the central portion of the area and extends an unknown distance to the east. It is subdivided into units of rocks which are related in genesis, but varied in composition. The main rock types constituting the massif are quartz diorite, diorite, trondhjemite, and granodiorite, and minor types are quartz monzonite, granite, and hypersthene diorite.

On Downey Mountain near the southeastern corner of the area a small portion of an intrusive trondhjemite body was mapped.

Dacitic porphyry dikes occur throughout the Green Mountain unit. Basalt, andesite, and microdiorite dikes crop out in the Green Mountain unit and portions of the Snowking massif.

PETROLOGY

General Statement

The metamorphic rocks of the Snowking area are described in order of increasing metamorphism and metasomatism. Pre-orogenic igneous rocks are treated as a part of the metamorphic units in which they occur.

The granitic rocks of the Snowking massif are believed to be the products of metamorphic processes, which in some places have culminated in the final generation of rocks of igneous character. This complex rock assemblage cannot easily be treated in terms of traditional systematic igneous petrology. For instance, all the rocks of granodioritic composition cannot be discussed in one chapter because their distribution is irregular and patch, and they display a variety of textures and have varying histories. For purposes of description and discussion the Snowking massif has been divided into six component units. Each of these units contains rocks of variable mineral composition, but of roughly similar, or at least closely related history and origin. These units do not always have sharp boundaries, and they overlap considerably. Their delineation has been partly influenced by the spacing of traverses and the lack of outcrops in parts of some of the traverses.

Post-orogenic intrusive rocks are treated separately, although they may, at least in part, be genetically related to earlier igneous and metamorphic rocks.

In each chapter a general description is given first as far as the rocks under discussion have common characteristics, and then individual outcrops and specimens are described. In some units few generalizations can be made. The author thought it best to describe the specimens in words rather than treat them in tables, in order to emphasize the relationships between minerals and to establish the history of the rocks. Despite the many descriptions, only a minority of the 730 rocks studied are mentioned.

Isochemically Metamorphosed Rocks

Epizonally Metamorphosed Sediments and Volcanics

Incompletely Metamorphosed Volcanics

At the bridge across White Creek on the eastern Sauk River road and where the second stream east of the old Suiattle Mountain trail crosses the road north of the Suiattle River, incompletely metamorphosed volcanics and associated sediments crop out. They are also found on a logging road on the lower south side of the Grade Creek-Suiattle River ridge about 1 1/4 miles from where the northern Suiattle River road crosses Big Creek and about 1/6 mile up the hill.

At White Creek the outcrop appears to be a massive greenstone with thin bedding in a few places. In thin section the rocks are in part very fine grained so that their composition is uncertain. Specimen B-16-2-a contains hornblende in small[1], haphazardly oriented, anhedral to subhedral crystals with an extinction angle Z C 18° and a pleochrism Z green, Y light green, and X tan. Aggregates of small pumpellyite grains make up 35% of the rock. Quartz (10%) tends to occur in narrow veinlets .2 mm. wide. The rest of the rock is made up of heavily kaolinized plagioclase and some cryptocrystalline aggregates of feldspar (?) that might be devitrified glass. Green penninite and pyrite are accessories. This rock is probably metavolcanic.

Specimen B-16-2-b from the same locality contains 10% very heavily

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[1] The terms small, medium and large used in this paper are defined: small - up to .66 mm.; medium .66 mm. to 1.7 mm.; large more than 1.7 mm.

kaolinized plagioclase that appears to have been crushed. Its grain outlines suggest altered phenocrysts. Pumpellyite (10%) forms aggregates of small crystals. Serpentine amounts to about 10% of the rock. Quartz is present in a veinlet and a few scattered grains. The main part of the rock (65%) consists of cryptocrystalline and microcrystalline aggregates which seem to be recrystallized volcanic glass. Apatite and opaque minerals are accessories. This rock appears to be an intermediate volcanic that has undergone cataclassis and hydrothermal alteration.

A third specimen from White Creek (B-16-2-c) consists of 65% anhedral to subhedral medium sized to large plagioclase grains heavily altered to sericite, kaolinite, and clinozoisite; what is left of the feldspar is albite. The rock contains 15% large to small, xenoblastic to hypidioblastic epidote grains. Green penninite makes up 15% of the rock. Quartz (5%) consists of xenoblastic crystals with sutured borders, which suggest that some recrystallization took place during metamorphism. Magnetite is an accessory. This rock might be derived from a tuffaceous arkose.

None of these specimens show the complete recrystallization necessary to produce a true greenschist or a fully reconstituted greenstone. Specimen b has the lowest grade aspect because it contains hardly any identifiable metamorphic mineral grains. Specimen c contains some well formed epidote and chlorite, but the plagioclase has not been recrystallized. Specimen a has the rather anomalous association of hornblende with an otherwise epizonal mineral assemblage and areas of incompletely metamorphosed material. There is no clue as to whether this hornblende represents a late magmatic alteration in the development of the original igneous rock, or whether it formed during the extremely low grade hydrothermal metamorphism.

At the second locality on the eastern Sauk River road three specimens of slightly metamorphosed volcanic rocks were collected. Specimen B-17-1-a contains 30% pumpellyite in the usual fine grained aggregates. Plagioclase (20%) occurs as a few large altered phenocrysts and abundantly as small grains in the groundmass (30%), which is probably altered volcanic glass. Light green penninite makes up 10% of the rock. A zeolite occurring as radiating aggregates filling rounded amygdules constitutes 10% of the rock. Stilpnomelane, calcite, and magnetite complete the rock.

Specimen B-17-1-b contains 80% pumpellyite derived largely from plagioclase (5%) and in part filling rounded amygdules. Small to large, xenoblastic quartz grains (10%) are strongly strained. Carbonate (5%) occurs mainly in fractures, although some is associated with pumpellyite and probably also derived from plagioclase. A sharp movement plane accompanied by mylonite passes through the specimen.

Specimen c contains 10% light green antigorite filling amygdules. Pumpellyite (15%) appears to be derived from plagioclase (10%). Sericite (5%) is also from plagioclase. Fine grained groundmass, in part brown colored, may be altered glass. Quartz occurs in a narrow veinlet. An unaltered monoclinic pyroxene grain is present. It is difficult to tell whether the plagioclase was originally present as phenocrysts or crystal fragments.

All three of these specimens display a lack of penetrative deformation and a lack of much constructive metamorphism. The new minerals formed appear mainly as hydrothermal alteration products localized within the boundaries of the parent pre-existing minerals, rather than as newly formed crystals capable in their own right of giving the rock a distinctly metamorphic texture.

On the lower south side of the Suiattle River-Grade Creek ridge is a metavolcanic breccia (specimen B-22-3-a) containing 25% albite, which occurs as altered plagioclase fragments and as fresh, recrystallized grains in amygdules and veinlets. Pumpellyite (30%) fills some amygdules and is an alteration product of plagioclase. A chlorite with abnormal interference colors and positive elongation (a variety of penninite ?) makes up 10% of the rock and fills fractures, sometimes accompanied by albite. Altered glass (?) (35%) composes most of the rest of the rock, while quartz, stilpnomelane, carbonate, and opaque minerals are accessories. The section has numerous narrow zones of mylonite, but the rock has not been thoroughly recrystallized.

Although the rocks discussed above superficially resemble fully metamorphosed volcanics of the epizone, they are actually characterized by a lack of metamorphic texture and structure compared to the normal greenschists and fully reconstituted greenstones. In the little metamorphosed rocks some volcanic features, such as amygdules and some of the original porphyritic texture, are preserved. The preservation of such features is due to a lack of more complete recrystallization. The old crystals have been altered to new minerals, but the new minerals formed have tended to remain within the parent grains rather than form at new locations.

These scattered occurrences of little metamorphosed rocks may represent part of a unit of little metamorphosed rocks which occurs on Whitehorse Mountain southwest of the present area and also on the lower part of Prairie Mountain ("Whitehorse unit" of Joseph A. Vance). Also slightly metamorphosed rocks occur on the west side side of the lowest Sauk River west of the present area, but no study has been made of them. East of and topographically higher than the incompletely metamorphosed rocks described above, there is the belt of greenschist, crossite schist, glaucophane schist, and phyllite described below. This belt continues south across the lowest Suiattle River into the area being studied by J. A. Vance, who has named it the "Whitechuck unit". There, on Prairie Mountain the "Whitechuck unit" is thrust over the "Whitehorse unit" (J. A. Vance, personal communication). To the north of the present area on the north side of the Skagit River epizonally fully metamorphosed rocks near Marblemount have an undetermined relationship with little metamorphosed rocks immediately to the west (Peter Misch, personal communication). Other outcrops found at the lowest possible elevation on the valley along the east side of the Sauk River and the north side of the Suiattle River in the Snowking area consist of definitely epizonal rocks. Lack of exposures precludes any decision on the relationship between these two units in the Snowking area.

Epizonally Metamorphosed Sediments and Volcanics ("Whitechuck unit" and Epizonal Part of the Cascade Valley Schist Zone)

General Statement

Epizonally metamorphosed sediments and volcanics occupy the western part of the area from the Sauk River east to Grade and Bluebell Creeks, and the northern part south of the Skagit River and the lowest Cascade River. From the ridge north of Illabot Creek the northern belt parallels the border of the Snowking massif, from which it is separated by a band of mesozonal rocks less than 1/4 mile wide. Epizonally metamorphosed Marblemount quartz diorite (see Chapter IIIB2a below) occurs in the northern belt from Boulder Creek to the east. A small slice of epizonally metamorphosed sediment occurs south of the Cascade River opposite Marble Creek.

Tentatively these rocks, except for the Marblemount quartz diorite and the rocks on the Jordan Creek-Boulder Creek ridge, have been assigned to the "Whitechuck unit" proposed by Joseph A. Vance for the group of greenschists, and glaucophane schists with a minor amount of phyllite well exposed on Whitechuck Mountain south of the Snowking area. The western belt of these rocks encountered east of the Sauk River is the direct continuation of Vance's "Whitechuck unit".

In the Snowking area this unit is composed dominantly of greenschists, crossite schists, and glaucophane schists, but it contains considerable phyllite. Minor amounts of only very weakly metamorphosed arkose and of quartzite and chert occur. Whether the arkose belongs to this unit is not certain.

Apart from a large serpentine body and the Marblemount quartz diorite, the epizonal portion of the Cascade valley schist zone consists of phyllite.

Greenschists, Greenstones, Crossite Schists, and Glaucophane Schists

Except on the Jordan Creek-Boulder Creek spur, greenschist, greenstone, crossite schist, and glaucophane schist make up most of the outcrop throughout the area of epizonally metamorphosed rocks. They are especially well exposed on cliffs on the east side of the Sauk River north of White Creek and on the Illabot Peaks.

The greenstones and greenschists contain 10 to 60% epidote (average 30%), 0 to 45% chlorite (average less than 10%), 0 to 25% quartz (average 10%), 5 to 45% albite (average 20%), and 0 to 60% actinolite (average 30%). Occasionally the amphibole is tremolitic. Glaucophane and crossite (up to 10%) and sodic actinolite (up to 45%) may occur. Accessories are carbonate (up to 15%), muscovite and sericite (up to 10%), sphene, stilpnomelane, pyrite, and magnetite.

The epidote is generally pistacite and quite often tends to form segregation lenses, bands, or pods. Also it commonly is subhedral in shape.

Chlorite is usually green penninite, often with very low birefringence. It fills in around the epidote crystals.

Quartz and albite are sometimes concentrated in segregation lenses or bands. Often the whole rock is banded, with quartz and albite-rich layers, and with epidote, actinolite and chlorite-rich bands. The scarcity of twinning in the albite makes it difficult to obtain very precise determinations of its composition. The composition as determined from the few favorable grains found varies throughout the albite range. In some rocks the albite forms small porphyroblasts. In a few localities the quartz and albite occurs in lenticular aggregates suggesting altered phenocrysts. This is quite common in the rocks in the eastern part of section 24, T. 35 N., R. 10 E. and the western part of section 19, T. 35 N., R. 11 E. on the logged slope facing the Skagit River west of Jordan Creek. The amphibole is mainly responsible for the folitaion in the rocks, for it is usually well aligned. Although most of the amphibole is true actinolite, some has pale absorption and $Z \wedge C = 20^{\circ}$. The extinction angle is that of tremolite, but the presence of absorption suggests it might be some other amphibole.

Stilpnomelane is sometimes synkinematic and sometimes post-kinematic; the latter may form radiating aggregates.

The rocks often have fractures filled with carbonate, quartz, and stilpnomelane. Carbonate especially tends to occur in fractures.

The blue amphibole-bearing schists contain 5 to 45% crossite (average 15%), 0 to 15% glaucophane (average 5%), 0 to 30% sodic actinolite (average 10%), 0 to 5% actinolite, 25 to 70% epidote (average 45%), 0 to 20% chlorite (average less than 10%) and an average of 10% quartz and 10% albite (combined quartz and albite amounts range from less than 5% to 30%).

Crossite often is intergrown with and intergrades with actinolite or glaucophane. Specimen A-20-1-a from an outcrop beside the northern Suiattle road contains a segregation band of crossite 1 mm. wide. The crystals in that band are unusually large for these rocks and measure up to .75 mm. in length. Many of them have narrow glaucophane rims. Some are rimmed by sodic actinolite or actinolite. No blue amphiboles occur outside this band.

Many rocks contain amphibole with a light blue or greenish blue absorption for Z. This amphibole is probably a sodic actinolite, and all gradations occur between actinolite and crossite and actinolite and glaucophane. Even a few amphiboles with a rather pale blue absorption display the crossite orientation. Many rocks called glaucophane schist in the field contain large quantities of sodic actinolite rather than true crossite or glaucophane.

Glaucophane occurs in the schists with crossite, but in none of the specimens studied was it the only blue amphibole, whereas several specimens contain crossite to the exclusion of glaucophane. Practically all the blue amphibole-bearing schists studied contain significant quantities of sodic actinolite and actinolite. One exception, however, is specimen D-9-1-b from the first slide west of Bluebell Creek on the south side of the Illabot Creek valley. This rock contains a relatively pure crossite and lacks actinolite or sodic actinolite.

The crossite and glaucophane schists differ little from the greenschists except for a higher epidote and a lower albite content. The blue amphibolies are often concentrated in bands. Sometimes for no apparent reason blue amphibole occurs in just one band in a given thin section. Thus there are all gradations from greenschists through crossite and glaucophane-bearing greenschist containing less than 10% blue amphibole to crossite and glaucophane-crossite schists.

Some rocks differ from the types mentioned above. At one locality on the south side of Suiattle Mountain the greenschist contains 15 to 25% very fine grained pumpellyite that tends to be in bands and knots (specimens B-28-2-a&b). In overall mineralogical aspect these rocks do not differ from ordinary greenschists, for they contain the usual epidote, albite, chlorite, and quartz with accessory sphene. Pumpellyite substitutes for part of the epidote. The main differences between the two specimens, which were collected from the same outcrop, is that specimen b contains 45% tremolitic (?) amphibole with Z∧C=18°, and specimen a has only accessory actinolite. Specimen a has about 35% quartz, while b has very little.

Specimen A-43-3 from the northwest part of the area contains 60% epidote, 25% albite, 15% quartz, and only minor chlorite. The quartz and albite are concentrated in bands. This rock must have lacked the magnesium necessary for the formation of much chlorite, while still having the iron, aluminum, and calcium to produce all the epidote.

Specimen D-9-1-c from the southwest side of the Illabot Creek trough west of Bluebell Creek is a tremolite epidote schist containing 50% rather iron-poor epidote, 30% tremolitic (?) amphibole, 15% quartz, 5% albite, and accessory light green clinochlore, muscovite, carbonate, and pyrite. The amphibole has Z∧C=20° yet shows some weak pleochrism: Z=light greenish, Y=colorless, and X=colorless. The quartz and plagioclase tend to be in bands. This rock is quite iron poor.

Specimen D-10-3 from about 3500 feet elevation on the ridge between Illabot Creek and the Sauk River is a chlorite amphibole schist. It contains 60% tremolitic (?) amphibole, 10% chlorite, 30% plagioclase and quartz, and accessory iron-poor epidote, sphene, and opaque minerals. The amphibole has Z∧C=20° and weak absorption. It is in small anhedral to euhedral crystals, and chlorite fills in between them. The quartz and albite occurs in stringers and lenses. The rock is somewhat poorer in iron than that described immediately above. In the outcrop from which the specimen came were some bands richer in chlorite and a few that contain glaucophane.

Quite a few rocks contain a relatively iron-poor epidote and an amphibole with pale absorption. The amphibole might be an unusual form of tremolite or another low temperature form of amphibole.

Several specimens contain bands rich in white mica, which is commonly referred to as sericite. If the mica were sericite, it would indicate an argillaceous bed within what must have been a tuffaceous sequence. However, it may be paragonite substituting for part of the albite. For instance, specimen A-40-2 has sericite (5%) throughout the rock associated with epidote (50%), glaucophane and crossite (30%), albite and quartz (5%) and accessory actinolite and chlorite. One band, however, contains 40% sericite, 30% epidote, 10% quartz and albite, and 20% glaucophane. This band grades into the less sericite-rich portion of the rock.

The greenschists, crossite schists, and glaucophane schists were derived from andesite and basalt flows and pyroclastics. On the basis of Daly's figures for the average chemical composition of igneous rocks, when recalculated to mineral percentages and assuming all the soda is accounted for by albite, an andesite-derived rock should contain about 30% albite and olivine basalt-derived rock about 11% albite (1933, pp 16-17). The greenschists as a whole have an average albite content of 20%, which falls midway between the above figures. Both the rocks containing larger and smaller quantities of albite than the average figure seem to contain similar amounts of quartz, but in not too many cases could the amount of quartz be estimated with appreciable accuracy because the quartz and plagioclase are fine grained and their grains do not often form mutual boundaries, and the plagioclase is mostly untwinned. Contamination might reduce the proportion of albite, but no evidence was observed.

As in the Sauk River area to the south (Vance, 1954) no evidence was found on the problem why some schists contain sodic amphiboles and some do not. Chemical composition, as indicated by mineral composition, of the crossite and glaucophane schists does not differ from that of the greenschists lacking sodic amphibole. The crossite and glaucophane schists are interlayered with greenschists, and they both display similar structural and textural features; so the temperature and stress conditions during metamorphism must have been the same throughout the rock.

The greenschists contain albite, epidote, chlorite, and actinolite, a typical epizonal mineral assemblage. The crossite and glaucophane schists contain the same assemblage with the addition of crossite, glaucophane, and sodic actinolite.

Phyllites

Phyllites occur interbedded with the greenschists, crossite schists, and glaucophane schists throughout the topographically lower portion of the area occupied by the "Whitechuck unit". None were observed on the Illabot Peaks. However, they may be present, but because of their non-resistant character, they may form the valleys and cols and not be exposed. Phyllite crops out on the Boulder Creek-Jordan Creek spur to the exclusion of greenschists, except for some greenschist formed from the marginal portion of the pre-orogenic Marblemount quartz diorite (see Chapter IIIB2a below).

The phyllites contain 55 to 85% quartz (average 65%), a trace to 30% albite (average 15%), 0 to 35% sericite (average 15%), 0 to 20% chlorite (average 5%), and graphitic material (up to 15%). Accessories are stilpnomelane, clinozoisite, tourmaline, and opaque minerals. Some of the phyllites contain small pebbles.

Except for segregation quartz, the phyllites are fine grained. Quartz very commonly makes up segregation lenses, pods, and stringers that may constitute up to 60% of the rock. The grain size of the segregations is often medium and sometimes coarse. In other cases sericite and chlorite occur in bands intercalated with bands of fine grained quartz and albite. This type of banding may, at least in part, be due to the presence of thin shaly and sandy beds in the original sediment.

The albite has a tendency to be concentrated in the sericite and chlorite-rich bands, although it often occurs in segregations. Occasional albite grains display zoning.

A few small pebbles of quartzite and chert occur in specimen A-39-1, which was collected where a logging road formerly crossed lower Illabot Creek, and in specimen A-45-1-b from the end of the highest logging road on the Boulder Creek-Jordan Creek ridge at about 4000 feet elevation.

In a few specimens, such as A-19-1-a collected where the northern Suiattle River road crosses Big Creek, original bedding is largely preserved even though the sericite-rich or more argillaceous beds have a strong first foliation (s_1) that has been folded and partially sheared into a second foliation (s_2). In detail the folding has been disharmonic with the sericite-rich beds more intensely folded than the quartz-rich beds. s_2 is better developed in the sericite-rich beds, and only a few shears cut the thicker quartz-rich beds. In the above specimens the small grain size of the quartz suggests that the original clastic grains have not recrystallized much. However, a few incipient segregations of coarser quartz are present.

In the field the phyllites are often so contorted that it is impossible to obtain even an approximate attitude. They yielded in a plastic manner. Thin sections demonstrate this. In a few of them the deformation of the original foliation (s_1) is mainly restricted to strong folding, and only some incipient shearing has taken place parallel to the axial planes of the folds, forming an incipient second foliation (s_2). In other rocks s_2 is well developed, but s_1 is still plainly visible in the general trends of the mica-rich bands. In still other specimens only a suggestion of s_1 remains within the mica rich bands. The quartz (and feldspar)-rich bands crystallized completely during and after the formation of s_2. On the basis of the gradational and unsystematic development of the s_2 within the phyllites of the "Whitechuck unit", the author believes both foliations may have been produced during one general period of stress, and the rock acted so incompetently that it yielded in a plastic, non-uniform manner.

The mineral composition of the phyllites indicates that some of them were derived from pure shales and sandy shales, but many of them must have been silt-sized "microgreywackes" or "microsubgreywackes". The specimen richest in feldspar is A-42-1 from the northwestern part of the area, and it contains approximately 30% albite. When recalculated to weight percent Na_2O, 3.6% is the value obtained. Thus the rock contains more than the average greywacke (Pettijohn, 1949, p. 250). Evidence for soda metasomatism is lacking. The mineralogical composition of some of the mesozonal schists indicates that some of the original sediments had even a higher original soda content than these phyllites (see Chapter III-B3c below).

Specimens A-43-1 and A-48-1-b from the northwest part of the area contain 10 and 35% carbonate respectively. They also contain 25% albite. These rocks must have been derived from calcareous "microsubgreywackes".

Arkose

A few outcrops of arkose occur in the logging road east of Tenas Creek about 400 feet above the northern Suiattle River road, on the road west of Grade Creek after it switches back for the first time and heads north, and at about 1400 feet elevation on the Big Creek-Huckleberry

Lookout trail between Big Creek and Tenas Creek.

The arkose contains 25 to 55% clastic plagioclase (average 40%), 40 to 65% clastic quartz (average 45%), 0 to 10% clastic biotite (average 5%), 0 to 15% pebbles (average 5%). Accessories are clastic muscovite, epidote, sphene, carbonate, hornblende, myrmekite, rutile, garnet, orthite, apatite, and zircon.

The plagioclase is partially altered to sericite, kaolinite, epidote and carbonate, and its composition ranges from albite in the more altered crystals to sodic andesine in the fresher grains. The plagioclase is medium to fine grained and generally sub-angular. The fragments are slightly bent and fractured. Quartz also occurs in small to medium sized, sub-angular grains.

Biotite occurs as small to medium sized, clastic grains. Practically all of them are strongly strained. In some cases the biotite has been altered to yellow and green penninite and clinochlore. The rocks from the locality east of Tenas Creek contain fewer biotite fragments than the others. Muscovite occurs in the same manner as biotite.

The rocks examined from the trail on the Big Creek-Tenas Creek ridge lack garnet.

The rock fragments are no larger than the feldspar grains. They consist mainly of chert, phyllite, and volcanics with minor amounts of quartzite and schist fragments. The source of most of the arkose must have been coarse to medium grained granitic rocks with low grade metamorphic rocks and volcanics furnishing a relatively minor portion of the clastic material. Of the specimens examined, the ones from the trail on the Big Creek-Tenas Creek ridge contain the most rock fragments (average 10%).

The field relations of the arkoses with the adjacent greenschists are not well displayed, for the outcrops occur along logging roads or in the forest. The best exposure is on the Grade Creek road. There it is about two hundred yards from a greenschist outcrop. The outcrop itself is massive. Although variations in grain size were observed, no well defined beds could be located. Perhaps further extension of the Grade Creek road will reveal more.

From the observed relations the arkoses seem to belong to the "Whitechuck unit" of greenstones and phyllites, for they appear interbedded with the epizonally metamorphosed rocks. If so, the rock must have behaved very competently during regional metamorphism, for few shears pass through it. The bent feldspar and mica show it has been subject to some stress. The plagioclase and biotite have been hydrothermally altered, and some of the alteration products, calcite, in particular, have been deposited in various places throughout the rock. South of the Suiattle River Joseph A. Vance has observed little metamorphosed arkoses in the Gold Hill phyllites, which have been subjected to the same degree of metamorphism as the "Whitechuck unit" (personal communication).

If the arkoses constitute a part of the "Whitechuck unit", then the problem of their source arises. Their composition would indicate that some older granitic and metamorphic terrane must have been exposed at the time of their deposition. However, since their relation to the rocks of the "Whitechuck unit" is not certain, they may be younger. It is interesting to note that the outcrops observed occur adjacent to and on the downthrown side of a large post-metamorphic reverse fault (Straight Creek fault, see Chapter IVE below).

Quartzite

The phyllites grade into impure quartzites. However, even the phyllites with 85% quartz still display the finely schistose and contorted structure of the less quartzose phyllites.

Massive quartzite occurs in at least one locality, namely just outside the contact of the Jordan ridge serpentine on a logging road at about 3500 feet elevation on the Jordan Creek-Boulder Creek ridge. The rock is a garnet-stilpnomelane quartzite (specimens C-55-1-b&c) and contains 80 to 95% quartz. The quartz varies from fine to medium grained and is xenoblastic. Some segregations along fractures occur. Stilpnomelane (5 to 15%) occurs in directionless small, xenoblastic crystals and is post-kinematic. In some places it grows between the quartz grains. Garnet, probably spessartine, is in small, hypidioblastic to idioblastic grains and tends to be concentrated in aggregates. A few small colorless actinolite crystals occur. Carbonaceous material is an accessory. This quartzite must have been derived from a manganese-bearing ferruginous sandstone.

Chert

Chert is exceedingly rare in the Snowking area. Bands 1/2 to 2 inches thick were observed in a phyllite on the south side of the Grade Creek-Suiattle River ridge. The specimen studied (B-24-2-b) consists of very fine grained quartz with coarse grained quartz in veinlets tending to be perpendicular to the bedding, which is indicated by trends of graphitic material. Muscovite and clinozoisite (?) occur in the coarser veinlets.

Other Rocks

Several rocks of different types occur on the south side of the lower Suiattle River valley in the bed of the second brook west of the junction of the roads to Darrington and Concrete.

At about 1000 feet elevation along the brook occurs an impure limestone (specimen D-37-1-d) which contains about 80% carbonate and 15% very fine grained pumpellyite (?) in lenses. Angular quartz grains (5%) are present. The rock has been strongly sheared after its crystallization.

At about 1050 feet elevation a sheared and altered rock (specimen D-37-2-b) crops out. It contains large plagioclase crystals that are bent and broken. The plagioclase has a composition of An 10. Also some large quartz crystals are present. The large plagioclase and quartz crystals occur singly or as aggregates in a mylonitic matrix. Carbonate, sericite, and chlorite complete the rock. This may have been originally a granitic rock. At about 1900 feet on the same stream is a crushed and sheared, somewhat mylonitic rock containing quartz, plagioclase, and carbonate (specimen D-38-3-a). The character of the original, unsheared rock is uncertain.

General Conclusions

The rocks of the "Whitechuck unit" are characterized by the epizonal mineral assemblage of albite, epidote, chlorite, and actinolite in the greenschists and chlorite, sericite, albite, and stilpnomelane in the phyllites. These assemblages are characteristic of the greenschist facies in metamorphosed igneous rocks and the chlorite zone in metamorphosed argillaceous rocks. The crossite and glaucophane-bearing rocks contain the whole greenschist mineral assemblage.

The "Whitechuck unit" is derived from a typical eugeosynclinal sequence consisting of thick volcanics and relatively minor predominantly argillaceous sediment.

The rocks were subjected to regional epizonal metamorphism under synkinematic conditions. They yielded incompetently, but the argillaceous rocks yielded far more incompetently than the volcanics. If the arkoses are part of the unit, they acted very incompetently and were scarcely penetrated by deformation.

The rocks of the "Whitechuck unit" are approximately on strike with rocks at Concrete about 15 miles to the northwest containing probable Carboniferous fossils in massive limestone (Misch 1952). On the basis of the same evidence Vance considers the rocks in the type area for the unit as Carboniferous (1954). Recent finds of probable Jurassic or early Cretaceous fossils in rock underlying the Carboniferous limestone northeast of Concrete (Misch personal communication) makes the age of the "Whitechuck unit" less certain.

Epizonally and Mesozonally Metamorphosed Intrusive Rocks

Pre-orogenic Quartz Diorite (Marblemount Quartz Diorite)

General Statement

North of the Cascade River and north and east of the settlement of Marblemount and along lower Bacon Creek and the Skagit River road Peter Misch has studied and named the Marblemount pre-orogenic quartz diorite (1952a, map p. 4).

In the Snowking area, the Marblemount quartz diorite occurs on the 6500 foot peak at the head of Irene Creek, on the north side of Razor Back, and along the south side of the Cascade River to east of Kindy Creek. It has been metamorphosed both in the epizone and the mesozone. The mesozonally metamorphosed part is best displayed on the 6500 foot peak at the head of Irene Creek and the epizonally metamorphosed portion on the south slope of Razor Back. Generally speaking, the margins of the quartz diorite body are schistose, while the interior portions are gneissose and directionless. Actually a few restricted zones of schist occur in the interior along with the gneiss zones. In the interior of the quartz diorite penetrative deformation tended to be confined to those zones. To the southeast along the Cascade River the intrusive body has been strung out considerably, so that just a thin tail extends beyond Kindy Creek. Although the quartz diorite acted as a competent mass in the less competent sediments during the metamorphism of the Cascade valley schist zone, it yielded to and was modified by the regional structure-forming stresses.

At about 4500 feet on the ridge north of the 6500 foot peak at the head of Irene Creek an infold or slice of metamorphosed sediment was observed (station C-8-1). Unfortunately the exposure is in the woods, making the exact relations difficult to determine. The rock is an albitized blastomylonite.

The age of the intrusive can only be fixed as later than the sediments into which it was intruded and earlier than the regional metamorphism. The age of the sediments is uncertain and may be anywhere from Ordovician to lower Mesozoic. It is possible that these rocks are Carboniferous, for they are roughly on strike with rocks containing Carboniferous fossils 35 miles to the northwest (P. Misch, 1952a, p. 8). The oldest known rocks definitely deposited after the main orogeny are Paleocene and possibly include some latest Cretaceous and occur in the Nooksak valley northwest of Mt. Baker 40 miles to the northwest and in the low foothills adjacent to Puget Sound to the west (P. Misch, personal communication). Thus a late Paleozoic or possibly earlier Mesozoic age of the Marblemount quartz diorite appears probable.

Epizonally Metamorphosed Quartz Diorite

Epizonally metamorphosed Marblemount quartz diorite was found on the north slope of Razor Back, at the mouth of Boulder Creek, on the slopes between about 1900 feet elevation south of the Cascade River on Irene way and 5500 feet on the north ridge of the 6500 foot peak at the head of Irene Creek, and on the south side of the Cascade River between Found Creek and Kindy Creek. Of course all gradations between epizonally and mesozonally metamorphosed rocks occur, and the epizonal-mesozonal boundary is drawn where biotite exceeds chlorite in the metamorphic assemblage of the rocks.

Epizonally metamorphosed Marblemount quartz diorite contains 35 to 50% albite (average 40%), 5 to 25% quartz (average 15%), 5 to 50% epidote (average 25%), 5 to 15% chlorite (average 10%), and 5 to 25% sericite (average 10%), and occasional biotite, hornblende, and carbonate. Apatite, sphene, rutile, tourmaline, and opaque minerals are accessory. These mineral percentages are based on estimates from the schistose specimens, for it was found that only in these specimens the amount of epidote and sericite can be properly determined because in the massive varieties the sericite and epidote are scattered as alteration products throughout the plagioclase and tend to be included in the estimate of the amount of plagioclase. The more thorough recrystallization in the schistose varieties has cleared the albite of the included sericite and epidote.

An example of the variations observable in the interior of the epizonally metamorphosed Marblemount quartz diorite are three specimens collected from about 2600 feet elevation on a logging road on the north slope of Razor Back. In the field this outcrop of meta-quartz diorite appears structurally heterogenous with local schistose zones accompanying epizonal gneiss and massive granitic rock in which chlorite is the mafic. Specimen D-24-2-a contains 60% fine to coarse grained, xenoblastic albite filled with epidote and some sericite. Fine to medium grained, strongly strained, xenoblastic quartz (10%) tends to be in aggregates. Pleochroic, fine grained, xenoblastic to hypidioblastic epidote (20%) and light green clinochlore (10%) are the other main constituents. Rutile, sometimes with sphene rims, is the accessory. The rock has been squeezed somewhat, producing a suggestion of alignment of the chlorite and some mortar, which is now partially recrystallized. Specimen c is fairly similar except it has more recrystallized mortar, and some of the larger plagioclase grains are bent and broken. Also the sericite formed from the plagioclase tends to be concentrated in certain areas. Specimen b is a blastomylonite containing 50% fine to fairly fine grained, xenoblastic albite, 20% fine grained, xenoblastic quartz, 15% fine to medium grained, xenoblastic to hypidioblastic epidote with weak absorption, and 5% sericite scattered in splotches. Lack of sharpness in the alignment of the chlorite and sericite indicates that considerable crystallization took place after deformation.

The margins of the Marblemount quartz diorite body are schistose. In some places deformation has been strong enough and continued long enough and/or recrystallization has assumed a small enough role to produce blastomylonites rather than ordinary schists. In other places, near, but not directly adjacent to, the margins cataclastic gneisses have formed. Typical of the blastomylonites is specimen D-13-3 occurring just a few hundred yards from the quartzitic schists which occur between the Marblemount quartz diorite and the Snowking massif. This rock contains 65% albite in small, xenoblastic grains to medium sized porphyroclasts, which have been made into porphyroblasts by incipient growth tending to include the groundmass of mortar on their margins. They are heavily sericitized. Quartz (15%) occurs in small, xenoblastic grains, strongly strained and strung out parallel to the foliation. Some is concentrated in segregations. Sericite (10%) tends to be concentrated in bands. Fine grained, xenoblastic, green clinochlore (5%), fine grained, xenoblastic epidote (5%), and rutile make up the rest of the rock.

In the mesozonally metamorphosed portion of the Marblemount quartz diorite there occur some zones of epizonal schistose rocks similar to those described above. These zones may be considered as retrogressive in relation to the surrounding rocks. The reasons for such selective epizonal alteration may have been that in them penetrative deformation and crystallization took place later, or perhaps longer, than in the adjacent rock, and epizonal blastomylonites formed. On the ridge west of the 6500 foot peak at the head of Irene Creek occurs a blastomylonite (specimen C-15-3) containing 65% quartz and albite. The albite occurs in the groundmass of mortar and in larger rounded grains or aggregates that were originally porphyroclasts, some of which have grown a little since shearing and partially have become porphyroblasts. The quartz is in the mortar and in aggregates of elongate, strung-out crystals. The orientation of these aggregates suggests a previous foliation. Small, fine grained, xenoblastic epidote (10%) with fairly weak absorption, green clinochlore (5%), sericite (20%), and accessory sphene, orthite, and carbonate make up the rest of the rock. The epidote and chlorite tend to be concentrated in bands. The rock has some b lineation, and since the section described was cut perpendicular to it, the banding is not sharp.

On the ridge north of the 6500 foot peak at the head of Irene Creek associated with a cataclastic biotite-quartz dioritic gneiss is a stilpnomelane-chlorite-muscovite-epidote schist (specimen C-9-2-a) containing 50% quartz and plagioclase (albite or sodic oligoclase), mainly in the form of mortar, 10% synkinematic and late-kinematic green penninite, 5% late-kinematic and post-kinematic stilpnomelane crystals, which grade into muscovite crystals in places, 15% synkinematic muscovite with a few post-kinematic transverse crystals, 20% epidote, and sphene. Some of the muscovite has been strained slightly.

In some localities in the interior of the Marblemount quartz diorite east of Razor Back where the temperatures during metamorphism were in the hotter epizone, the rocks have not attained mineralogical equilibrium with the prevailing conditions. For example, specimen C-7-4 contains 70% albite in small to large, xenoblastic grains that are somewhat bent and strained and that include quartz and plagioclase. The rock also contains 15% fine to coarse grained, xenoblastic quartz, strongly strained and broken. Relict hornblende (10%) is in small to medium sized, anhedral to subhedral crystals and displays patchy alteration from an original green hornblende to a very light green one. The extinction angle is the same for both kinds. The large crystals include quartz and plagioclase. Fine to medium grained, xenoblastic to idioblastic epidote (5%) with weak absorption has been derived mainly from the plagioclase by decalcification. A small amount of green clinochlore, sphene, rutile (often rimmed by sphene), and opaque minerals make up the rest of the rock. The textures are completely crystalloblastic. It seems strange that in this rock the plagioclase should be so completely altered, yet the hornblende is not chloritized.

On the ridge north of the 6500 foot peak at the head of Irene Creek above 5000 feet elevation, approaching the area of mesozonally metamorphosed

Marblemount quartz diorite, the rocks start to contain biotite and chlorite which are contemporaneous.

Also at about 2500 feet elevation on Irene Way is a greenschist probably derived from the Marblemount quartz diorite (specimen C-7-2), containing 40% albite in small to medium sized grains filled with epidote. The larger ones tend to be rounded and suggest former porphyroclasts, although they display some growth features. 10% fine grained, xenoblastic quartz, 30% fine to medium grained, xenoblastic to idioblastic epidote with weak absorption, 15% green clinochlore, 5% biotite, and opaque minerals make up the rest of the rock. The biotite is intimately intergrown with the chlorite. Thus the rock formed at temperatures at the biotite-chlorite zone boundary.

Biotite-bearing greenschists also occur where the next brook west of Kindy Creek reaches the Cascade valley floor. They contain 5 to 10% olive green to brown biotite contemporaneous and intergrading with green penninite (15%). The rocks also contain 3 to 35% epidote and 55% quartz and albite. In some bands part of the albite forms small to medium sized, rounded porphyroclasts. Tourmaline (O=dark brown to blue and blue green, E=light brown to light purplish tan), carbonate, apatite, and opaque minerals are accessories. Farther west, about 1/2 mile east of the mouth of Found Creek, is a quartz dioritic gneiss with a minor amount of biotite contemporaneous with chlorite.

On the Irene way trail at about 2000 feet elevation occurs an epidote bearing chlorite schist that may represent the edge of the Marblemount quartz diorite, perhaps tectonically mixed with adjacent argillaceous sediments. The specimen (C-6-2) contains 40% small to medium grained, xenoblastic to hypidioblastic plagioclase, some of which is in rounded, albitized porphyroclasts, 15% strongly strained, small to medium sized, xenoblastic quartz, 35% sericite, 5% green clinochlore, small to medium grained, xenoblastic epidote, carbonate, stilpnomelane, and opaque minerals (5%). s_1 (the first foliation) as indicated by the alignment of the sericite, is cut at an angle of 20° to 25° by s_2 (the second foliation), along which chlorite is concentrated.

One specimen from the upper north slope of Razor Back (D-24-1-b) contains a lenticular concentration of tourmaline (10% of the section) with the absorption: O=dark slate green and E=light pinkish tan.

The epizonally metamorphosed portion of the Marblemount quartz diorite is characterized by the assemblage albite, epidote, and chlorite, a typical epizonal assemblage. Locally relict hornblende is present, sometimes in significant amounts. Many rocks have a minor amount of biotite contemporaneous with the chlorite, indicating metamorphism in the epi-mesozonal transitional interval.

Mesozonally Metamorphosed Quartz Diorite

Mesozonally metamorphosed Marblemount quartz diorite is especially well exposed on the 6500 foot peak at the head of Irene Creek. Float from slope wash and creep on the south side of the Cascade River east of Found Creek consists of mesozonally metamorphosed Marblemount quartz diorite.

Like the epizonally metamorphosed portion, the mesozonally metamorphosed Marblemount quartz diorite consists of schistose rocks, gneisses, and directionless meta-quartz diorite. They contain 40 to 60% plagioclase (albite to andesine in composition), 10 to 25% quartz, 0 to 30% hornblende, 2 to 15% biotite, 2 to 30% epidote, up to 15% muscovite, up to 5% carbonate and accessory sphene, rutile, zircon, tourmaline and opaque minerals.

The massive mesozonally metamorphosed Marblemount is concentrated in the vicinity of the 6500 foot peak at the head of Irene Creek. Coming from the east and northeast out of the massive mesozonally metamorphosed Marblemount into the schistose mesozonally metamorphosed portion towards the Snowking massive, first zones of incipient shearing are observed, next restricted gneissose and blastomylonitic zones, then the whole rock becomes gneissose with local blastomylonitic zones, and finally at the junction of the ridge from Razor Back west of the peak the rock is entirely blastomylonite.

Some of the massive Marblemount quartz diorite appears to have been incompletely metamorphosed in both the epizone and the mesozone. Specimen C-8-3 from about 5400 feet on the ridge north of the 6400 foot peak on the Irene Creek-Found Creek ridge contains about 60% small to large, xenoblastic plagioclase. A few unaltered grains have the composition An 28 to 32 and show normal zoning. One has an altered rim of An 4. Many of the crystals are filled with epidote and sericite, and their composition is albite. Those that are only sericitized maintain a composition of about An 30. Plagioclase also includes quartz and hornblende. Quartz (25%) is in small to large, xenoblastic crystals that tend to form mosaic textured segregations. Hornblende with absorption Z=dark green, Y=olive green, and X=tannish yellow is in small to large, xenoblastic to hypidioblastic crystals, and it includes quartz and plagioclase. Epidote (5%) with some weak absorption occurs in small grains included in the plagioclase and in medium sized, xenoblastic crystals associated with the mafics. Somewhat strained biotite (5%) is found in small to large, xenoblastic to hypidioblastic crystals. It appears to be derived from hornblende in most cases, although in a few places it might be interpreted as forming from chlorite. Medium grained, hypidioblastic chlorite has formed from hornblende and biotite. The general relationships suggest metamorphism took place at temperatures near the epizonal-mesozonal boundary. Accessories are orthite, occurring in the core of an epidote crystal, rutile, and sphene, the sphene often rimming rutile cores.

On the north side of the ridge between the 6400 foot peak on the Irene Creek-Found Creek divide and the 6500 foot peak at the head of Irene Creek on the slope at the head of the middle fork of Irene Creek is a partially altered hornblende-quartz diorite in which the hornblende and biotite are more sheared than in specimen C-8-3. The biotite is rather light brown. Again the biotite was formed from hornblende, and in this case the chlorite seems to have formed from the biotite.

At about 5600 feet elevation on the ridge north of the 6500 foot peak at the head of Irene Creek occurs a cataclastic biotite-quartz dioritic gneiss (specimen C-9-2-b) associated in a shear zone with mylonitic epizonal schist described above. The gneiss contains 50% plagioclase in medium sized, rounded, cataclastic grains with mortar in between. It ranges from calcic oligoclase to albite in composition, depending on the amount of alteration. Quartz (15%) consists of partially recrystallized mortar, and the recrystallized portions are strongly strained. Biotite (15%) is shredded and strained and locally reconstituted. Some penetrates the plagioclase. Epidote is minor; carbonate (5%) seems to take its place. Sericite (15%) is derived from the plagioclase. The sodic composition of some of the plagioclase grains is the only epizonal feature of this rock. In comparison the more thorough shearing in the adjacent rock, the stilpnomelane-chlorite-muscovite-epidote schist described above (specimen

C-9-2-a), seemed to make a favorable zone for longer continuing and more complete recrystallization under epizonal conditions.

At the head of the middle fork of Irene Creek the whole rock is gneissose (e. g. specimen C-10-1-b) and contains 55% small to large, xenoblastic to hypidioblastic plagioclase ranging in composition from sodic andesine to highly altered grains whose index indicates they are albite. Small to medium grained, anhedral quartz (15%) is partially concentrated in segregations. Medium to large, xenoblastic to hypidioblastic, green hornblende (8%) formed synkinematically with crystallization outlasting deformation. Post-kinematic, fine to medium grained biotite (7%) is derived from hornblende. Epidote (15%) with weak absorption occurs in small to medium sized, xenoblastic to hypidioblastic grains, and it formed from plagioclase and hornblende. A little light green clinochlore was derived from biotite. Sphene and opaque minerals complete the rock. In a zone about 1 foot wide is a much more strongly sheared rock (specimen C-10-1-a) containing similar but generally finer grained, incompletely altered plagioclase. Quartz (20%) tends to be concentrated in elongate lenses and stringers and is strongly strained. Synkinematic green hornblende forms small to large, xenoblastic to hypidioblastic crystals and includes sphene, quartz, and plagioclase. Synkinematic and late-kinematic biotite (7%) was formed from hornblende. Accesories are muscovite, sphene, and opaque minerals. A sharp, small late shear plane with mortar passes through the section. This rock underwent more complete shearing during recrystallization than specimen b, and the grain size was reduced and the mafics were sharply aligned.

Just northeast of the junction of the ridge from Razor Back with the 6500 foot peak at the head of Irene Creek the rocks become very gneissose and schistose. The gneissose rock (specimen C-10-2-b) contains 35% fine to coarse grained, xenoblastic plagioclase which is very heavily altered. Quartz (20%) is small to medium sized and xenoblastic and tends to be concentrated in lenses and stringers with mosaic texture. Fine to medium grained, synkinematic and late-kinematic biotite (15%), fine grained, xenoblastic to hypidioblastic epidote (30%) (very fine grained where included in the plagioclase), light tannish green clinochlore from biotite, and sphene make up the rest of the rock. Some mortar is present. The schist (specimen C-10-2-a) contains 45% fine to medium grained, xenoblastic to hypidioblastic plagioclase, which, where unaltered, is sodic andesine, but many grains have been decalcified to a varying degree. The plagioclase is mainly in angular fragments, and some grains are bent and broken. The quartz (15%) shows some strain but has recrystallized considerably, frequently as small segregation stringers. Fine grained, xenoblastic biotite (15%) is synkinematic with crystallization outlasting movement. In places it fills in between epidote grains. Fine grained, xenoblastic to hypidioblastic epidote (25%) with fairly strong absorption, fairly light green clinochlore from biotite, and sphene make up the rest of the rock. Epidote, quartz, and plagioclase constitute mortar. This schist is a blastomylonite.

At the junction of the ridge from Razor Back with the 6500 foot peak at the head of Irene Creek schistose rocks (specimens C-11-1-a&b) definitely supplant gneissose rocks. The schists contain 40% sodic andesine in small to medium sized, xenoblastic grains, some of which are porphyroclasts. The porphyroclasts are bent and broken. They have been partially healed and they have grown a bit, incorporating some of the mortar. Fine grained, xenoblastic quartz (20%) is fairly well recrystallized, partially

PLATE V

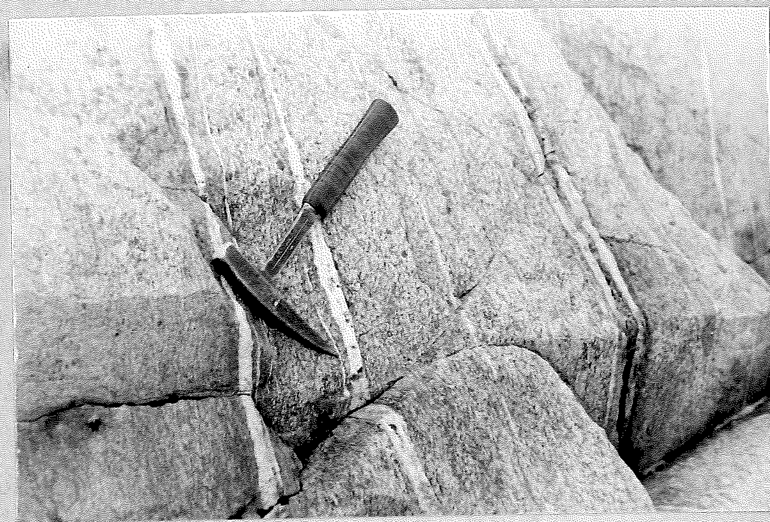

Fig. 1 Gneissose, mesozonally metamorphosed Marblemount quartz diorite at the head of Irene Creek.

Fig. 2 Zones of schist in mesozonally metamorphosed Marblemount quartz diorite at the head of Irene Creek near the southern margin of the body.

into a medium grained mosaic. Biotite (10%) is fine to medium grained and xenoblastic, and it formed synkinematically and post-kinematically. Some crystals are strained and bent; others are oriented transverse to the foliation. Synkinematic muscovite (5%), epidote (20%), light green late-kinematic and post-kinematic clinochlore from biotite, sphene, zircon, tourmaline, and opaque minerals are present. The tourmaline has the pleochrism: O=green and E=light purplish. The rocks contain much fine grained partially recrystallized, quartzo-feldspathic mortar.

The float picked up west of Kindy Creek is essentially similar to rocks already described, for it contains plagioclase in various stages of decalcification, probably averaging sodic oligoclase in composition, recrystallized biotite, and hornblende, the usual epidote, a small amount of retrogressive chlorite, and accessory apatite, sphene, and opaque minerals. The quartzo-feldspathic portion of the rock consists of recrystallized mortar and former porphyroclasts that have become porphyroblasts by considerable growth subsequent to shearing.

At about 1500 feet elevation on the ridge east of Kindy Creek is an outcrop of epidote-biotite mylonite (specimen B-55-1-a) with 70% quartz and plagioclase, mainly as mortar but also in strung-out grains and a few small porphyroclasts of plagioclase. It contains 10% biotite in a very ground-up condition, 15% epidote, and late-kinematic muscovite. The mineral composition of the rock suggests it may be a strung-out slice of metamorphosed Marblemount quartz diorite.

The mesozonally metamorphosed portion of the Marblemount quartz diorite is characterized by varying amounts of biotite derived from hornblende and considerable epidote derived from plagioclase and hornblende. The plagioclase has usually become considerably more sodic than one might expect in mesozonal metamorphism, for at least some of it is albite. Probably the average composition is sodic oligoclase. In the more thoroughly reconstituted schists adjacent to the band of mesozonal schists between the Marblemount quartz diorite and the Snowking massif, the newly formed plagioclase is less sodic.

General Conclusions

The Marblemount quartz diorite was originally a rock containing andesine, hornblende, and quartz as its main constituents. The homogeneity of the chemical composition as indicated by the mineral composition of the Marblemount quartz diorite and the pre-metamorphic age of that body suggests it originally may have been an igneous intrusion. Metamorphism has produced the following assemblages: andesine to sodic oligoclase, hornblende, biotite, and epidote in the mesozone; albite, epidote, sericite, and chlorite in the epizone. In the epizonal-mesozonal transition interval mineralogical equilibrium is lacking in the more massive portions of the body, and individual plagioclase grains are altered to varying degrees, biotite and chlorite are both stable, and hornblende is only slightly or partially altered.

Structurally and texturally both the epizonally and mesozonally portions of the Marblemount quartz diorite may be considered together. They vary from blastomylonites of very small grain size to massive metaquartz diorite in which the grain size ranges from small to large. Even the more massive rocks that do not seem to have attained complete equilibrium with the conditions of metamorphism have entirely granoblastic textures. No relict primary textures or structures were observed; so we have no clue from that point of view as to the origin of the Marblemount quartz diorite.

Considering the amount of calcium available from decalcification of the plagioclase in the metamorphosed Marblemount quartz diorite, it is surprising how commonly rutile occurs as an accessory. One possible explanation might be that is formed before the calcium was released from the plagioclase and hornblende, and it was incompletely, or not at all, affected during the later stages of metamorphism. The sphene rims on the rutile grains, which are quite common, may represent either an alteration of the original rutile during a late metamorphic stage in a calcium-excess environment, or an additional growth on the rutile core at that time. The general aspect of the rim favors the latter hypothesis.

Variously Metamorphosed Ultrabasic Intrusives

General Statement

Small ultrabasic bodies occur at scattered localities in the schists of the Snowking area, and one larger body occupying an area of over a square mile is located adjacent to the Snowking massif on the ridge east of Jordan Creek. Since the latter consists predominantly of serpentine, it is convenient to refer to it as the Jordan Ridge serpentine.

Small Ultrabasic Bodies Occurring in Mesozonal Rocks

Five small ultrabasic bodies were observed in the mesozonal rocks at the following localities: on the east side of the 6622 foot peak on the Buck Creek-Downey Creek ridge, on the west side of the south part of Buckindy, on the ridge between Boulder Creek and Found Creek just outside the contact of the Snowking massif, in the little cirque west of the 6500 foot peak at the head of Irene Creek, and on the northeast side of the 6000 foot knob above and east of the lower Granite Lake. The ultrabasic bodies have a distinctive rusty brown, rough, weathered surface.

They are so small that even on the ridges traversed they could easily be missed, especially in July when the snow cover is still heavy.

The rocks contain olivine altered to varying amounts of antigorite, talc, and tremolite. Less important constituents are carbonate, chlorite, and opaque minerals. None of the ultrabasic bodies studied in the meso-zonal rocks contain any relict pyroxene; so they must originally have been dunites. Ultrabasic dikes and sills occur in the vicinity of the bodies. One sill (specimen C-12-2-c) on the ridge between Boulder Creek and Found Creek contains slightly less than 100% fine grained talc. Accessories are small, hypidioblastic, post-kinematic, greenish tan clinochlore, small, post-kinematic tremolite porphyroblasts, and fine grained opaque minerals. Another sill at the same locality contains 60% talc, 30% tremolite, and 10% chlorite.

Near these sills is an ultrabasic body containing some relict olivine; so we can probably assume that these rocks were originally dunites. In that body talc appears to have formed directly from olivine rather than having passed through an intermediate serpentine stage. In order to form the talc, tremolite, and chlorite, silica and water must have been introduced. Calcium was needed to form the tremolite, and aluminum was needed for the chlorite. Not much can be said concerning the possible sources of these elements. The adjacent rock is a biotite quartzite and might have been a source of silica during metamorphism.

In most of the rock the olivine has been fractured and somewhat sheared, and often the rocks are foliated. Specimen D-20-2 from the north-east side of the 6000 foot knob east of lower Granite Lake is quite thoroughly sheared and has a smaller grain size than the other specimens. It contains 40% olivine, 35% antigorite, 25% carbonate, tremolite, and opague minerals.

The antigorite and tremolite are derived from olivine. The carbonate appears to replace some portions of the olivine directly. In places the alignment of the antigorite is controlled by the olivine cleavage.

On the east side of the 6622 foot peak on the Buck Creek-Downey Creek divide a small intrusive body about 100 by 300 feet is entirely exposed. The schists adjacent to the intrusive are very contorted. The intrusive contains inclusions of almost pure green clinochlore with considerable tremolite at their borders. These seem to be schist inclusions enriched in magnesium. The extreme contortion of the foliation planes in the adjacent schists indicates that the ultrabasic body was emplaced after the formation of the foliation in the schist. Yet the fact that the ultrabasic is altered (specimen B-12-3-a contains 30% talc and 10% antigorite derived from olivine) and has been somewhat sheared suggests that it might have been intruded during a late stage in the metamorphism of the area. The contacts of the other small ultrabasic bodies are not so clearly exposed as those of the body on the east side of the 6222 foot peak on the Buck Creek-Downey Creek ridge which has been described in the preceding paragraph. That some of the bodies have foliation which is partially megascopically visible and which is parallel to that in the adjacent schists argues for a pre-metamorphic emplacement of these ultrabasic intrusives. However, the absence of any metamorphic minerals indicative of metamorphism under mesozonal conditions makes the hypothesis of pre-metamorphic emplacement untenable.

Jordan Ridge Serpentine

The Jordan Ridge serpentine occurs on the broad ridge east of Jordan Creek from an estimated elevation of 1800 feet to the northern contact of the Snowking massif at about 4300 feet. At its maximum width it extends

PLATE VI

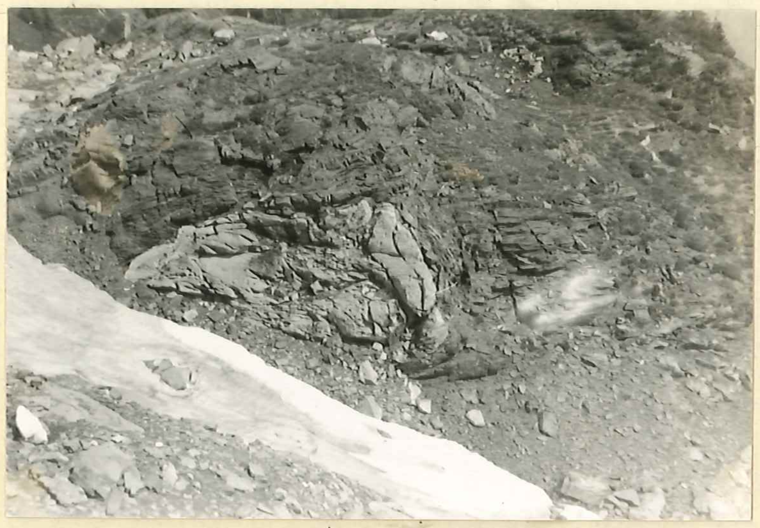

Fig. 1 Small ultrabasic intrusion in the Green Mountain unit of the east side of the 6622 foot peak on the Downey Creek-Buck Creek ridge.

Fig. 2 Contact of small ultrabasic intrusion on the east side of the 6622 feet peak on the Downey Creek-Buck Creek ridge. Ultrabasic on the right; contorted schist on the left.

little more than half way across the ridge to Boulder Creek on the east. Its northeastern border is well exposed in logging road cuts, but its western border is not exposed and probably lies somewhere in the Jordan Creek valley. Slope wash on the east side of the valley consists mainly of serpentine, but no outcrops were observed in the lower part of the slope.

Specimens studied from the Jordan Ridge serpentine contain from a few to almost 100% antigorite (average 75%). Where olivine is preserved, antigorite replaces it. The antigorite occurs usually in rather fine grained, felted aggregates. In the marginal portion of the body the antigorite crystals tend to be aligned, producing foliation in the rock. One specimen (C-54-1) from near the southeastern border contains unusually coarse antigorite in fibers and blades of various sizes in a criss-cross pattern.

Olivine makes up 0 to 60% of the rock. In two specimens relict monoclinic pyroxene occurs in quantities of 10 and 20% respectively. It is partially decomposed and has a very cloudy appearance. At station C-56-2 near the eastern margin of the body the altered pyroxene crystals stand out on the weathered surface of the outcrop. Opaque minerals make up to 0 to 5% of the rock. Minor chlorite is rare. In one rock picro-chromite is an accessory. In a specimen (C-57-1) from near the southern contact of the Jordan Ridge serpentine the main alteration product of the olivine is talc, amounting to 35%.

Where its borders are exposed, or nearly exposed, the Jordan Ridge serpentine tends to be schistose in a direction parallel to its contact. On the highest logging road on the spur between Jordan Creek and Boulder Creek at an elevation of about 3300 feet, the serpentine is sheared for a few tens of feet from the contact, and the shear planes wrap around non-sheared, more competent-acting lenticular fragments of the mass. Some marginal introduction of silica, alumina, and calcium has occurred. Specimen C-54-1-b from this locality, for instance, contains 20% tremolite, 10% light green clinochlore, and a few grains of clinozoisite, in addition to antigorite and carbonate.

At an elevation of about 1000 feet on a logging road on the slope between Jordan and Boulder Creeks and about 3/4 of a mile east of Boulder Creek is an isolated outcrop of talc carbonate schist. Whether or not this rock has any direct relationship with the main Jordan Ridge serpentine is unknown.

The Jordan Ridge serpentine was originally at least partially a pyroxene-bearing peridotite and not a pure dunite. If all of it had been pyroxene-bearing peridotite, one might expect more relict pyroxene in the rocks which contain large quantities of unaltered olivine.

General Conclusions

Both the Jordan Ridge ultrabasic mass and the ultrabasic bodies in the mesozonal schists were metamorphosed under epizonal conditions, for talc and serpentine are the principal metamorphic minerals occurring in both. However, the Jordan Ridge ultrabasic mass was converted mainly to serpentine, while the bodies in the mesozonal rocks were altered principally to talc. This would indicate that silica was available to the latter and not to the former. Locally calcium, aluminum, and carbon dioxide were introduced to form tremolite, chlorite, and carbonate.

The ultrabasic bodies in the mesozonal rocks must have been emplaced during a late phase of metamorphism, for they contain an epizonal mineral assemblage, and have undergone some shearing in directions parallel to the foliation in the adjacent schists. However, this epizonal metamorphism must have been endogenitic because the adjacent schists display no appreciable retrogressive features. Yet some of the ultrabasic bodies have been sheared in a direction parallel to the foliation trends in the adjacent schists. This indicates they were emplaced before the end of penetrative rock deformation.

Since the Jordan Ridge ultrabasic body occurs in an area of epizonal metamorphism, a late metamorphic emplacement cannot be demonstrated by the mineral assemblage. Its generally massive character indicates, however, that a pre-metamorphic emplacement is not probable because penetrative rock deformation accompanied regional metamorphism and severely deformed such a competent mass as the Marblemount quartz diorite (see above). The schistose margins of the Jordan Ridge serpentine suggest that it may have been intruded in late-metamorphic time.

Mesozonally Metamorphosed Sediments and Volcanics

Mesozonal Portion of the Cascade Valley Schist Zone

General Statement

The Cascade valley schist zone is an area of isochemically metamorphosed rocks 5 to 7 miles wide extending up the Cascade River and southeast to the Cascade crest. South of the Cascade River and east of Sonny Boy Creek it has not been studied. The zone includes the Marblemount pre-orogenic quartz diorite (see Chapter IIIB2a above), and the Hidden Lake granodiorite, which has intruded the schists subsequent to the main regional metamorphism (P. Misch 1952a; p. 12, 16, map p. 4). The Cascade valley schist zone is bordered on the northeast by the Skagit gneiss (P. Misch, op. cit.) and on the southwest by the Snowking massif.

The epizonal portion of the Cascade valley schist zone is tongue shaped, and it extends up the Cascade River valley to about 1/2 mile west of Kindy Creek. East of Marble Creek epizonal rocks occur only south of the Cascade River. The mesozonal portion occurs between the epizonal part and the Skagit gneiss on the north and the Snowking massif on the south.

South of the Cascade River in the Snowking area, mesozonal schists occur in a narrow belt about 1/4 mile wide along the northern border of the Snowking massif, and this belt widens to 1 1/2 miles on the Found Creek-Kindy Creek ridge. East of Irene Creek part of the Marblemount quartz diorite has been mesozonally metamorphosed. This rock has been discussed above and is not included in the units covered in the present chapter.

In the schist zone between the Marblemount quartz diorite and the Snowking massif two units may be distinguished: the first consists of impure quartzites and quartzitic schists that are adjacent to the Snowking massif for at least five miles, and the second comprises the other mesozonal rocks, which are schists and amphibolites.

Quartzitic Unit

The quartzitic unit was observed on the Jordan Creek-Boulder Creek ridge, in the Boulder Creek valley, on Razor Back and the ridge to the south, and on the ridge between Boulder Creek and Found Creek. It occupies a narrow belt less than 1/4 mile wide between the Snowking massif on the south and the metamorphosed Marblemount quartz diorite and phyllites on the north. On the ridge south of Razor Back it occurs as partially mylonitic remnants in the adjacent granitic rock.

In other localities quartzitic schists occur, but it is uncertain whether they belong to the same stratigraphic unit. Quartzitic schists occur on the south side of the Cascade River valley west of Kindy Creek and at the falls in lower Kindy Creek. If a slight bend in the foliation occurred, the rocks near Kindy Creek would be on strike with those on the Boulder Creek-Found Creek ridge, but the valley of Found Creek is too large a gap to project them across with much certainty. Also adjacent to and included in the margin of the Snowking massif on the ridge west and in the cirque northwest of the 5200 foot knob above the upper Falls Lake occur quartzitic schists which are about 6 miles southwest of those on the Jordan Creek-Boulder Creek ridge.

All the quartzites and quartzitic schists, whether definitely in the apparently continuous belt or not, have the same general characteristics. They contain 70 to 95% quartz, 0 to 15% biotite, 0 to 5% chlorite, 0 to 20% muscovite and sericite, and minor amounts of garnet, clinozoisite, hornblende, sphene, and graphitic material. They range from blastomylonites to schists with dominantly late-kinematic and post-kinematic crystallization. Often quartzitic and argillaceous layers produce banding, and several specimens display disharmonic folding.

On the ridge south of Razor Back in the vicinity of the 6000 foot peak above and east of the lower Granite Lake adjacent to the contact of the Snowking massif are what appeared in the field to be mylonitic zones in the granitic rock but turned out to be quartzitic schists. Sometimes granitic rock and/or granitic gneiss is interbedded with the schists. In places the schists fade out into the granitic rock along their strike. At about 5500 feet on the ridge north of the 6000 foot knob between the lower Granite Lake and the head of Irene Creek in the granitic rock occurs a schistose biotite quartzite (specimen D-20-1-a) containing tectonically strung out bands of material of argillaceous derivation in which the micas are late-kinematic and post-kinematic. This rock may be a recrystallized mylonite. On the col between two knobs (6100 feet and 6000 feet) east of the lower Granite Lake outside the granitic contact is a blastomylonite (specimen D-20-3) with synkinematic muscovite and contemporaneous synkinematic and late-kinematic light green clinochlore and biotite. On top of the 6000 foot knob east of the lower Granite Lake in the zone of the granitic contact occurs a banded quartzitic two mica schist with late-kinematic and post-kinematic micas in which s_2 makes an angle of 30° with s_1 as observed in thin section. This is interesting because very nearby the schist has a strike deviating 30° from the strike observed at the locality where the specimen (D-20-4-a) was collected. However, without an oriented specimen, it could not be proved whether the foliation in the adjacent outcrop was s_2.

Outside the contact on the northeast and northwest ridges of Razor Back the schists directly adjacent to the granitic rocks lack contemporaneous biotite and chlorite. On the northeast side in the col between Razor Back and the small adjacent knob occurs a hornblende and zoisite-bearing quartzitic biotite schist (specimen D-13-1). It contains small, xenoblastic to hypidioblastic, post-kinematic biotite (5%), small to medium sized, sutured, xenoblastic quartz (85%) including biotite, plagioclase, and quartz, plagioclase with the composition An 29 (5%), fine grained, xenoblastic to idioblastic zoisite, hornblende with $Z \wedge C = 19^{\circ}$, Z=lightish green, Y=light green, X=light tannish green, and light green penninite from biotite. Some fine grained,relict quartz is present between the larger,recrystallized grains. At about 4600 feet on the northwest ridge next to the granitic rock is a mylonitic biotite-sericite quartzite (specimen D-23-2) with some recrystallization in the later shears.

Very fine grained biotite (5%) with weak pleochroism fills crosscutting fractures, and a small quartz segregation occurs.

At a distance of about 200 yards from the rocks described above on the ridges of Razor Back occur phyllitic chlorite-two mica quartzites. They contain sericite and muscovite and very fine-grained, almost incipient, biotite. The chlorite is partially contemporaneous with the biotite. In one specimen (D-23-3) the very fine-grained biotite appears to be intergrown with and intergrade with sericite. In specimen D-12-2-a the foliation planes have been folded disharmonically, and a very incipient s_2 has developed.

On the west side of the Boulder Creek valley at about 2700 feet elevation just outside the granitic contact the quartzite is quite variable in composition in a single outcrop. One specimen (D-28-2-a) contains 95% quartz; the remaining 5% are clinozoisite, zoisite, tremolite, muscovite, biotite, and sphene, which are concentrated in thin bands. Specimen b from the same locality contains 10% muscovite, specimen c 10% clinozoisite, and specimen d 15% biotite. Little or no plagioclase is present. The micas are late-kinematic except in d where they are postkinematic and mimetic after the foliation.

Between the ~~two mica~~-epidote blastomylonites at the margin of the Marblemount meta-quartz diorite and the Snowking massif on the ridge between Boulder Creek and Found Creek occurs biotite quartzite which contains minor green hornblende, clinozoisite, and tannish garnet. The garnet (5%) is fine to medium grained and xenoblastic and occurs both between quartz grains and including them. The specimen (C-12-2-b) has a mosaic texture. The minerals mentioned above are distributed in bands. These bands are the site of late-metamorphic shearing, which laster longer than crystallization. In a narrow zone of metasomatism adjacent to the granitic rock the quartzitic schists contain up to 10% introduced microcline.

On the Jordan Creek-Boulder Creek ridge near the end of the highest logging road at about 3400 feet elevation where the road crosses a small brook occurs a quartzitic two mica schist interbedded with a thinly banded diopside quartz schist. Float indicates the granitic contact is nearby. The quarztitic schist (specimen C-58-3-a) contains 85% quartz in small to very small xenoblastic grains forming a mosaic and a few incipient segregations. Other major constituents are synkinematic muscovite and sericite (5%) and synkinematic biotite (5%), some of which is very fine grained and olive green in color. The green biotite occurs between the grains in the quartzitic bands. Synkinematic and late-kinematic, green penninite from biotite, fine grained, xenobalstic to hypidioblastic garnets, graphitic material, and opaque minerals complete the rock. Specimen C-58-3-b contains 90% quartz, 10% fine grained, xenoblastic diopside with $Z \wedge C = 42$, fine grained, xenoblastic to hypidioblastic actinolitic hornblende with $Z \wedge C = 15^{\circ}$, Z=light green, Y=very light greenish and X=colorless, medium grained, xenoblastic garnet, fine grained, xenoblastic clinozoisite tending to be associated with garnet, graphitic material, and opaque minerals. The constituents are distributed in bands. A small amount of the hornblende is derived from the diopside. The quartzitic two mica schist appears to have been metamorphosed at temperatures on the epi-mesozonal boundary, for the chlorite is nearly contemporaneous with the biotite. This with the occurrence of graphitic phyllite and garnet-stilpnomelane quartzite described above in Chapter IIIBlbv only 100 yards away makes occurrence of diopside associated with these rocks appear anomalous. One possible explanation might be that the adjacent schists and quartzites are retrogressive, while the diopside-quartz schist resisted retrogression because of its chemical composition.

Among the quartzites that may or may not belong to the unit discussed above is one from about 2500 feet on the south side of the Cascade River valley west of Kindy Creek. The rock (specimen C-25-2) contains 85% fine grained quartz. Biotite (10%) is synkinematic and post-kinematic. Muscovite and sericite (5%) are synkinematic, with crystallization lasting longer than movement. Plagioclase, light tannish clinochlore from biotite, and graphitic material are accessories. The micas are concentrated in thin bands, and when the rock was folded, these bands yielded disharmonically. The thicker, more competent quartzose bands folded simply, while the thin, mica-rich bands tended to accumulate on the crests and thin on the limbs of the folds. Minute drag folds and incipient shears parallel to the axial planes of the larger folds occur in the mica-rich layers.

At the top of the falls where Kindy Creek Starts to enter the Cascade River valley occurs a quartzitic blastomylonite (specimen D-25-1-c) with very strong b lineation. Some of the blastomylonite is strongly deformed into drag folds. The schistosity observed in the field is parallel to the axial planes of these folds. A section cut perpendicular to the folds (specimen D-25-1-b) shows disharmonic folding of muscovite-rich and quartzitic layers and an incipient s_2 parallel to the axial planes of the folds. The muscovite and sericite grains in the argillaceous bands have been bent where minute drags or shears cut them. Some of the fine grained quartz in the quartzitic bands shows a slight tendency to be oriented with the long dimension parallel to the incipient s_2.

On the ridge west of the 5200 foot knob above upper Falls Lake, less than 20 feet inside quartz diorite of the Snowking massif, is found an inclusion of garnet-two mica zoisite quartzite (specimen D-44-1-d). In the field the impression was that the granitic rock had been sheared to produce the schistose-appearing zone, which is about 1 1/2 feet wide. In the specimen quartz (85%) is strongly strained and broken into subindividuals. It is in small to large, xenoblastic grains. Muscovite (5%) is in small, xenoblastic crystals, and it formed synkinematically for the most part. A few transverse grains occur. Biotite (5%) is synkinematic, and some crystals are partially altered. Zoisite (5%) occurs in small, xenoblastic strung-out grains.

In the cirque northwest of the knob, probably outside the Snowking massif, is a mylonitic quartzitic biotite-garnet schist (specimen D-45-2-b). Besides fine to fairly coarse grained, xenoblastic quartz (80%), it contains fine grained, xenoblastic plagioclase (10%?). Garnet (5%) forms small idioblastic crystals with cloudy cores. Synkinematic biotite (5%) is partially altered to light green clinochlore and penninite. Muscovite, sphene, graphitic material, and opaques (pyrrhotite ?) are accessories. Mortar is found in zones throughout the rock. Also at this locality occurs a synkinematic quartzitic biotite schist (specimen D-45-3-c) containing (10%) plagioclase (An 32) concentrated in bands with biotite. The plagioclase crystallized late, for it includes quartz and biotite in quantities approaching sieve texture. Biotite (10%) is synkinematic with a few post-kinematic transverse crystals, whereas accessory muscovite is late-kinematic and post-kinematic. The quartz (80%) is strongly strained and displays incipient fracturing to subindividuals.

Because of the occurrence of these rocks isolated so far from other observed quartzitic schists one hesitates to definitely assign them to the same unit. However, they are very similar petrographically to the quartzitic schists occurring near Boulder Creek and on Razor Back.

The occurrence of biotite indicates that the quartzitic schists were metamorphosed at temperatures at least as high as those of the mesozone. On the Jordan Creek-Boulder Creek ridge the chlorite almost contemporaneous with the biotite and the closely adjacent phyllite suggests, apart from the anomalous diopside quartz schist described above, that these were formed in the coolest mesozone. On Razor Back one of the schists included in the granitic rock contains contemporaneous biotite and chlorite, indicating crystallization at temperatures close to the epi-mesozonal boundary. Outside the contact on Razor Back the rocks contain biotite and hornblende and are at least mesozonal, whereas just a few hundred yards away contemporaneous chlorite and biotite characterize the rocks. The fact that chlorite is dominant another few hundred yards away makes this telescoping of the metamorphic zones even more obvious. On the ridge between Boulder Creek and Found Creek, the quartzitic schists are associated with more pelitic schists containing biotite, clinozoisite, and sodic andesine, an assemblage indicative of the warmer mesozone.

The quartzitic schists were derived from slightly to fairly argillaceous sandstones, some of which contained calcareous components.

Schists and Para-amphibolites

The second unit is comprised of schists and para-amphibolites occurring on the Illabot Creek-Jordan Creek ridge adjacent to the granitic contact, on the ridge between Boulder Creek and Found Creek, and on the ridges on either side of Kindy Creek.

On the Illabot Creek-Jordan Creek ridge about 200 yards from the contact is exposed an amphibolite (specimen B-3-1-d) which contains 65% late-kinematic and post-kinematic, fine grained, xenoblastic to idioblastic hornblende with the absorption; Z=greenish brown, Y=brownish olive green, and X=light brown. A minor amount has the absorption; Z=green, Y=tannish green, and X=very light tan. All gradations between the two types occur, and the absorption does not seem to affect the extinction angles. The rock also contains somewhat altered fine to medium grained, xenoblastic plagioclase (20%) including hornblende in sieve texture, biotite (5%) from hornblende, sphene (3%) in sheared out appearing aggregates, small to medium sized anhedral diopside (2%) concentrated in one band, quartz (5%), calcite in a fracture, and clinozoisite. The rock has been subjected to late shearing.

Nearby occurs a banded amphibolite (specimen B-1-2-a) containing hornblende (50%) varying in absorption. The principal type of absorption is Z=olive green, Y=light olive green, and X=light greenish tan. This grades in some crystals without change in extinction to Z=light green, Y=lighter green and X=light tan. The rock contains 15% iron-poor epidote, partially in a coarse grained segregation associated with diopsidic augite (5%) in a compositional band. Plagioclase (25%) occurs in small, xenoblastic, somewhat zoned grains and in fairly large porphyroblasts which include fine grained hornblende in helicitic structures. Some of the grains appear to have been strained and broken down into subindividuals. The distribution of the plagioclase is controlled by compositional banding. Quartz (5%), sphene, graphitic material, and opaque minerals make up the rest of the rock. Strong late shearing has taken place, especially in the hornblende and pyroxene-rich bands, and the opaque minerals tend to be concentrated along the shears. Thus the metamorphic-structural history of the rock is as follows: 1) shearing and re-crystallization forming crystallization foliation and the main mineral assemblage, 2) folding of the foliation, 3) growth of the plagioclase porphyroblasts, 4) shearing, 5) late fracturing and filling of the fractures.

From the same locality specimen B-1-2-b, an amphibolite, contains 65% light green hornblende which is in very fine aggregates except near an epidote-rich band where it is somewhat coarser. Plagioclase (15%) includes hornblende in sieve texture. Late, crosscutting veinlets are filled with plagioclase (albite?) and calcite. The rock is quite similar in overall aspect to specimen B-1-2-a discussed above, and appears to have undergone cataclassis and some recrystallization. Associated with these amphibolites is a partially chloritized biotite schist with plagioclase which has been sericitized in zones of late shearing. The biotite that is not entirely altered to chlorite is partially altered and has weaker absorption and lower birefringence than well-preserved biotite.

Adjacent to the contact of the Snowking massif on the ridge west of the 5200 foot knob above Upper Falls Lake occur similar para-amphibolites containing diopside- and clinozoisite-bearing lime silicate bands and hornblende (30 to 80%) with varying absorption. They contain 55 to 65% plagioclase (sodic andesine). In the specimen with the high plagioclase content are two replacement bands. Quartz is mostly absent. Crystallization is dominantly late-kinematic and post-kinematic, but some late shears occur.

At about 4500 feet on the ridge east of Kindy Creek a biotite schist is exposed (specimen C-55-2) which contains fine grained quartz and plagioclase (75%), synkinematic biotite (20%), clinozoisite, sphene, potash

PLATE VII

Fig. 1 Disharmonic folding in phyllitic two mica quartzite. Mesozonal portion of the Cascade valley schist zone. (specimen C-25-2) 17x, plane light.

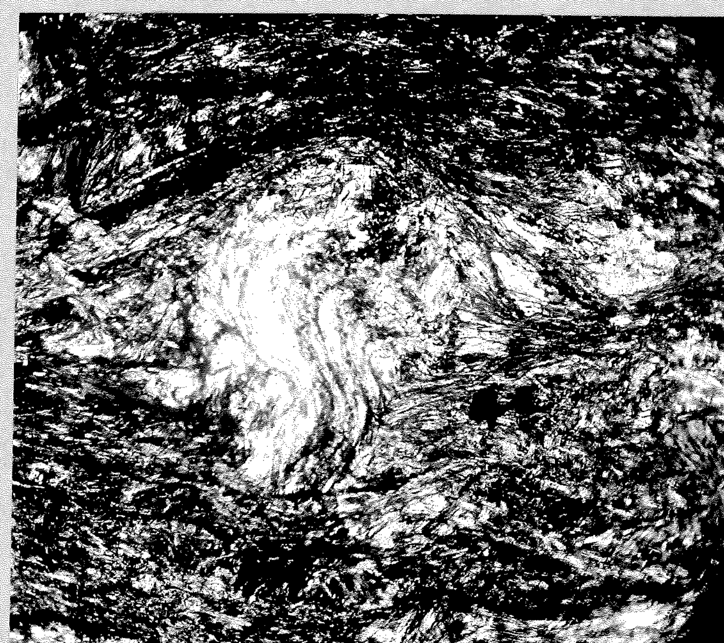

Fig. 2 Helicitic structure in plagioclase porphyroblast in amphibolite. Mesozonal portion of the Cascade valley schist zone. (specimen B-1-2-a) 60x, crossed nicols.

feldspar, and apatite. The earlier banding has been cut by shears during the latest phase of movement. The late movement determined the alignment of the biotite.

Adjacent to the northeastern contact of the Snowking massif on the east side of the head of Sonny Boy Creek are several rocks which are quite rich in plagioclase but display no definite evidence of soda metasomatism and fall within the limits of composition of the isochemical rocks discussed in the Green Mountain Unit (see Chapter IIIB3c below). However, they have undergone considerable recrystallization under static conditions, and the quartz and feldspar have tended to develop pavement texture. One reversely zoned crystal varies in composition from An 31 in the core to An 37 on the rim. Hornblende (25%) is synkinematic with crystallization lasting longer than deformation, is fine to medium grained, xenoblastic to hypidioblastic, and has sieve texture. Its optical properties are: $Z \wedge C = 18^{\circ}$, Z=lightish green, Y=light green, X=light tan. Biotite (10%) is synkinematic and fine to medium grained. Quartz (15%), apatite, and opaque minerals constitute the rest of the rock. The quartz and feldspar tend to be elongate parallel to the foliation. Crystallization lasted longer in some portions of the rock than in others. Nearby is a garnet-bearing biotite schist (specimen C-2-5) which contains 40% plagioclase An 28, 40% quartz, 20% postkinematic, mimetically oriented biotite, garnet, clinozoisite, apatite, sphene, and opaque minerals. It displays pavement texture modified by the weak lepidoblastic tendency of the biotite.

Associated with the quartzitic schists near the contact of the Snowking massif on the ridge between Boulder Creek and Found Creek is a clinozoisite and garnet-bearing biotite schist (specimen C-13-2-f) containing sodic andesine, late kinematic and post-kinematic biotite (15%) with a tendency to be aligned parallel to the axial planes of the minor folds, clinozoisite, garnet, muscovite, sphene, and apatite. The proportions of quartz and feldspar (total 85%) are uncertain due to the generally fine grain size of the mosaic they form. Locally they are medium grained.

At 1400 feet on the south side of the Cascade River valley west of Kindy Creek is a clinozoisite-two mica blastomylonite (specimen C-25-1) containing 70% quartz and plagioclase, mainly as fine mortar. The plagioclase (sodic oligoclase) has some zoning and occurs sometimes as small porphyroblasts with sieve texture. In places a somewhat coarse mosaic is developed in the quartz. Biotite (15%) looks as if it had been shredded and partially recrystallized. It formed synkinematically and post-kinematically. Muscovite (10%) is synkinematic, clinozoisite (5%) occurs in small to very small, xenoblastic to idioblastic grains, and green penninite has formed from biotite. Apatite, sphene, zircon, calcite and opaque minerals are accessories. The rock has some banding of the quartzose, argillaceous, and calcareous layers. The association sodic oligoclase and clinozoisite suggests that this rock crystallized at cooler mesozonal temperatures.

On the ridge between Found and Kindy Creeks just outside the contact of the Snowking massif, chlorite-hornblende schists and biotite-hornblende schists are exposed. The former (e.g. specimen C-26-4) contains 35% fine to medium grained, xenoblastic to hypidioblastic hornblende, somewhat actinolitic in aspect with the properties; $Z \wedge C = 16^\circ$, Z=lightish drab green, Y=light drab green, and X=very light yellowish. The hornblende formed synkinematically with crystallization lasting longer than deformation. Light greenish clinochlore (5%) occurs in small to medium sized, xenoblastic to hypidioblastic grains and is synkinematic although a few post-kinematic transverse crystals are present. Some of it is derived from hornblende. Essentially it is contemporaneous with the hornblende except that crystallization of the chlorite probably started later and lasted longer. Also penninite occurs as pseudomorphs after biotite. Plagioclase (35%) An 32 is found in small anhedral grains with some normal zoning. Adjacent to a quartz segregation it is medium grained. Garnet occurs as large, hypidioblastic to idioblastic crystals. A minor amount of rather pale brown biotite has formed from hornblende. Muscovite, apatite, and opaque minerals are the accessories.

Specimen C-26-5-b, a biotite-hornblende schist, is similar except that the hornblende (30%) has $Z \wedge C = 18$ and has somewhat stronger absorption; Z=green with a bluish tinge, Y=lightish drab green, and X=light greenish tan. The hornblende is synkinematic, biotite (15%) is synkinematic with crystallization outlasting movement, and chlorite synkinematic and post-kinematic. Thus the chlorite and biotite are mainly contemporaneous, but the crystallization of the chlorite lasted longer than that of the biotite. The rocks were probably derived from argillaceous tuffs. The crystallization during falling temperature, as indicated by the development of the chlorite, apparently did not affect the sodic andesine.

Associated with the quartzitic schists above the falls of Kindy Creek is a band of amphibolite about 25 feet thick. It is characterized by fine to fairly coarse grained, post-kinematic hornblende (55%), which replaces the fine grained plagioclase and quartz (30%). Carbonate (10%) forms fairly small crystals that tend to be in aggregates. Light green clinochlore (5%) from hornblende, biotite, clinozoisite, sphene, and opaque minerals make up the rest of the rock.

Although lime silicate bands and biotite bearing bands occur in the amphibolites of the mesozonal portion of the Cascade valley schist zone, they contain quite a bit of plagioclase. This suggests that they were derived from tuffaceous shales or subgreywackes.

General Conclusions

Generally the rocks of the mesozonal portion of the Cascade valley schist zone have undergone a greater amount of shearing in the later part of their development than the ordinary schists, as for instance, those in the Green Mountain Unit of the present area. Lack of access to and outcrop at the lower elevations south of the Cascade River at the present time would make it very difficult, if not impossible, to carry out the detailed study necessary to delineate any zones where the later deformation might be concentrated. The majority of the rocks showing late movement are blastomylonites rather than ordinary mylonites. Thus the deformation was late-metamorphic rather than post-metamorphic, and the mylonites produced were recrystallized in varying degrees.

Illabot Creek Schist Zone

General Statement

In the lower part of the Illabot Creek trough mesozonally metamorphosed sediments and volcanics occur east of Bluebell Creek between the Chaval unit and the Northern unit of the Snowking massif. The heavily wooded and brushy valley sides were not thoroughly explored to determine the full extent of this unit. Schists were observed below 2500 feet elevation just east of Bluebell Creek, and below 3400 feet elevation on the ridge east of Arrow Creek, and at 3000 feet on the ridge between

Otter Creek and Illabot Creek. Outcrops are rather scarce on the densely forested, though steep slopes. In part these schists have undergone soda metasomatism. From 3600 to 4600 feet elevation on the ridge east of Illabot Creek adjacent to the Chaval unit of the Snowking massif, statically recrystallized amphibolites occur.

Schists

At about 2000 feet elevation in a gulley on the south side of the Illabot Creek trough east of Bluebell Creek a biotite schist (specimen C-50-1) containing 45% fine grained, xenobalstic quartz is exposed. Plagioclase (30%) with a composition of about An 30 occurs in very small grains. Synkinematic biotite (15%) forms small, rather strongly altered crystals. Light green, retrogressive clinochlore (5%) has replaced biotite and occurs in post-kinematic transverse crystals. Carbonate (5%) is found in fractures and scattered thoughout the rock. Muscovite (post-kinematic), clinozoisite, hornblende, graphitic material, and opaque minerals complete the rock.

At about 3000 feet elevation on the Otter Creek-Illabot Creek ridge occurs a biotite garnet schist (specimen A-50-1). Whether it is contiguous with the other schists in the Illabot Creek trough is uncertain. It is thinly bedded, with alternating quartz-rich layers and mica-rich layers. It contains 65% quartz, 20 % synkinematic biotite, and 5% plagioclase. Garnet (5%) formed somewhat later than the biotite and occurs in small to medium sized, subhedral to euhedral porphyroblasts. Clinochlore (5%) is xenoblastic to idioblastic and is late- and post-kinematic. Some large, well-formed porphyroblasts occur.

The occurrence of biotite indicates that these rocks were metamorphosed under at least mesozonal termperatures. Crystallization was synkinematic followed by a fairly strong, post-kinematic phase under conditions of the warmer epizone, which formed the late chlorite.

In addition to the isochemical rocks, albitized schist occurs on the ridge east of Arrow Creek. Only a few specimens were studied, and although schist float occurs up to 3400 feet on this ridge, it is uncertain how much of the rock is albitized along the ridge up to that elevation.

The specimens from the highest outcrop found in the portion of the ridge in schists consist of a partially chloritized epidote-biotite granulite (specimen D-8-3-a) and an epidote-biotite-muscovite-chlorite blastomylonite (specimen D-8-3-b). The granulite contains 75% quartz and plagioclase. In part it is very fine grained; so it is difficult to estimate the percentages of quartz and plagioclase. Plagioclase with a composition of An 32 seems to comprise about 25% of the rock. Besides very small crystals, it forms a few medium sized porphyroblasts, which are heavily altered to epidote and muscovite. Because of the alteration, the plagioclase may be somewhat more sodic than the composition given above. Iron poor epidote occurs in small, xenoblastic, partially skeletal, crystals. Directionless, fine grained, xenoblastic to hypidioblastic biotite makes up 5% of the rock. Light green clinochlore (15%) occurs as pseudomorphs after biotite. Muscovite, sphene, and opaques are accessories.

The blastomylonite contains 40% plagioclase and quartz, which is mostly very fine grained. A few large plagioclase crystals occur, and they include some quartz and biotite. They are heavily altered to sericite and clinozoisite. Unaltered crystals have a composition of about An 35. Fine grained, xenoblastic, late-kinematic and post-kinematic biotite amounts to 5% of the rock. Light green clinochlore is post-kinematic and partially contemporaneous with the biotite. Muscovite (15%) is late-kinematic and static. Epidote (5%) occurs in small, xenoblastic crystals, some of which are skeletal. In this rock the micas and chlorite re-crystallized after movement. Also a few plagioclase porphyroblasts grew at that time. Whether soda metasomatism played a part in their growth is not known. In view of soda metasomatism in adjacent rocks (see below), it seems likely that a small amount of soda introduction occurred here. A two mica quartzite (specimen D-7-a) occurs at 2600 feet elevation. It contains 85% quartz in a mosaic of sutured small to medium sized grains. Fine grained muscovite (10%) occurs in bands. Biotite (5% counting also the chlorite after biotite) has been partially altered to light brown penninite and light green clinochlore. Sphene and graphitic material are accessories. A few grains of albite occur. The muscovite-rich bands display tiny drag folds.

On the ridge at about 2500 feet elevation occur albite porphyroblast gneiss and biotite-sericite blastomylonite containing albite porphyroblasts. The gneiss (specimen D-7-1-a) contains 50% quartz mainly in small, xenoblastic grains, but also in medium sized porphyroblasts. Plagioclase with the composition An 4 constitutes 40% of the rock and is fine to medium grained and xenoblastic. The larger grains are post-kinematic porphyroblasts. Biotite (5%) occurs in late kinematic to post-kineamtic porphyroblasts, which are small to medium sized and anhedral to euhedral. They are somewhat sheared. Muscovite (5%) has formed from biotite and is synkinematic. Carbonate and zircon are accessories. This rock was metamorphosed under synkinematic and post-kinematic mesozonal conditions and underwent late shearing and albitization.

The biotite sericite blastomylonite (specimen D-7-1-b) contains

45% quartz in small, xenoblastic grains and medium sized, anhedral, strongly strained porphyroblasts. Albite (35%) occurs also in small, xenoblastic grains and medium sized porphyroblasts. Muscovite and sericite (15%) are concentrated in bands. Biotite is small to medium sized and xenoblastic to idioblastic. Carbonate and chlorite are accessories.

As a whole these albitized rocks have undergone mesozonal synkinematic and post-kinematic metamorphism followed by late shearing and introduction of soda leading to albitization, which was contemporaneous with the formation of late muscovite, partly after biotite. The quartz-rich rock was more resistant to soda metasomatism than the other rocks.

Amphibolites

Between 3400 and 4600 feet elevation on the ridge east of Arrow Creek ortho-amphibolites occur adjacent to the quartz diorite of the Chaval unit of the Snowking massif. They are similar to ortho-amphibolites found in a zone on the Big Creek-Tenas Creek ridge south of the Chaval unit (see Chapter IIIB3cvii below). In the field these ortho-amphibolites look migmatitic, but none of the specimens collected from supposedly feldspathized rock display any evidence of feldspathization when studied under the microscope.

The amphibolites contain 60 to 70% fine to coarse grained, xenoblastic to hypidioblastic hornblende which varies from light green to brown. Specimen D-7-3-a, a piece of float from about 3500 feet elevation on the ridge, has actinolitic hornblende with $Z \wedge C = 14^{\circ}$ and the pleochroism formula; Z=light drab green, Y=light greenish tan, and X=very light tan. Specimen D-7-3-c from the same locality has light green and brown hornblende, the brown variety forming patches in the green crystals. In specimen D-8-1-a from an outcrop at about 4500 feet elevation on the ridge east of Arrow Creek the hornblende has an extinction angle of 31° and a patchy brown and green absorption. Sometimes green hornblende occurs as only a rim on the brown hornblende crystals in this rock.

Plagioclase (30 to 35%) occurs in small, xenoblastic crystals which are, in part, normally zoned. They range from An 40 to An 27 in composition. In specimen D-7-3-a, which is a dioritic amphibolite, the plagioclase forms large grains.

Small to medium sized, xenoblastic quartz grains make up 0 to 5% of the rocks. Light green clinochlore from hornblende occurs in quantities varying from a trace to 5%. Specimen D-7-3-c contains zoisite (10%) in small to medium sized, xenoblastic grains. Epidote, sphene, apatite, rutile, and magnetite are accessories.

One specimen (D-7-3-b) of float from 3500 feet elevation on the ridge is a metamorphic hornblendite and contains over 95% small to large, xenoblastic to idioblastic hornblende crystals.

These rocks look migmatitic because they have undergone differential static recrystallization and metamorphic differentiation. In the coarsely recrystallized rocks the plagioclase is much more obvious than in the unrecrystallized or finely recrystallized rocks.

Conclusions

In some specimens of both the schists and the amphibolites of the Illabot Creek schist zone the association of sodic andesine with epidote minerals indicates that these rocks have been metamorphosed at temperatures of the warmer mesozone. If the temperature had been higher, the epidote minerals would have supplied more anorthite component to the plagioclase; if it had been lower, the plagioclase would have been able to hold less anorthite. These relationships have been treated by Peter Misch (1954). Soda introduction in some of the schists took place under later, cooler conditions.

The signifigance of the position of the Illabot Creek schist zone between the Northern unit of the Snowking massif and the Chaval unit is a problem that can be solved only by further and more detailed observations which will be impossible to make until the thick forest of the Illabot Creek valley is logged.

Green Mountain Unit

General Statement

The Green Mountain unit of mesozonal, isochemically metamorphosed schists and amphibolites occurs in the southeastern quarter of the Snowking area and is best displayed in the vicinity of Green Mountain, farther north along the ridge to Buckindy, and on the south ridge of Downey Mountain. On the lower part of the Tenas-Big Creek ridge and on the north side of the Big Creek valley, schists and amphibolites are also found.

In addition, isochemically metamorphosed rocks predominate in the somewhat migmatitic zone of Huckleberry Mountain, and to a lesser degree in the scattered outcrops along the northern Suiattle road. On the Bench Creek-Downey Creek ridge a few bands of isochemical rocks are preserved in the gneisses.

The boundary between isochemical and allochemical rocks is rather arbitrary because there are all gradations. The distinction is based on quantitative mineral compositions and textures. For example, plagioclase-rich and coarsely recrystallized rocks associated with less plagioclase-rich and less coarsely recrystallized rocks, which otherwise are of the same general type and mineral composition, suggests that the former have been metasomatically feldspathized.

The age of these rocks is unknown. To the north they pass into the Snowking massif, which is bordered by faults and intrusive contacts on the north and west sides. To the west they are cut by the Straight Creek fault. To the southeast they have not been studied. It can only be said they belong to part of the composite sequence of the part of the Cordilleran eugeosyncline, in which very rare fossils have shown ages ranging from Ordovician to Cretaceous (see discussion in Chapter VA below).

Pelitic Schists with Al-excess Minerals

Pelitic schists with Al-excess minerals are relatively rare in the Snowking area, and their occurrences are rather scattered. Only seven definite examples were found; three on the ridge north of Green Mountain, one on Huckleberry Mountain, one in the Suiattle valley, one on the Tenas Creek-Big Creek ridge, and one in an inclusion in granodiorite on Snowking Mountain.

The best example is a staurolite-garnet-two mica schist from about 3000 feet elevation on the Tenas Creek-Big Creek ridge (specimen D-17-a). It contains less than 5% staurolite in small to fairly large, xenoblastic to hypidioblastic crystals with the normal absorption (Z=yellow, Y=light yellow, and X=light pinkish tan). It is partially altered to muscovite, sericite, and biotite with some finely divided magnetite (?). Also present is a small grain of probable kyanite, in a sericitic alteration patch. Garnet makes up 5% of the rock and is in medium sized, xenoblastic to hypidioblastic crystals that deflect the mica trends. Biotite makes up 20% of the rock, and three generations can be distinguished; I synkinematic, II post-kinematic (probably represents a continuous sequence with I), and III from later alteration of staurolite. Muscovite (5%) has a similar history, but is mainly sericitic in III. A considerable amount of light green clinochlore has formed from biotite. Quartz and plagioclase make up about 65% of the rock, but are so fine grained that it is difficult to determine their exact proportion. The plagioclase has a composition of about An 28. Accessories are apatite, rutile, sphene, zircon, tourmaline, iron-poor epidote, and graphitic material.

On the ridge north of Green Mountain occurs a garnet-biotite schist containing a few very small, xenoblastic staurolite crystals surrounded by secondary sericite (specimen A-18-1-a). Biotite (10%) is synkinematic and post-kinematic, while garnet (5%) is in fairly large to fairly small, xenoblastic to idioblastic crystals with some sieve texture. The rock contains 35% plagioclase An 25. Rutile, tourmaline, and graphitic material are accessories.

On the summit of Green Mountain occurs a garnet-two mica schist (specimen B-10-2) which contains muscovite and sericite in large knots making up 35% of the rock and including a few grains of relict kyanite. Both within and outside these aggregates large muscovite porphyroblasts are found. The rock also contains large garnet porphyroblasts with sieve texture and a zonal arrangement of the inclusions (mainly quartz, but also rutile, plagioclase and finely divided opaque material). Biotite (15%) is fine to medium grained and xenoblastic to hypidioblastic. About half of it is chloritized. Quartz makes up 50% of the rock. Rutile, plagioclase, apatite, and graphitic material are accessories.

On Huckleberry Mountain a similar garnet-two mica schist (specimen B-8-1-b) contains large muscovite crystals (10%) tending to be in knots, which include a few very small grains of relict kyanite. A few plagioclase crystals include small, xenoblastic grains of staurolite. Another specimen from the same locality (specimen B-8-1-c) is a partially chloritized biotite schist with similar knots of sericite. In this rock chlorite and relict garnet are associated with the sericite knots, indicating that they have been derived from garnets. Similarly, in specimen B-8-1-e from the same locality knots of sericite appear to have formed with chlorite and clinozoisite from some garnets.

About 1.1 miles west of Downey Creek on the north Suiattle road a chloritized garnet-two mica schist (specimen A-9-1-b) has about 10% muscovite and sericite. The sericite occurs in knots, probably representing porphyroblasts which were altered after the formation of the first, synkinematic generation of muscovite. Biotite (5%) is synkinematic and partially altered to chlorite (5%). Large, subhedral to anhedral, sieve textured almandine porphyroblasts (10%) with inclusions of quartz, plagioclase, and rutile are surrounded by polygonal arcs of both micas and are slightly altered to biotite and chlorite. Plagioclase with the composition An 31 and quartz are present in about equal amounts. Apatite, rutile, and graphitic material are accessories. The rock displays excellent crystallization foliation and a marked b lineation. In a section perpendicular to b, a more complex history of the rock is apparent. The garnets have formed later than the plane foliation (s), and inclusions representing that s trend, or s_i, in the garnets show the garnet grains have been rotated subsequent to formation. Also, one garnet grain has been broken and healed by quartz. During the later phase of movement the micas recrystallized, for they show no effects of deformation. Then quartz and plagioclase partially recrystallized to larger crystals and porphyroblasts, biotite formed from garnet under static conditions, and finally retrogressive chlorite formed from biotite and garnet.

Specimen B-11-1-a, a garnet-two mica schist from the west ridge of Green Mountain, also has about 15% sericitized porphyroblasts containing no identifiable relicts. The garnets are unaltered, which suggests that the sericite patches represent a former aluminum silicate mineral.

At 5600 feet elevation on the northwest side of a knob about 3 miles N 80° W from the summit of Snowking is an inclusion of staurolite-garnet-two mica schist (specimen A-60-1) in biotite granodiorite. The staurolite (3%) forms medium to small, xenoblastic to hypidioblastic crystals with the absorption: Z=yellow, Y=light yellow, and X=light yellow. The grains are filled with graphitic inclusions. Fine grained, xenoblastic biotite is synkinematic and post-kinematic and forms polygonal arcs with chlorite. The chlorite occurs as post-kinematic, medium sized, anhedral porphyroblasts, some with polysynthetic twinning. The chlorite (5%) is derived from biotite. Muscovite (5%) is partially synkinematic and partially post-kinematic. In some places the post-kinematic muscovite forms large, anhedral porphyroblasts with helicitic structure. Garnet occurs in small to large, idioblastic crystals which are generally free from inclusions. Quartz makes up 50% of the rock, and zoned plagioclase (An 33) constitutes 25% of it. Graphitic material, tourmaline, and opaque minerals are accessories. The history of this rock can be summarized as follows: formation of s and growth of synkinematic minerals; growth of staurolite; folding of s; growth of garnet and staurolite; and static growth of muscovite and chlorite porphyroblasts.

The Al-excess-mineral bearing rocks of the Snowking area are characterized by staurolite and kyanite, which indicate that regional metamorphism took place under conditions of the warmer mesozone (kyanite zone). The Al-excess minerals were not stable under the conditions present during the latest, retrogressive phase of crystallization, when the muscovite and sericite formed.

These rocks contain on the average considerably more plagioclase than one would expect in rocks derived from a pure shale. The soda content of these Al-excess rocks is equal to that of Pettijohn's average subgreywacke (1949, p. 256). Only the specimen from the Big Creek-Tenas Creek ridge has the composition of a pure shale. Thus the shales from which these schists were derived were typically eugeosynclinal rocks, being impure and probably containing considerably more fine grained clastic fragments of feldspar than geochemically mature shales, which have a significantly lower soda content.

Pelitic Schists Without Al-excess Minerals

The ordinary pelitic schists are distinguished from the Al-excess rocks by a lack of aluminum silicate minerals of pseudomorphs after such minerals. Chemically the boundary is gradational, and the amount of aluminum in this group varies greatly, as indicated by the great variability in the quantity of mica. The rocks of this group contain little or no hornblende and/or epidote minerals. Generally these rocks can be considered as Al-saturated without having an Al-excess. Such schists occur at various localities throughout the area of the Green Mountain unit. They tend to be more abundant in association with the rocks of the Al-excess class than those groups described below.

These rocks are garnet-biotite schists and garnet-two mica schists. Their biotite content varies from 5 to 35% (average 15%); almandine varies from 0 to 10%; and muscovite from 0 to 10%. The micas usually have formed synkinematically with crystallization lasting longer than deformation. Sometimes the crystallization of the muscovite has lasted longer than that of the biotite. Almandine forms porphyroblasts, sometimes with sieve texture, and it tends to be late-kinematic or post-kinematic. Occasionally some biotite is later than garnet. The biotite has sometimes been altered to light green clinochlore. The amount of plagioclase varies from 1 to 55%, and its composition averages An 30-35. Accessories are sphene, rutile, zircon, tourmaline, and graphitic material. In addition some epidote and/or hornblende are occasionally present.

Several specimens from Huckleberry Mountain and below it contain almandine altered to sericite, chlorite, clinozoisite, and an opaque mineral, probably magnetite. Among these alteration products, sericite predominates and is associated with one or several of the other minerals mentioned. In many pseudomorphs no garnet relicts are present, and the shape of the sericite masses suggests derivation from a mineral other than garnet. In some cases the alteration patch might be derived from an aluminum silicate. In others, however, the presence of clinozoisite in the pseudomorphs argues against such an hypothesis for obvious chemical reasons.

The inclusions of schist in the granodiorite northwest of Snowking Mountain contain late, statically formed porphyroblasts. One has muscovite porphyroblasts that started to grow under synkinematic conditions and continued to grow after movement had ceased (specimen A-52-1).

North of the Green Mountain Lookout is a garnet-biotite schist with about 60 volume percent of plagioclase An 38 showing marked reverse zoning (specimen A-18-1-b). The high amount of plagioclase corresponds to an Na_2O content of the rock of approximately 4.2% weight (calculated on the basis of a pure albite-anorthite mixture), which is high above that of common shales and even well above that of the average arkose or greywacke (Pettijohn, 1949, p. 250, 259, 271). This large amount of plagioclase must be due either to soda introduction or to an unusually high soda content of the original sediment. There is no indication of soda metasomatism in the vicinity. Therefore, if there were any Na introduction in this rock, it must have been of the "sneaking" or "concealed" variety.[1] Other occurrences of schists with a high Na_2O content were found to be adjacent to definitely metasomatised rocks which have been converted into gneiss. If the high Na_2 content is primary, the sediment must have been of an unusual character, presumably containing both clay and large quantities of clastic feldspar with plagioclase greatly predominating over potash feldspar.

The ordinary pelitic schists contain no minerals or mineral assemblages which fix their exact zonal position. The micas or garnets could be mesozonal or katazonal. In the absence of Ca-excess minerals, such as epidote, the presence of sodic andesine is not critical except to indicate the rocks formed at temperatures at least as warm as the warmer mesozone. Where the andesine is associated with accessory epidote minerals, a position in the warmer mesozone is suggested.

A few of the rocks are derived from fairly pure or from sandy shales, but most of them seem to have been derived from semipelitic sediments high in clastic plagioclase. The plagioclase content in the schists of this group averages 33% with an average composition of An 30.

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[1] "Concealed" soda metasomatism is metasomatism not accompanied by any conspicuous textural evidence of replacement (Misch, unpublished MS).

This average corresponds to an average Na_2O content of 2.7% in weight. Pettijohn gives 2.0 Na_2O as the average for subgrewyackes and arkoses (1949, p. 250, 256, 259). Some of the high Na_2O values in the schists here described may be due to metasomatism. This is difficult to establish because it is not possible to trace these rocks along their strike into an area of low grade metamorphic rocks lacking any pronounced metasomatism.

The question is whether or not an argillaceous sediment can have a high content of clastic feldspar without simultaneously being sufficiently rich in calcium and magnesium to form hornblende or epidote minerals upon metamorphism. Given the right kind of source rocks, this would seem feasible. If intermediate or basic igneous rocks were present in the source area, it would be difficult to obtain the type of rock mentioned above. A geochemically immature sediment derived from the incomplete weathering of a trondhjemitic terrane might have a composition like the soda rich schists of the Snowking Area. Pettijohn cites an analysis of a summer silt layer in a varved clay from Leppakoski, Finland which has 3.8% Na_2O (1949, p. 272). No information is given as to the source rocks. Nevertheless it illustrates the high soda content obtainable in an example of a fine grained, immature sediment.

As regards possible metasomatism, nothing is proved even where schists with a high plagioclase content are associated with migmatitic rocks unless individual layers of the schist can be traced into an area of lower soda content; for the question arises whether a certain layer was granitized because of its higher soda content, or whether its higher soda content is the result of metasomatism associated with its granitization.

Biotite Schists with Epidote and Hornblende

Much of the isochemical rocks of the Snowking area are schists containing garnet, biotite, and/or epidote minerals in varying proportions. They are found throughout the area of the Green Mountain unit except on Huckleberry Mountain.

Normally zoned plagioclase averaging sodic andesine in composition makes up to 10 to 65% of the rocks (average 30 to 35%). Again in some places a close association of plagioclase-rich varieties of these schists with feldspathized migmatitic rocks, such as gneiss layers and replacement dikes suggests that soda may have been introduced.

The schists all contain either biotite or hornblende, or both these minerals. Biotite varies from 0 to 25% (average 10%) and hornblende from 0 to 40% (average 15%). Clinozoisite is the most common epidote mineral, but epidote and zoisite also occur. The amount of epidote minerals in this group varies from 0 to 20%. Almandine is often present in quantities of 5% or less, but reaches a maximum of 15%. Common accessories are sphene and apatite. Muscovite, rutile, graphitic material, and opaque minerals are less common.

In the field, in hand specimen, and in thin section many of the rocks of this group are banded. On the 6622 foot peak on the Buck Creek-Downey Creek divide occurs a hornblende-biotite schist (specimen B-14-1-a) containing 20% biotite and 1% hornblende in some bands and 5% biotite and 10% hornblende in other bands; the two types of bands grade into each other. On the south ridge of Downey Mountain a very sharply banded biotite-plagioclase schist is exposed (specimen C-19-2-b). Its biotite-rich bands contain as much as 45% biotite with or without hornblende, which reaches a maximum of 5 to 10%. Its hornblende-rich bands contain about 30% hornblende and only minor biotite. These bands are about 1/4 inch thick.

On Green Mountain Lookout occur garnet-zoisite-biotite-schists and zoisite-garnet-hornblende schists. In specimen A-16-1-e xenoblastic zoisite crystals greatly varying in size make up about 3% of the rock. The zoisite poikiloblastically includes the other minerals and has replaced plagioclase. Also present is 25% of xenoblastic to hypidioblastic hornblende varying from small to large in grain size. It has sieve texture. Medium to fairly large, hypidioblastic almandine grains make up 5% of the specimen. They have sieve texture, including clinozoisite, quartz, plagioclase, and rutile. Plagioclase amounts to 35%. Its composition averages An 33, and it is inversely zoned. Much of it occurs in a directionless mosaic formed by static recrystallization. The quartz content is 25% if a replacement stringer in the thin section studied is included. Minor constituents are rutile and sphene, which tends to rim the former, apatite, biotite formed from hornblende, and garnet. The other rock mentioned from this locality (specimen A-16-1-f) contains 8% of zoisite in rather spectacular porphyroblasts, which include a few grains of biotite, quartz, and clinozoisite. In a few places these late zoisite porphyroblasts are associated with earlier formed, smaller zoisite crystals occurring in the groundmass. There are all transitions between the earlier groundmass zoisite and the later porphyroblasts of the same mineral. The groundmass zoisite is similar to small, xenoblastic to idioblastic clinozoisite grains, which are present throughout the rock and constitute 4% of it. Synkinematic and post-kinematic biotite makes up 20% of the rock. Its crystallization lasted longer than that of the garnet. Almandine amounts to 3% and forms medium-sized to fairly large, subhedral porphyroblasts which poikiloblastically include clinozoisite. The rock contains about 50% of inversely zoned plagioclase. In one crystal composition was determined to change from An 27 to An 31. Quartz amounts to 16%. Hornblende, sphene with rutile cores, and opaques make up the rest of the rock. With regard to the spectacular zoisite porphyroblasts, perhaps static recrystallization under conditions of rising temperature favors the formation of such porphyroblasts in a rock of this composition.

North of the Green Mountain Lookout a garnet-bearing biotite schist (specimen A-17-1) was collected in which biotite occurs (1) in polygonal arcs, (2) parallel to the axial planes of microscopic folds, (3) in post-kinematic, non-oriented crystals. The rock displays irregular folds of highly plastic appearance. Its original parallel structure (s) is brought out by graphitic material. Biotite crystallized while the s was folded and thus formed polygonal arcs. Continuing crystallization under stress conditions produced biotite which now aligned itself parallel to the axial planes rather than to the limbs and arcs of the folds. Crystallization continued after stress had ceased to operate, and now non-oriented crystals of biotite were formed. The rock also contains large, anhedral to subhedral, sieve textured almandine porphyroblasts including epidote which is concentrated in the marginal parts of the garnet grains. The garnets also contain late epidote and iron oxide along cracks. In some garnets alteration has gone further, producing patches of sericite and of yellowish green chlorite with very low birefringence, which include epidote and garnet remnants.

On the 6622 foot peak at the Downey Creek-Buck Creek ridge occurs a hornblende-plagioclase schist with biotite-rich bands (specimen B-13-1-b). This rock contains several percent of cloudy sphene in crystals elongate parallel to the foliation.

On the summit of the same peak andalong the ridge south of it the plagioclase in the schists tends to be inversely zoned; in one crystal a variation from An 34 in the core to An 65 in the rim was measured (specimen B-14-1-b). In some crystals the zoning is oscillatory with one recurrence. Some static recrystallization of quartz and feldspar has tended to produce a mosaic texture, and in some rocks sieve textured porphyroblasts of hornblende have grown under late-kinematic and static conditions. The calcic rims of the plagioclase in these rocks suggests that in this area somewhat higher temperature prevailed during the later part of crystallization than in most of the rocks of the Green Mountain unit. This later phase of crystallization outlasted deformation.

In two specimens of this group prehnite occurs as an accessory mineral often associated with biotite. In specimen B-14-3-b it is found with biotite derived from hornblende. Specimen B-21-1-e from the north side of the lower Big Creek valley is a biotite-hornblende-plagioclase schist in which some of the hornblende has been altered to biotite and prehnite, and some of the plagioclase has been replaced by prehnite. The prehnite is usually intergrown with biotite, though sometimes it occurs alone in elongate crystals. Also it seems to make up at least part of the mass of fine grained alteration products present throughout the rock. In these rocks prehnite is a second generation metamorphic mineral substituting for the clinozoisite, which is commonly obtained from the biotitization of hornblende and the alteration of plagioclase.

The biotite schists with epidote and hornblende in the Green Mountain unit are characterized by the association of sodic andesine with epidote minerals. If the temperature had been higher, the plagioclase would be more calcic, and if it had been lower, the plagioclase would be less calcic. The presence of epidote minerals, except if they are very sparse accessories, indicates that there was a sufficient supply of potential anorthite component to allow the plagioclase to obtain the most calcic composition possible under the temperature existing during crystallization. This association, andesine plus epidote, is characteristic of the warmer mesozone.

The schists described above have been derived from sediments which, in addition to clay minerals and clastic quartz, contained varying amounts of greywacke, dolomitic, tuffaceous, and/or arkosic components. Thus all gradations exist from garnet-biotite schists containing just a grain or two of hornblende and/or epidote to para-amphibolites containing epidote minerals, garnets, and an occasional intercalated lime silicate layer. Gradations from these schists to ortho-amphibolites also occur, indicating the presence of tuffs.

Para-amphibolites

Para-amphibolites are found scattered throughout the area. The arbitrary boundary separating them from hornblende-rich schists is placed at 40% amphibole content. They are especially conspicuous at the end of the northern Suiattle River road opposite Milk Creek and at about 3000 feet on the south ridge of Downey Mountain. These two occurrences may represent the same general stratigraphic horizon, although their mineral compositions differ. Para-amphibolites are found in the lower Big Creek valley where they are associated with mica and hornblende schists, on Green Mountain and the ridge north of it, on the ridge north of Huckleberry Lookout, and in the migmatitic zone on the Downey Creek-Bench Creek ridge. Many specimens called amphibolite in the field are hornblende-rich schists in thin section. However, if the specimens had been collected a short distance away, they well might have been from a bed with the right composition to allow more than 40% of hornblende to form, which has arbitrarily been set as the limit of the amphibolites.

The para-amphibolites contain 40 to 85% amphibole, usually hornblende. They contain up to 40% plagioclase (average 20%) of an average composition of An 35, in many cases with normal zoning. They have 0 to 10% biotite and muscovite and 0 to 20% quartz. They contain 0 to 40% zoisite, 0 to 30% clinozoisite, and/or 0 to 10% epidote. Some almandine is present. The predominant accessory is sphene, but rutile and apatite are common. Carbonate occurs rarely.

At the end of the northern Suiattle River road is an outcrop from which four specimens were studied. They contain from 50 to 65% hornblende which varies in absorption; X=pale greenish with a pinkish tinge to pale greenish tan, Y=pale yellowish green to green, and Z=pale green to green. The other minerals are 0 to 10% muscovite, 0 to 7% epidote, 0 to 15% clinochlore, 0 to 10% quartz, 1 to 20% plagioclase, and considerable rutile. One specimen (A-5-1-d) contains about 25% iron-poor epidote and has a band consisting of about 65% iron-poor epidote and 35% hornblende. In this specimen considerable sphene rather than rutile occurs in small grains and long strung-out aggregates. Also this specimen has the darker hornblende. Some of the biotite, subsequently pseudomorphosed by chlorite, is synkinematic. Muscovite is partially contemporaneous with biotite but mainly later than it, though earler than the retrogressive chlorite. Some of the muscovite is derived from plagioclase. In specimen A-5-1-d the foliation is preserved within large, post-kinematic hornblende crystals in the form of sharply aligned inclusions of strung out sphene and epidote. The rocks have undergone considerable retrogressive recrystallization under static conditions, first under cooler mesozonal (late muscovite) and then under epizonal (chlorite) conditions.

On strike from the rocks described above, occur zoisite amphibolites. Chemically they are characterized by much more calcium and less iron and magnesium than the rocks at the end of the northern Suiattle road described in the preceding paragraph. They contain 50 to 85% amphibole with $2v=85^{\circ}$, $Z \wedge C=18$, and absorption very pale greenish tan for all directions. Some crystals display weak pleochroism. The amphibole varies from small, xenoblastic, synkinematic grains to large, subhedral, late- to post-kinematic porphyroblasts including fine grained zoisite. Zoisite is present in quantities from 5 to 40% and forms small, xenoblastic to idioblastic crystals which tend to be concentrated in bands. 2 to 10% plagioclase (probably sodic andesine) occurs in small, xenoblastic crystals with some oscillatory zoning. Some very light green clinochlore has formed from the amphibole. Muscovite and sphene are the other accessories. Crystallization in these rocks has continued under post-kinematic conditions but not to as great an extent as in those at the end of the Suiattle road.

On Huckleberry Mountain occurs an amphibolite (specimen B-7-2-a) containing a few percent diopside concentrated in hornblende rich bands. Other bands are plagioclase rich, and one thin layer carries garnet throughout its extent in both the thin section and hand specimen. Normally zoned plagioclase averaging An 45 makes up 40% of the rock. Clinozoisite, zoisite, sphene, carbonate, and opaques are accessories.

On the south side of the col south of the Chaval ridge occurs a zoisite amphibolite (specimen A-32-1) as a remnant in the gneiss. It contains 20% plagioclase with very strong normal zoning, sometimes with faint oscillations, ranging in composition from An 60 to 32. Hornblende amounts to 75% and has the following absorption: X=pale tan, Y=light greenish tan, and Z fairly light tannish green. It grew both synkinematically and post-kinematically. Clinozoisite and zoisite make up 5% of the rock, and in one band are large, anhedral to subhedral zoisite porphyroblasts including earlier plagioclase and hornblende and replacing hornblende. In some cases the zoisite porphyroblasts are surrounded by later plagioclase. Accessories are rutile, apatite, garnet, and quartz.

On the 6622 foot peak on the Downey Creek-Buck Creek ridge occurs a biotite-bearing garnet amphibolite that is transitional in composition between an ortho-amphibolite and a para-amphibolite (specimen B-13-1-a). It contains 40% oriented synkinematic and minor late transverse hornblende which has the following absorption: X=light green, Y=green, and Z=dark green. Plagioclase of average composition An 32 amounts to 35% and is fairly strongly zoned. Quartz makes up 15% of the rock. Sphene and apatite are accessories. Medium to large, subhedral garnet porphyroblasts make up 5% of the section. They show snowball structure of the variety indicating that growth lasted longer than movement. Many of them are fractured. Some of the fragments have been strung out, and the intervening space has been filled by quartz. Two phases of movement took place during crystallization, one during the formation of the foliation (s) and the early part of garnet growth, and one after garnet growth. Synkinematic biotite amounts to 5% and is concentrated in a band with hornblende. The biotite-bearing band represents a more shaly bed in a sequence that must have been dominantly tuffaceous. Without that bed and the concentration of garnets in certain bands one might mistake this rock for an ortho-amphibolite.

The para-amphibolites are characterized by the joint occurrence of sodic andesine and epidote minerals, which is indicative of the warmer mesozone. In the rocks in which the plagioclase contains considerably more calcic cores, ranging up to sodic labradorite in composition, there is no evidence that the epidote minerals crystallized at the same time as the cores, but on the contrary epidote tends to be later, as in specimen A-32-1 described above. In specimen B-7-3-a diopside occurs in the same section as clinozoisite but their time relationships are not clear.

These rocks were derived from dolomitic argillites with varying admixtures of sandy and tuffaceous material, and all gradations in composition are found. The amphibolite zone which extends from the end of the Suiattle road to the south ridge of Downey Mountain, is notable for its compositional variation. At the end of the Suiattle road much of the rock lacks any excess calcium but has a considerable argillaceous component, while on Downey Mountain the dolomitic and sandy components are dominant.

Lime Silicate Rocks

Lime silicate bands occur at widely scattered localities in the Green Mountain unit. Occurrences were noted on the southern part of the Buckindy ridge, northeast of the summit of the 6622 foot peak on the Downey Creek-Buck Creek ridge, on the Bench Creek-Downey Creek ridge, and on the south ridge of Downey Mountain.

Most of these are thin bands (1/2 inch or less thick) intercalated in para-amphibolite or hornblende schist. The ones on Downey Mountain and on the Bench Creek-Downey Creek ridge are thicker.

On the west side of the south part of the Buckindy ridge occurs a hornblende schist (specimen B-51-1-c) containing a lime silicate band 1/4 inch wide. It has diopside (40%) associated with epidote (10%) in a granular aggregate. Sodic andesine makes up 35% of the band and quartz 15%. Sphene and opaque minerals are accessories. All the grains are small and xenoblastic except for the plagioclase, which is sometimes a bit larger.

Northeast of the summit of the 6622 foot peak on the Downey Creek-Buck Creek ridge is another 1/4 inch wide lime silicate band (specimen B-13-1-c) in an amphibolite, and it contains about 25% diopsidic augite concentrated in the middle of the band in small to medium sized, xenoblastic grains. Considerable iron oxide is associated with it. Also present is hornblende (10%) with the properties; $Z \wedge C \approx 22^{o}$, Z=light green, Y=light green, X=very light yellowish tan. It forms small, xenoblastic to idioblastic crystals. Zoned epidote with more iron rich cores in small to medium sized, xenoblastic grains makes up about 30% of the band. The rest consists of fairly fine grained plagioclase An 30 with reverse zoning. Quartz, sphene, and apatite are accessories. The diopsidic augite and epidote appear to be contemporaneous.

At about 4000 feet elevation on the Bench Creek-Downey Creek ridge is a relict band of lime silicate schist (specimen D-15-1) in the metasomatic gneisses occurring there. Hornblende (15%) with absorption; Z=olive green, Y=light olive green, and X=light tan grades in the same crystal to hornblende (?) having the same extinction but absorption Z=very light greenish, Y=very light greenish, X=colorless. $Z \wedge C$ is 20^{o} in both cases. The light colored hornblende makes up 10% of the rock and is later than the more strongly colored hornblende (15%). Both hornblendes are late kinematic and in small, xenoblastic to hypidioblastic grains. Fine grained, xenoblastic clinozoisite (45%) with a slightly more iron in the cores is present. Zoisite (15%) is in late, small, xenoblastic crystals including both types of hornblende. The zoisite crystals have the appearance of being an aggregate of many small individuals welded together. Small, xenoblastic diopside grains occur scattered in one layer, and they are associated with the clinozoisite in a manner which indicates they are in equilibrium with the clinozoisite. Small anhedral quartz (10%) and plagioclase An 36, sphene, and opaque minerals complete the rock. The rock is weakly banded.

At 5000 feet on the south side of Downey Mountain is exposed a diopside quartz granulite (specimen C-20-2-a) containing lime silicate bands 1 to 2 inches thick, and it is associated with amphibolites. The granulite consists of quartz (75%), plagioclase An 33 (10%), diopside (15%) and accessory sphene and apatite. The plagioclase encloses quartz and appears to have crystallized later. The diopside is fine to fairly coarse grained and includes quartz.

These lime silicate rocks are critical for metamorphic zoning, for they contain contemporaneous diopside and epidote minerals, as well as the association of sodic andesine with epidote minerals. That fixes the grade of metamorphism as that of the warmer mesozone, for if the temperature had been higher, the epidote would have gone into the anorthite components of the plagioclase, and if the temperature had been lower, diopside could not have formed (Misch, unpublished MS).

These bands were derived from intercalations of argillaceous dolomite, limey dolomitic sandy argillite, and impure sandstones in the more aluminum and less calcium-rich sequence of para-amphibolites and hornblende schists adjacent to them.

On the north side of lower Big Creek occurs a band of dubious origin 1/8 to 3/16 inches thick in a para-amphibolite (specimen B-21-1-a). Instead of diopside it contains a pyroxene with some of the properties of aegerine-augite. Other minerals present are epidote, hornblende, plagioclase, and sphene. The pyroxene is light greenish in thin section and pleochroism, if any, is very weak. $Z\wedge C=63^{\circ}$. It is in small to medium sized, xenoblastic grains and makes up about 15% of the band. One crystal has a little uralite around it. Hornblende with absorption Z=olive green, Y=light olive green, and X=greenish tan grades in individual crystals into amphibole having the same extinction, but Z=light green. It occurs in small to medium sized, xenoblastic to hypidioblastic crystals and makes up 35% of the band. Sphene and apatite are in small, xenoblastic to hypidioblastic grains. Completely sericitized plagioclase (?) accounts for the rest of the layer.

Ortho-amphibolites

Ortho-amphibolites are fairly abundant in the Green Mountain unit. They occur especially near the margins of the Chaval unit of the Snowking massif on the lower east side of the 6108 foot peak east of Grade Creek and on the Tenas Creek-Big Creek ridge. Huckleberry Mountain and Downey Peak are other good localities.

The separation of ortho-amphibolites from para-amphibolites is somewhat arbitrary, for there are all gradations. However the former are characterized by a substantial amount of plagioclase and usually an only minor quartz content.

The ortho-amphibolites contain 40-80% green to brown hornblende, 15 to 55% plagioclase averaging An 35 and usually normally zoned, 0 to 15% quartz, clinozoisite, garnet, chlorite, prehnite, epidote, and zoisite, and sphene, rutile, and apatite are accessories.

On the Big Creek-Tenas Creek ridge is a zone from 2600 feet to 5000 feet in elevation containing both isochemical and allochemical ortho-amphibolites. The isochemical rocks are garnet-bearing plagioclase amphibolites containing rather light green hornblende (50 to 60%), sometimes with relatively light reddish brown cores. The hornblende includes considerable amounts of quartz, plagioclase, and rutile, and approaches sieve texture. Pinkish almandine (2 to 5%) includes epidote, plagioclase, quartz, hornblende, and rutile. The plagioclase (35 to 45%) has strong normal zoning. The zones range in composition from An 62 in the cores to An 33 in the rims (average composition estimated at An 43). The plagioclase occurs in small to fairly large, xenoblastic crystals and includes some hornblende. Quartz is present in quantities up to 5%. A little light green clinochlore and minor penninite has formed from hornblende and garnet. Accessories are clinozoisite, epidote, rutile, sphene, apatite, prehnite, and opaque minerals. All these rocks have been late-kinematically and post-kinematically recrystallized, and the preferred orientation of the hornblende is rather weak. One specimen (D-18-4-a) has a coarser grain size, which might suggest the name hornblende-rich diorite, but a remnant of finer grained amphibolite and abundant small inclusions in the larger crystals indicate that the rock has passed through a finer grained stage before acquiring its present coarse texture. The textures of these rocks suggest that a small amount of soda metasomatism might have taken place, but their chemical composition as indicated by their mineral composition, does not differ greatly from that of ordinary isochemical amphibolites of the area.

Float from the brooks draining into Grade Creek from the east is composed in part of ortho-amphibolites that must be derived from the lower reaches of their courses, for the ridge above consists of quartz diorite. The stream from the east just south of Bluebell Pass contains float of synkinematically recrystallized, fine grained amphibolites with

40% plagioclase (An 32) and brownish green hornblende tending to be green at the margin. In specimen B-35-2-a the plagioclase and hornblende are concentrated in bands, probably due to metamorphic differentiation. They contain opaque minerals with sphene rims, indicating the mineral is probably ilmenite. Associated with the amphibolites are coarse grained metagabbros. In the next stream south is amphibolite, statically recrystallized amphibolite, and metagabbro. A specimen of the statically recrystallized amphibolite contains 30% plagioclase An 48, 70% hornblende with $Z \wedge C = 18^{\circ}$, Z=reddish brown with light green rims, Y=brown with light green rims, and X=tan to light tan. Accessories are small to medium grained, xenoblastic garnets, light green clinochlore, rutile, carbonate, opaque minerals, and a yellowish green chlorite (?) which occurs in veinlets in hornblende and plagioclase and has positive elongation, birefringence of about .010, and some anomalous blue interference colors.

Specimen B-7-4 from Huckleberry Mountain has a band containing 30% hornblende, 30% clinozoisite, and 40% plagioclase as compared to 75% hornblende, 15% plagioclase, 5% clinozoisite, and 5% sphene in the rest of the rock. Probably this band was a basic tuff, while the less hornblende-rich band represents a tuffaceous, calcareous sediment. In the field interbeds of schist were observed in this rock; they support this conclusion. Similarly specimen A-18-3 from the south peak of the 6622 foot mountain on the Downey Creek-Buck Creek ridge is a plagioclase amphibolite that was found interbedded with mica schists.

The ortho-amphibolites of the Green Mountain unit are characterized by the joint occurrence of epidote minerals and andesine, generally sodic, thus fixing their metamorphic grade as that of the warmer mesozone.

These rocks were originally andesitic and basaltic in composition, in about equal proportions. Although in some cases it is difficult to tell whether one is dealing with a basalt-derived rock with soda metasomatism or an andesite-derived rock, the rocks considered in this group are believed to be at least approximately isochemically metamorphosed. Because of the presence of closely adjacent mica schist outcrops or interbeds of schist in a given outcrop, of which a few examples have been cited above, it seems most probable that many of these ortho-amphibolites were derived from tuffs interbedded with the eugeosynclinal sediments, rather than from flows.

Quartzites

Quartzites are rather scarce in the Green Mountain unit. They were found at the end of the northern Suiattle River road, at 4500 feet on Downey Mountain, on the south peak of Buckindy, on the ridge north of Green Mountain, and on the Bench Creek-Downey Creek Ridge.

Apart from the dominant quartz they are characterized by minor amounts of sodic andesine (up to 5%), biotite (up to 5%), epidote minerals, muscovite, garnet, graphitic material, sphene, and apatite. One specimen (D-14-1-b) has a few grains of potash feldspar, perhaps introduced, for it is intercalated with a metasomatic microline-bearing trondhjemitic gneiss.

The largest amount of quartzite observed occurs associated with amphibolites on the southern peaks of Buckindy. As shown in specimen B-47-1 the rocks there have a cataclastic foliation emphasized by narrow zones of mortar in which most of the mica and chlorite is concentrated. The rock has subsequently undergone metallization, and pyrite has formed along the grain boundaries and in disseminated, anhedral to euhedral crystals.

On the ridge north of Green Mountain occurs a garnet-bearing schistose quartzite (specimen A-18-2) containing very small, hypidioblastic to idioblastic, zoned garnets. They are scattered throughout the rock, and some of them are skeletal crystals. Apparently a lack of the constituents needed and the difficulty of diffusion of the available material in the quartzite inhibited further growth of the garnets. Some of them have muscovite or biotite cores. Later biotite has formed from some of the garnets. The early biotite has excellent crystallization foliation.

At about 4500 feet on the south ridge of Downey Mountain occurs a zoisite-bearing biotite-amphibole quartzite (specimen C-19-1). It contains about 10% of an amphibole with the following properties: $Z \wedge C = 20^{\circ}$, and absorption Z=light tan, Y=tannish and X=colorless. This mineral occurs in late-kinematic and post-kinematic, medium sized, xenoblastic crystals, and some of the post-kinematic transverse porphyroblasts include quartz and plagioclase. Biotite (5%) is synkinematic with crystallization outlasting deformation. A minor amount of plagioclase occurs in small turbid grains. Zoisite consists of small to medium sized crystals, some of which are skeletal. Epidote, sphene, and graphitic material are accessories. Pure quartzitic and impure schistose layers alternate, and probably this banding has been accentuated by metamorphic differentiation.

Several of the quartzites had enough calcareous and argillaceous components to allow epidote and sodic andesine to form, thus indicating a warmer mesozonal grade.

These rocks were derived from sandstones containing impurities, mainly of argillaceous material, but also minor dolomitic and calcareous admixtures.

Marble

Marble bands are exceedingly rare and were observed only on the ridge northeast of the summit of the 6622 foot peak on the Downey Creek-Buck Creek ridge where a few bands 4 to 8 inches thick parallel the foliation. One studied in thin section is quite pure, containing carbonate with excellent twinning and cleavage, and the carbonate includes graphitic material trending parallel to the schistosity. The adjacent rock is an impure quartzite containing biotite, clinozoisite, sodic andesine, graphitic material, and sphene.

Conclusions

The Green Mountain unit is a typical eugeosynclinal sequence and has been metamorphosed throughout the area under approximately similar temperature conditions. Thus its various rock types constitute an isophysical series.

Pure argillaceous sediments were rather rare in this portion of the geosyncline. The generally high soda content of much of the sediments as shown by the amount of plagioclase in the mica schists indicates that most of the original sediments were geochemically immature shales and silts that must have contained considerable clastic feldspar. Where calcium and/or magnesium were present in quantities sufficient to allow epidote minerals and/or hornblende to form, the participation of dolomitic, calcareous, or volcanic components is indicated. (Whether the volcanic material was air or water borne is immaterial.) The original sediments were probably greywackes and microgreywackes with all gradations from more argillaceous rocks on one hand to dolomitic argillites and tuffs on the other. The volcanics were of intermediate to basic composition, and some flows were probably present. Few pure sandstones or carbonate rocks were deposited.

Throughout the area of the Green Mountain unit the association of epidote minerals and sodic andesine and the rare occurrence of staurolite and kyanite indicate metamorphism took place in the kyanite zone, or warmer mesozone, while the occurrence of contemporaneous diopside and epidote in the lime silicate bands in a number of widely scattered localities fixes the metamorphic grade as that of the warmest mesozone. Epidote and zoisite are stable with calcic andesine in those rocks in which the plagioclase has this composition. Some rocks may have reached a coolest katazonal temperature during an early phase of their crystallization, for some of the plagioclase cores are sodic labradorite, although in these cases the main portion of the plagioclase is andesine, indicating that during the main phase of crystallization temperatures had become somewhat lowered to those of the warmer mesozone. That this change in plagioclase composition is thermally controlled, and not due to introduction of soda, is indicated by the fact that most of these rocks contain epidote minerals - in other words potential anorthite component would have been available for the formation of a plagioclase more calcic than andesine if temperature had permitted. These relationships have been treated by Peter Misch (1954). In the Green Mountain rocks in question the epidote minerals include zoisite as well as epidote and clinizoisite. They are obviously in equilibrium with the major portion of the plagioclase, which is andesine. There is no evidence to indicate whether the epidote-clinozoisite was present at the time of formation of the cores of sodic labradorite and was stable with it. That zoisite (but not epidote) is often found in equilibrium with considerably more calcic larbadorite has been stated by P. Misch (op. cit.).

Although rutile tends to occur to the exclusion of sphene in the aluminum excess rocks, considerable sphene is present in the rocks lacking an aluminum excess, but not having a calcium-magnesium excess either, and although sphene is common in the calcium and magnesium-rich schists and the amphibolites, rutile is often present also. A calcium excess does not seem to force all the titanium to be used in the formation of the sphene.

Metamorphism generally took place under synkinematic conditions with crystallization outlasting deformation. However, locally considerable static crystallization took place, notably where isochemical rocks are intimately associated with migmatities, and at the contact of the Downey Mountain trondhjemite.

No stratigraphic subdivisions of the Green Mountain unit could be set up, for all the various rock types are generally intimately interbedded. Thus the whole area of outcrop of this unit is heterogeneous in detail, yet homogeneous in overall aspect. To what extent tectonic repetitions occur is impossible to say from the information so far obtained, and thus it is not feasible to estimate any true stratigraphic thickness. The total thickness of the rocks as exposed is about 32,000 feet. That considerable tectonic repetition must have occurred is obvious, and is also suggested by numerous minor isoclinal folds observed.

Katazonally Metamorphosed Sediments and Volcanics

Katazonally metamorphosed rocks occur in a zone about 300 yards wide on the ridge between Snowking and Chaval Mountains. The metamorphosed and metasomatized igneous rock of the Chaval unit adjoins the zone on the south, and metasomatized and partially mobilized schists and amphibolites (now quartz diorite, etc.) of Snowking Mountain border it on the north. The zone constitutes two small 6000 foot knobs just south of the lowest part of the ridge.

Amphibolites and schists are interbedded. One amphibolite (specimen D-40-2-b) contains 85% weakly aligned small, xenoblastic to hypidioblastic, green hornblende and 10% plagioclase in small, xenoblastic grains with the composition An 36. Biotite, apatite, and opaques are accessories. The rock is dominantly post-kinematic. Another specimen examined (D-39-1-c) is a hornblende schist containing 30% small, xenoblastic hornblende, which formed synkinematically and post-kinematically. A few larger crystals are skeletal. Plagioclase (30%) has a composition of An 36. Quartz (40%) is fine to fairly fine grained and xenoblastic, and tends to be concentrated in stringers and lenses. Small anhedral epidote grains occur with chlorite from the alteration of hornblende. Sphene, apatite, and pyrite are accessories. The first specimen has probably formed from a basic tuff, and the second from a tuffaceous, arenaceous sediment.

Specimen D-41-1-a is a biotite-plagioclase schist from near the southern edge of the schist zone. Plagioclase (40%) of composition An 33 partially forms post-kinematic porphyroblasts including biotite. Quartz (50%) is partially concentrated in bands. Biotite (10%) tends to occur in plagioclase-rich bands, and it has formed statically.

In about the middle of the schist zone occurs a garnet-biotite-plagioclase schist (specimen D-40-2-a) containing 60% plagioclase. A few small plagioclase porphyroblasts are present, but if soda has been introduced to allow so much plagioclase to form, this introduction must have been mainly of the "concealed type", for there are no textures indicating replacement by plagioclase, most of the grains of this mineral being small. Quartz (20%) occurs in small to medium sized, xenoblastic grains. Biotite (5%) is fine to fairly fine grained and xenoblastic and has formed synkinematically for the most part. A few post-kinematic transverse crystals are present. Garnet (5%) occurs in medium to large, anhedral to subhedral porphyroblasts. Some display snowball structure, which indicates they were rotated both during and after growth. Thus the garnets crystallized during shearing, but shearing continued after they stopped growing. Some were broken and have been healed by plagioclase and biotite. Light greenish penninite and clinochlore are retrogressive after garnet and biotite.

Near the northern edge of the schist zone occurs a garnet and sillimanite-bearing biotite plagioclase schist (specimen D-41-1) containing 45% sodic andesine in small to fairly small, xenoblastic crystals. Quartz (40%) is found in small to medium sized, xenoblastic grains. Small, xenoblastic biotite (15%) is dominantly synkinematic but a few post-kinematic transverse crystals occur. Garnet occurs in small to medium sized, xenoblastic crystals. The small crystals tend to be in clusters with biotite and plagioclase, and the clusters probably represent former, larger garnets that have been broken down and altered. Small, xenoblastic sillimanite needles have a light greenish yellow tinge. Light green penninite from biotite, apatite, and opaque minerals complete the rock.

At both the north and south contacts of the schists and amphibolites occurs a fairly coarse grained leucocratic rock that in the field appeared to be sheared and altered granitic rock. Petrographic study, however, reveals that this rock is a quartz feldspar granulite and blastomylonite, which does not seem to be related to the adjacent granitic rock. The boundary between the granulite and leucocratic blastomylonite and the granitic rock on one side and the more mafic schists on the other is sharp.

Specimen D-39-1-a from the northern granulite band contains 40% coarse grained, xenoblastic albite, which is heavily altered. Medium grained, xenoblastic quartz (30%) tends to be concentrated in mosaic textured areas. Fine to coarse grained, xenoblastic potash feldspar (30%) replaces plagioclase, and some crystals include quartz and plagioclase. A small amount of perthite is present. One large crystal is cut by a fracture filled with fresh albite. A garnet grain is present in the section, and other accessories are sericite, epidote, partially altered biotite, and altered opaque minerals. Specimen D-39-1-b from the same locality is very similar. It contains some less altered plagioclase with the composition An 15. It displays apparent cataclastic texture in which the small grains are inherited from an earlier phase in the evolution of the rock.

Adjacent to the northern granulite band is a biotite blastomylonite (specimen D-39-1-d). It contains 30% of very fine grained, xenoblastic, directionless biotite, which gives the rock a hornfelsic texture. A few grains are green. Small, xenoblastic potash feldspar crystals (50%) are concentrated in lenses with quartz and also occur with biotite. A few remnants of albite (?) are included in the potash feldspar. Quartz (10%) is fine grained and xenoblastic and tends to occur in lenticular aggregates with the potash feldspar. Very fine grained andalusite (?) comprising about 10% of the rock is highly concentrated in certain areas. Accessories are apatite, zircon, and opaque minerals.

These granulites may have been derived from argillites that underwent soda and potash metasomatism, or from arkoses containing considerable potash feldspar. The replacement relationship of potash feldspar to the other minerals suggests that some potash, at least may have been introduced. The directly adjacent granitic rock was not sampled, but about 1/4 mile away it is a quartz diorite and lacks evidence of potash metasomatism. However, restricted portions of the Snowking massif have undergone considerable potash introduction. The granulites could represent a narrow zone of strong potash metasomatism like those on Snowking Mountain and to the north. As for soda, if the rock had been an arkose, the clastic plagioclase would probably have been oligoclase or andesine. Therefore if it had been converted to albite during metamorphism, some anorthite component should have been left over. Exceedingly few minerals containing anorthite component, or calcium, were observed. Thus if the original rock had been an arkose, calcium must have been leached. However, in view of the preponderance of soda metasomatism in the surrounding rocks it seems more likely that soda was introduced.

The biotite blastomylonite was derived from an argillaceous sediment, and the quartzo-feldspathic lenses may represent either former pebbles or later porphyroblasts. Cataclasis reduced the grain size, shredded the biotite, and strung out the pebbles or porphyroblasts. Static heating recrystallized the mineral fragments into their present unstrained state. Unless this rock was originally a very feldspar-rich sediment, potash must have been introduced. Because of the Al-excess in the rock, as shown by the andalusite, it seems unlikely that the quartzo-feldspathic lenses were derived from granitic pebbles, for it is not likely that a very high proportion of clay minerals would be deposited simultaneously with granitic pebbles. Therefore, the lenses were probably derived from porphyroblasts. No definite clue as to when potash introduction occurred was found, but the absence of replacement textures suggest it was before cataclasis. Probably porphyroblasts formed at that time.

A specimen (D-41-1-b) examined from the southern granulite band contains 50% fine grained, xenoblastic quartz. Plagioclase (35%) has a composition of about An 22 and occurs in small to medium sized, xenoblastic grains. The larger crystals have grown at the expense of the fine grained groundmass. Small grains of potash feldspar (10%) have replaced plagioclase. Muscovite and sericite have formed synkinematically and post-kinematically, the muscovite tending to be post-kinematic. Post-kinematic andalusite occurs in small, xenoblastic to idioblastic grains with splotchy absorption: X=pink, Y=colorless, and Z=greenish. Sillimanite occurs in xenoblastic to hypidioblastic needles, and some crystals are skeletal. It is synkinematic and post-kinematic. Biotite is present, but most of it is altered, some to andalusite and sillimanite. Garnet, rutile, and zircon are accessories. This rock was derived from a sandy shale and underwent late shearing and recrystallization under katazonal conditions. Soda and potash were probably introduced during this recrystallization.

The presence of sillimanite in the Al-excess schists on the Chaval-Snowking ridge indicates that those schists and amphibolites were metamorphosed under katazonal conditions. Metamorphism took place primarily synkinematically, but a late static phase was quite strong in some rocks. The sillimanite formed mainly during the synkinematic phase, but some grew post-kinematically. The Al-excess rocks also contain andalusite, which crystallized post-kinematically.

The original rocks were shales and tuffs. That the schists contain considerable plagioclase suggests that the shales may have been rich in silt of a greywacke composition. However, the occurrence of Al-excess minerals shows that some of them were geochemically relatively mature. Since a rock containing enough argillaceous component to permit the formation of aluminum silicates by metamorphism does not have enough soda to allow the formation of the amount of plagioclase present in these rocks, soda metasomatism must have taken place. The granulites were probably derived from shales, but they underwent extensive soda and potash metasomatism.

The schist zone on the Snowking-Chaval ridge strikes down into the Illabot Creek trough. Information from this trough is scanty, but schists occur in the bottom of the valley near Bluebell and Arrow Creeks. These two areas of schist might be parts of a narrow zone in which the Illabot trough has been eroded.

Allochemically Metamorphosed Rocks

Feldspathized Schists and Amphibolites and Migmatitic Gneisses

Rocks of Huckleberry Mountain and the Ridge Between Huckleberry Mountain and Mt. Chaval

General Statement

Feldspathized schists and amphibolites and migmatitic gneisses are best displayed on the ridge from north of the col south of Huckleberry Lookout to the east end of Mt. Chaval and on the west end of Huckleberry Mountain. Between these two localities the outcrop is poor, but float indicates the rocks are predominantly isochemically metamorphosed.

West Ridge of Huckleberry Mountain

On the west end of the high part of Huckleberry Mountain at 5000 feet elevation all gradations from slightly feldspathized amphibolites to garnet-bearing hornblende gneiss are present. The bulk of the rock is feldspathized amphibolite. The feldspathized amphibolites from the westernmost 5000 foot knob of Huckleberry Mountain contain 30 to 45%

medium grained, hypidioblastic, brownish green hornblende tending to be greenish at the margins. Plagioclase (30 to 65%) is in medium sized, xenoblastic grains and displays strong normal zoning. In specimen B-6-2-e one plagioclase crystal varies from An 82 in the core to An 43 in the rim. In specimen B-6-2-b from the same locality the compositional range in one grain is from An 43 in the core to An 28 in the rim. Most grains are much less extremely zoned. Reverse zoning and oscillatory zoning occur in a few plagioclase grains. The more calcic cores of the crystals tend to be highly altered to zoisite, sericite, and kaolin.

Specimen B-6-2-d has so much plagioclase (65%), and the grain size is so large that it is a true gneiss. In specimen B-6-2-c the plagioclase forms large, anhedral to euhedral porphyroblasts, which occur in a matrix of amphibolite. The porphyroblasts include hornblende and smaller plagioclase grains. Even the more euhedral porphyroblasts have borders that are sutured in detail.

Quartz occurs in small, xenoblastic grains varying from 0 to 10% in quantity.

Light pinkish tan garnet occurs in small to large, hypidioblastic crystals. Specimen B-6-2-b contains 30% garnet, probably almandine. The garnet is in large, subhedral prophyroblasts that include epidote, hornblende, quartz, and apatite.

Chlorite, both penninite and clinochlore, is derived mainly from hornblende, but also from biotite and garnet. It is concentrated in alteration bands with retrogressive epidote and clinozoisite.

Clinozoisite and epidote occur principally in this manner, i.e. as alteration products from hornblende and plagioclase. In the alteration bands the epidote tends to be hypidioblastic. A small amount of early epidote is present in the rocks.

Prehnite sometimes substitutes for epidote as an alteration product of hornblende, and sometimes occurs intergrown with biotite or chlorite.

These rocks crystallized under synkinematic and post-kinematic conditions. Post-kinematic crystallization was strong, and in some specimens it has erased the synkinematic alignment of the hornblende.

On the ridge over half way to the next knob on the east occur plagioclase amphibolite and hornblende plagioclase gneiss. Specimen B-7-1-a from this locality has a fairly fine grained pavement texture and contains a few small quartz porphyroblasts and some hornblende porphyroblasts with sieve texture. Normally zoned plagioclase with a composition ranging from An 42 to 31 makes up 45% of the rock. A small, sharp, late shear accompanied by mortar cuts the hornblende porphyroblasts.

Specimen B-7-1-b from the same locality is mainly post-kinematic, but the hornblende retains weak alignment. This rock is medium grained and contains about 45% plagioclase.

Specimen B-7-1-d is partially coarse grained and contains 75% plagioclase which probably averages An 45 in composition. The plagioclase displays the strong normal zoning characteristic of these rocks. Hornblende makes up 25% of the rock. In a hornblende-rich band the plagioclase-hornblende proportions are reversed. Except for the hornblende-rich band, in which parallel alignment has been preserved, the rock shows a thorough post-kinematic recrystallization which has eliminated preferred orientation.

At the most easterly outcrop observed along the ridge are amphibolites containing 35 to 50% plagioclase with strong normal zoning ranging from An 50 in the cores to An 30 in the rims. Specimen B-7-3-a from this locality described above with the isochemically metamorphosed rocks is a andesites. Thus these migmatitic looking rocks containing 50% plagioclase could be isochemically metamorphosed andesites or diorites. Static recrystallization would eventually form a metamorphic diorite which could not be distinguished from a metamorphosed igneous diorite. However, the specimens that contain 60 to 75% plagioclase have a soda content well above that of an andesite. They grade into the less plagioclase-rich amphibolites. This intergradation between rocks with varying feldspar content leads to the conclusion that differential soda metasomatism is a more important agent in producing these migmatitic rocks than differential static recrystallization. The latter process accompanied and modified the results of the former. It is unlikely that metamorphic differentiation without metasomatism could have played any significant role in producing these various rocks, for it tends to act only locally, producing small, sharp features, such as the thin plagioclase lenses and stringers so often present in amphibolites.

Ridge Between Huckleberry Mountain and Mt. Chaval

Migmatitic schists, amphibolites, and gneisses occur from the col south of Huckleberry Lookout north to the east end of Mt. Chaval ridge.

In the area of migmatitic schists and amphibolites both replacement and mobilized dikes of trondhjemite, quartz diorite, and pegmatite occur abundantly (see Chapter IIIC2 below). Garnet-biotite schist tends to be transitional into gneiss without any spectacular development of plagioclase porphyroblasts, whereas amphibolite tends to acquire large plagioclase porphyroblasts that stand out in the dark groundmass. Sometimes porphyroblasts form in the amphibolites even when little soda metasomatism appears to have occurred.

On the upper south side of the knob north of the col east of Boulder

Lake (the 1949 edition of the Forest Service map incorrectly shows Boulder Lake draining to the east) the rock rather suddenly becomes migmatitic gneiss. On that knob the gneiss contains incompletely feldspathized amphibolite and some biotite-rich inclusions. The inclusions and the gneiss are conformable, and they intergrade. Along the ridge to Hurricane Mountain the gneiss has many inclusions, and even some unfeldspathized biotite schist occurs. Near the summit of Hurricane Mountain the inclusions are less abundant, and they tend to be more shadow-like. North along the ridge to the col below Mt. Chaval the rocks become less sharply gneissose, and in a few places there are migmatitic areas which appear to have formed statically. Large inclusions of partially feldspathized amphibolite occasionally occur all the way to the col south of Chaval. About half way up the east end of the Chaval ridge from the col to the south a chlorite-sericite-quartz schist occurs in a zone of retrogressive alteration. This is the most northerly occurrence of sediment-derived rock in the gneisses south of the allochemically metamorphosed igneous rock constituting the Chaval unit of the Snowking massif (see Chapter IIIC3b below). Quite a few mafic inclusions occur on Mt. Chaval, but they all seem to be amphibolite-derived.

Few generalizations can be made concerning the petrography of the migmatitic rocks. They contain 40 to 70% plagioclase that usually displays normal zoning and sometimes oscillatory and reverse zoning. The normal zoning is often quite strong; the maximum variation observed is from An 65 in the cores to An 25 in the rims. Quartz ranges from 5 to 35% of the rock (average 20%). Generally speaking, introduction of soda and the development of coarse grain size took place late-kinematically and post-kinematically. Post-kinematic crystallization becomes dominant adjacent to the Chaval complex.

PLATE VIII

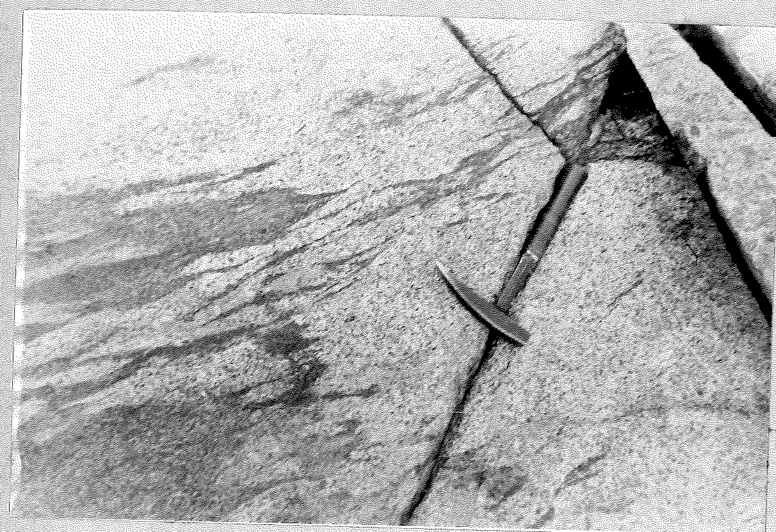


Fig. 1 Relict amphibolite inclusions in migmatitic hornblende quartz diorite gneiss on the ridge south of Hurricane Mountain.

A better idea of the petrography of these migmatites may be obtained by examining suites of rocks collected at a single outcrop, which may be quite varied.

Specimen A-21-2-a from the col south of Huckleberry Lookout is a banded biotite-hornblende gneiss. One band contains 15% fairly light green, synkinematic hornblende in small to medium sized, xenoblastic crystals. It also contains 5% synkinematic and late-kinematic, fine to medium grained biotite, partially derived from hornblende. Another band in the same specimen contains 10% biotite, fine to medium grained, xenoblastic garnets, and no hornblende. Some of the smaller garnets are included in plagioclase. In both bands plagioclase in small to medium sized, xenoblastic grains makes up about 55% of the rock. It is normally zoned; one measurement gave a range from An 37 in the core to An 33 in the rim. Fine to medium grained, xenoblastic quartz constitutes 30% of the rock. Light green clinochlore is derived from biotite and garnet and forms some pseudomorphs after garnet. Rutile, apatite, clinozoisite, and opaque minerals are accessories.

Specimen A-21-2-b from the same locality is also a banded gneiss. One band is quartz dioritic and contains 60% plagioclase with normal zoning; in one case the core is An 40 and the rim An 31. The plagioclase forms medium to large, xenoblastic grains. Quartz makes up 35% of the band and is fine to coarse grained and xenoblastic. In portions of the band large quartz crystals replace plagioclase. Small, hypidioblastic garnets and directionless biotite constitute the rest of the band. The texture is completely granoblastic. Two other bands contain 25% statically formed biotite with some mimetically controlled alignment after the foliation. Plagioclase (50%) and quartz (20%) are the other main constituents. The grain size of the quartz and plagioclase is smaller than that in the quartz dioritic band, whereas the biotite is the same size in both bands. Fine to medium grained, xenoblastic garnet with sieve texture makes up 5% of this band. Light green clinochlore occurs as pseudomorphs after biotite and garnet. One thin band composed of biotite, garnet, and chlorite transects the quartz dioritic band.

Specimen A-21-2-c from the same locality is a garnet-biotite gneiss containing 55% plagioclase with the composition An 35. The plagioclase displays normal and oscillatory zoning. It occurs in medium to large, xenoblastic grains. Fine to coarse grained, xenoblastic quartz makes up 30% of the rock. The larger grains formed later than the smaller ones. Biotite (10%) is late-kinematic and post-kinematic. Garnet (5%) is found in small to large, hypidioblastic to idioblastic crystals. Muscovite from the alteration of garnet, chlorite from biotite and garnet, clinozoisite, orthite with weak absorption, and rutile complete the rock. The rock has a sutured granoblastic texture with a weak parallel structure. One band has more garnet and biotite left.

On the knob north of the col east of Boulder Lake where the rock becomes dominantly gneissose, four specimens studied illustrate the migmatitic aspect of the outcrop. Specimen A-27-1-b is a massive amphibolite containing 75% fairly light brownish green hornblende in medium to large, xenoblastic crystals including small quartz and feldspar grains in quantities almost sufficient to produce sieve texture. The hornblende formed post-kinematically. Medium to fairly coarse grained, normally zoned plagioclase (15%) ranges from An 35 to An 28 in composition. Quartz (5%) occurs mainly as small, xenoblastic grains. Biotite (5%) from hornblende, chlorite from biotite, prehnite from hornblende, rutile, and opaques complete the rock. This rock has been statically recrystallized with resultant increase in grain size. No soda metasomatism has occurred in this rock. If any introduction has occurred, it would have been enrichment in iron and magnesium.

Specimen A-27-1-c from the same locality is a banded, partially chloritized, garnet-hornblende-plagioclase-quartz granulite. One band is amphibolitic and contains 45% green hornblende in medium sized, xenoblastic crystals including small quartz and plagioclase. Plagioclase (10%) has the composition An 33 and is fine to medium grained and xenoblastic. It is quite altered to sericite, kaolinite, and epidote minerals. Medium grained, hypidioblastic garnet (10%) includes epidote. Fine to medium grained, xenoblastic quartz makes up 20% of the band. Another band contains about 25% garnet, 25% plagioclase, 20% hornblende, 5% quartz, and 25% chlorite. The chlorite is mainly light green clinochlore derived from hornblende and garnet. Clinozoisite from the retrogressive alteration of hornblende and plagioclase, rutile, and sphene are accessories. A third band contains 60% quartz occurring mainly in large, sutured, xenoblastic crystals replacing the other minerals. Plagioclase (30%) and hornblende (10%) are the other constituents of this band. This rock is predominantly isochemical except for the quartz-rich band, where silica may have been introduced.

Specimen A-27-1-d is a garnet-hornblende-biotite gneiss containing 25% coarse grained, xenoblastic to hypidioblastic, green hornblende, which includes small quartz and plagioclase grains in quantities almost sufficient to produce sieve texture. It is dominantly post-kinematic, but it has some alignment mimetic after the foliation. Fine to coarse grained, xenoblastic plagioclase (45%) is normally zoned and ranges in composition from An 45 to An 23. Biotite (10%) is found in small to large, post-kinematic crystals and is at least in part derived from hornblende. Quartz (20%) occurs in small to large xenoblastic crystals. Large anhedral garnet porphyroblasts include small quartz and plagioclase grains and are slightly altered to biotite. Clinozoisite,apatite, sphene, rutile, and opaque minerals are accessories.

The fourth specimen from this locality (A-27-1-f), a garnet-biotite-hornblende granulite, contains 15% fine grained, xenoblastic to idioblastic, green hornblende. Biotite (10%) is post-kinematic and displays some alignment mimetic after the foliation. Fine to medium grained, xenoblastic plagioclase (65%) is normally zoned and has an average composition of about An 32. It includes hornblende, biotite, and a few small quartz grains. Quartz (5%) occurs in small, xenoblastic crystals. Garnet (5%) forms large, subhedral to anhedral porphyroblasts, which include plagioclase, hornblende, and epidote. Light greenish clinochlore from biotite and garnet, rutile, and opaque minerals complete the rock. Although this specimen contains more plagioclase than the gneiss, it looks much less granitic because of the smaller grain size. In the field it was believed to be less feldspathized than the gneiss.

On Hurricane Mountain metasomatic quartz dioritic and dioritic gneisses occur, and they are relatively uniform in overall aspect. They contain 20 to 40% fine to coarse grained, anhedral to subhedral hornblende which has the absorption: Z=fairly light brownish green; browner in the core or sometimes in an ill-defined zone between the core and the rim, Y=light brownish green, and X=very light greenish tan. Plagioclase (40 to 60%) occurs in medium to large, anhedral to subhedral crystals, and some grains have very strong normal zoning. The most extreme example is from An 65 in the core to An 27 in the rim. The estimated average composition is An 37. Biotite (10 to 15%) is in medium to large crystals and appears to have formed partially from hornblende and to be partially contemporaneous with the hornblende. Specimen A-29-2-c from this locality contains some large biotite porphyroblasts up to a centimeter in length. Quartz (10%) is fine to medium grained and anhedral. Clinozoisite,sphene, rutile, and opaque minerals are accessories. Specimen A-29-2-b has undergone late-metamorphic shearing in restricted zones producing mortar that is mostly recrystallized. The plagioclase in that specimen is highly altered to sericite,kaolinite, and clinozoisite. In the field some gneissose structure was observed, but in some of these specimens it is not apparent. However, the texture in these specimens is completely granoblastic.

In the col northeast of Hurricane Mountain an inclusion of hornblendite occurs in the gneiss. The specimen (A-29-3) consists of over 90% small to very large, anhedral hornblende crystals with the absorption: Z=light brownish green, Y=light yellowish brown, and X=light tan. Plagioclase and quartz account for most of the rest of the rock. Opaque minerals (magnetite) are distributed in bands which suggest a previous foliation. In the field a portion of the inclusion displays foliation. Fairly large, euhedral apatite crystals are included in the hornblende. Other accessories are garnet, rutile, and chlorite. This rock was probably an amphibolite and has been enriched in iron and magnesium driven out of the surrounding rock during the introduction of soda and silica, which produced the adjacent quartz dioritic rocks.

On the north end of the ridge south of the col south of Mt.Chaval the gneissose quartz diorite contains hornblende with a stronger absorption than in the rocks previously described. The pleochroism is: Z=dark

PLATE IX

Fig. 1 Contemporaneous biotite, plagioclase, and epidote in gneissose epidote-biotite-hornblende quartz diorite. Well-developed crystal faces of epidote in biotite; poorly developed faces in plagioclase. From migmatitic gneiss on ridge between Huckleberry Mountain and Mt. Chaval. (specimen A-31-1) 13x, plane light.

bluish green, Y=green with a brownish tinge, X=light greenish yellow. It also contains epidote, part of which formed simultaneously with the plagioclase. Some euhedral crystals of epidote are included in the plagioclase, and the adjacent part of the plagioclase grain shows no zoning in relation to the epidote. This contemporaneous epidote comprises some grains which crystallized partly in biotite and partly in plagioclase. The portion of the epidote crystal in the biotite grain has well-developed crystal faces, whereas the portion in the plagioclase has an irregular boundary. There also occurs some epidote which appears to be later than the plagioclase.

Conclusions

The rocks on Huckleberry Mountain and the ridge north to Mt. Chaval have been mesozonally metamorphosed under synkinematic conditions, as shown by the occurrence of contemporaneous epidote and andesine in the amphibolite-derived rocks. During an early phase of metamorphism katazonal temperatures probably prevailed, for the cores of some of the plagioclase grains are labradorite.

Strongly zoned plagioclase occurs only in the rocks that contained some potential anorthite component, which was released by biotitization of hornblende and/or occurred as epidote minerals in the early- metamorphic rock. In many specimens, however, most of this anorthite component has been used by the plagioclase, and little, or no epidote remains.

Crystallization continued in late-kinematic and post-kinematic time, accompanied by soda metasomatism. The proportion of plagioclase increased, and porhyroblasts formed. The definitely isochemical amphibolites on the ridge north of Huckleberry Mountain contain on the average 20 to 25% plagioclase, whereas the allochemically metamorphosed rocks average about

55% plagioclase.

In certain places in the rock conditions were favorable for the migration of material, but little was added from outside; so plagioclase porphyroblasts grew, and no large increase in the proportion of plagioclase in the rock occurred. Sometimes both hornblende and plagioclase recrystallized to form a directionless coarse grained amphibolite. On the other hand, some mica schists seem to have been subjected to soda metasomatism without an attendant increase in grain size.

A small amount of potash introduction must have accompanied the soda in some cases, for the hornblende in the amphibolite-derived rock is biotitized in some localities. The source of the quartz in the quartz dioritic gneisses at the north end of Huckleberry ridge near Mt. Chaval is uncertain. With a few exceptions, quartz in these gneisses does not display any conspicuous replacement features from a textural point of view. However, the isochemical amphibolites on the ridge do not contain much quartz. This does suggest quartz introduction in the gneisses derived from similar amphibolites. The scarcity of replacement textures seems to be a common characteristic of introduced quartz. (P. Misch, unpublished MS).

South Ridge of Buckindy

Migmatite crops out in the schists and amphibolites on the south ridge of the southernmost peak of Buckindy above 6000 feet elevation. In some places all gradations from biotite-hornblende schist to a directionless biotite quartz diorite occur. However, most of the feldspathized rocks are gneissose. A few intrusive dikes and sills of mobilized migmatitic material occur in this area.

A suite of specimens from about 6100 feet elevation on the south ridge of the southernmost peak of Buckindy illustrates the development of a coarse grained granitic rock.

Specimen B-45-2-a from this locality is a clinozoisite-bearing biotite-hornblende-plagioclase granulite. It contains fine to medium grained, xenoblastic, normally zoned plagioclase (60%) which varies in composition from An 28 in the core to An 24 in the rim. A few large plagioclase porphyroblasts occur, and they include biotite. Fine to medium grained, xenoblastic quartz makes up 20% of the rock. Green hornblende (10%) occurs in medium sized, xenoblastic to hypidioblastic crystals that formed post-kinematically. It includes some quartz, and the cores of the larger crystals contain very fine grained opaque minerals in a zonal arrangement. Biotite (10%) is post-kinematic, and only a small portion of it is derived from hornblende. Fine to medium grained, xenoblastic to idioblastic clinozoisite often occurs with biotite and is probably derived from hornblende. Many small crystals are included in unaltered plagioclase and therefore are early. Garnet, sphene, apatite, and zircon are the accessories. The rock has a mosaic texture.

Specimen B-45-2-b from the same locality is a clinozoisite-hornblende-biotite-quartz dioritic granulite. It contains fine to coarse grained, xenoblastic, normally zoned plagioclase with a composition of An 33. Some of the plagioclase crystals are large porphyroblasts with sutured borders. They include clinozoisite, hornblende, biotite, quartz, and plagioclase. Small to large, xenoblastic biotite flakes (10%) include sphene and clinozoisite. At least some of the biotite is derived from hornblende. Medium sized, xenoblastic to hypidioblastic hornblende crystals (5%) include small quartz and plagioclase grains. Xenoblastic to idioblastic clinozoisite grains (5%) are often associated with biotite. They are earlier than the large quartz and unaltered plagioclase grains which include them. Sphene, garnet, and apatite are accessories. The rock has a well-developed sutured granoblastic texture.

Specimen B-45-2-c is an epidote-biotite-quartz dioritic porphyroblastic gneiss. Plagioclase (60%) occurs in small to large, xenoblastic crystals with normal and occasional oscillatory zoning. It is calcic oligoclase. Some large plagioclase prophyroblasts are sieve textured and include biotite, epidote, quartz, and plagioclase. Occasionally a porphyroblast has graphitic inclusions that form an internal trend (s_i). Fine to coarse grained, xenoblastic quartz (20%) includes biotite. Biotite (15%) is in small to large, xenoblastic to hypidioblastic flakes, which are in part synkinematic and in part post-kinematic. The flakes include sphene and epidote, and some of them are probably derived from hornblende. Epidote (5%) occurs in small to medium sized, xenoblastic to idioblastic crystals, many of which are early. Orthite is found in the core of a large epidote grain. Sphene, apatite, and garnet are accessories. This rock formed late-kinematically, and the plagioclase displays outstanding porphyroblastic growth features.

Specimen B-45-2-d from the same locality is a directionless biotite quartz diorite which contains 70% of fine to coarse grained, anhedral to subhedral plagioclase with a composition of An 28. The plagioclase includes biotite, hornblende, epidote, and quartz. Quartz (15%) occurs in small to fairly large, anhedral grains. Biotite (15%) is found in small to large, anhedral flakes that include sphene, epidote, and quartz. Iron-poor epidote is associated with biotite and is probably derived from hornblende. Some retrogressive epidote from plagioclase also occurs.

The epidote occurs in small to medium sized, anhedral to subhedral grains. Green hornblende is in fairly small, anhedral grains. Fairly light green penninite is retrogressive. A few orthite grains occur and have epidote rims. Zircon, garnet, and opaques are the other accessories. The rock displays some apparent cataclastic texture which, however, is actually due to the presence of relict grains from an earlier fine grained stage in the evolution of the rock. This rock is metamorphic and is characterized by the metamorphic growth of plagioclase, quartz, and biotite. No doubt it originally contained more hornblende.

Just slightly higher on the ridge occurs a hornblende-bearing biotite-quartz dioritic gneiss (specimen B-45-3) which displays all the metamorphic features of the rocks described above. In addition it contains large plagioclase porphyroblasts that push aside the biotite trends. Where the biotite has been pushed aside, it forms polygonal arcs around the porphyroblasts. The hornblende in the rock has a deep green color with a somewhat bluish tinge for Z.

Specimen B-46-1-b is a biotite granodioritic porphyroblastic gneiss, which was collected from an intrusive dike. The rock contains 50% plagioclase with normal and oscillatory zoning. It occurs in fairly small, anhedral grains and scattered, anhedral to subhedral porphyroblasts that include quartz. Its composition is about An 20. Quartz (30%) forms small, anhedral grains and occasional, anhedral porphyroblasts. Microcline (10%) occurs commonly as small, anhedral grains and rarely as porphyroblasts that replace plagioclase and quartz. Biotite (10%) is mainly synkinematic, but a few transverse flakes occur. Clinozoisite, sphene, and apatite are accessories. This rock appears to have been subjected to cataclasis and subsequent recrystallization. It was probably intruded

PLATE X

Fig. 1 (left) Epidote-biotite quartz dioritic porphyroblastic gneiss. Graphitic trends parallel to foliation. From migmatitic area on south ridge of Buckindy (specimen B-45-2-c) 8x, plane light.

Fig. 2 (right) Crossed nicols. Graphitic trends form s_i in plagioclase porphyroblast and continue into adjacent grains.

Fig. 3 Quartz dioritic rock from intrusive dike of mobilized metasomatically-derived material. Plagioclase porphyroblasts in fine grained, recrystallized cataclastic groundmass. Biotite sharply aligned (specimen C-46-2-b) 18x, crossed nicols.

in a fairly solid state.

These rocks have been formed by metasomatism of biotite-hornblende schists. This is shown by their gradational relationships to the isochemically metamorphosed country rock, and by their outstanding metamorphic textures.

Green Mountain

On Green Mountain some local feldspathization has taken place in the mesozonal schists.

Just north of the summit of Green Mountain occurs a biotite-hornblende-garnet quartz diorite (specimen B-10-1-b) which contains 45% plagioclase in small to large, xenoblastic crystals. The plagioclase is zoned, in some crystals from An 52 in the core to An 33 in the rim. Some of the zoning is oscillatory. Large porphyroblasts include garnet, hornblende, biotite, and earlier plagioclase. Quartz (20%) is in small to medium sized, xenoblastic grains. Garnet (15%) occurs in large, subhedral porphyroblasts and small, xenoblastic crystals. It includes clinozoisite. Biotite (10%) is derived from garnet and hornblende. Brownish green hornblende (10%) occurs in small to fairly large, xenoblastic crystals. Clinochlore, sphene, rutile, apatite, zoisite, and clinozoisite are accessories. The texture of the rock as a whole is porphyroblastic and is characterized by plagioclase crystals with irregular borders tending to surround and include smaller grains of all other minerals.

Specimen B-10-1-c from the same locality contains 60% fine to medium grained, xenoblastic plagioclase with normal and oscillatory zoning. The compositional range in zoned crystals measured is from An 36 in the core to An 27 in the rim. Fine to fairly coarse grained, xenoblastic garnet (10%) includes biotite and plagioclase. Some of the larger crystals contain a zone of fine grained opaque inclusions (graphitic material ?). Chlorite from biotite, rutile, and muscovite are accessories. In its finer grained portion, this rock has, except for the lepidoblastic tendency of the biotite, a mosaic texture. In the coarser grained portion the boundaries of the plagioclase crystals are more irregular, the texture is granoblastic, and in places the biotite lacks alignment.

These rocks are argillites and impure argillites that have been metamorphosed under mesozonal conditions (see Chapter IIIB2c on Green Mountain unit) and have undergone metasomatism. In specimen B-10-1-c the metasomatism has been principally of the "concealed" variety, while in specimen B-10-1-b considerable static recrystallization of the minerals and growth of the plagioclase has taken place. These rocks occur as layers intercalated with and grading into isochemical rocks.

Lower Big Creek

On the logging road heading east up Big Creek valley from the Grade Creek road, para-amphibolite is feldspathized in zones only a few feet wide. These zones are partially parallel to the foliation. At about 4300 feet elevation on the ridge between Grade Creek and Big Creek some locally derived, angular float of partially feldspathized amphibolite was observed.

The migmatitic rocks are located about two miles east along the road (1 mile air line) from the Grade Creek road. In specimen B-21-1-f, a small pod of hornblende diorite occurs in a biotite amphibolite. The boundary between the two is fairly sharp, but locally it is gradational. The diorite consists of large, xenoblastic to hypidioblastic brown

PLATE XI

Fig. 1 Amphibolite (right) recrystallized to coarse grained hornblendite (left) adjacent to dioritic patch in Green Mountain unit in lower Big Creek valley.
(specimen B-21-1-f) 13x, plane light

Fig. 2 Oscillatory zoning in plagioclase grain in garnet-biotite schist adjacent to quartz dioritic patch in Green Mountain unit on Green Mountain.
(specimen B-10-1-c) 20x, crossed nicols.

hornblende (45%) whereas the amphibolite contains 45% fine to medium grained, xenoblastic green hornblende with brown cores. The hornblende in the dioritic portion displays some sieve texture. The brown hornblende of the diorite replaces the green hornblende of the amphibolite. The diorite contains 55% medium to coarse grained, hypidioblastic, normally zoned plagioclase, and the amphibolite about 35% medium grained, xenoblastic plagioclase. The plagioclase in the diorite includes small hornblende grains. In both cases its composition is around An 35.

The other feldspathized rocks are medium grained hornblende-plagioclase granulites of dioritic composition containing about 65% plagioclase, 25 to 35% green to greenish brown hornblende, and minor quartz, biotite and prehnite.

Tenas Creek-Big Creek Ridge

Between an elevation of 2600 feet and the 5000 foot knob on the Tenas Creek-Big Creek ridge migmatitic amphibolite occurs. At about 3000 feet the highest sediment-derived schist was observed on this ridge, so above this locality the rocks may constitute a marginal part of the metamorphosed igneous complex that constitutes the Chaval unit of the Snowing massif.

At 2600 feet elevation on the ridge feldspathized amphibolite intergrades with approximately isochemical amphibolites, which have been described above. Specimen D-17-1-d contains 40% fine to fairly coarse grained, xenoblastic, normally zoned, sodic andesine, which includes biotite and hornblende. Quartz makes up 20% of the rock, is fine to medium grained and xenoblastic, and includes occasional hornblende. Hornblende (35%) is actinolitic, and $Z \wedge C = 16^{\circ}$. Its absorption is; Z=fairly light brownish green, Y=greenish tan, X=light yellowish tan. The hornblende occurs in small to medium sized, xenoblastic to hypidioblastic crystals. It contains minute opaque inclusions, partially concentrated in zones. Light green clinochlore, sphene, apatite, rutile, and opaque minerals are accessories.

Specimen D-17-1-c from the same locality has an even more striking metasomatic aspect. It contains 50% fine to coarse grained, xenoblastic plagioclase ranging in composition from An 45 in the core to An 34 in the rim. The normal zoning may originally have been stronger, for the cores of many of the crystals are altered to sericite and epidote minerals. The larger crystals are rather spectacular porphyroblasts with sieve texture produced by many small, included hornblende and garnet grains. Small, xenoblastic quartz constitutes 5% of the rock. Hornblende (35%) is similar to that in specimen d. Garnet (5%) occurs in small to large, xenoblastic to hypidioblastic crystals that have a slight yellowish tan tinge. Biotite from garnet and hornblende and chlorite from biotite and garnet amount to 5% of the rock. Apatite, zircon, and opaque minerals are accessories.

Specimen D-17-1-b contains only 20% plagioclase, and it has normal and oscillatory zoning. Nevertheless, it forms large porphyroblasts with sieve texture. Fine to fairly coarse grained, xenoblastic to hypidioblastic, actinolitic hornblende (60%), fine grained, xenoblastic quartz (15%), and biotite (5%) are the other main constituents. In this rock the quantity of plagioclase does not suggest soda metasomatism, but the texture certainly does. Perhaps the rock was subjected to static recrystallization accompanied by very incipient soda introduction, and these conditions were favorable for the collective crystallization of the plagioclase already present.

At about 4100 feet elevation on the ridge the rock is a quartz diorite with a coarse granoblastic texture. One specimen (D-18-1-b) contains 30% quartz, part of which occurs as late, large, porphyroblasts replacing plagioclase.

At about 4300 feet elevation occurs a more or less isochemical amphibolite in which some of the hornblende and plagioclase have recrystallized into large porphyroblasts, giving it a migmatitic aspect in the field. The plagioclase porphyroblasts are heavily altered. Most of the plagioclase (35%) is in fine to medium grained, xenoblastic, normally zoned, crystals with a composition of An 43. Hornblende (60%) in small, xenoblastic to large, idioblastic grains includes small quantities of quartz, plagioclase, and rutile. It has the absorption: Z=fairly light reddish brown in the cores of the larger crystals; light green on the margins and in the smaller crystals, Y=light brown in the cores, very light green in the rims and in the smaller crystals, and X=very light tan. Quartz (5%) occurs in small, xenoblastic grains. Medium to coarse grained, xenoblastic to idioblastic garnet displays sieve texture with hornblende, rutile, and plagioclase. Light green clinochlore, sphene, rutile, apatite, and opaques are accessories.

A hornblende diorite containing 40% hornblende with sieve texture and 55% plagioclase occurs at about 4600 feet elevation. The texture of the rock is granoblastic.

On the 5000 foot knob on the Big Creek-Tenas Creek ridge the rock is still migmatitic. It varies from perhaps only slightly allochemical coarse and medium grained massive amphibolite to a dioritic granulite. The amphibolites have been mentioned in the chapter on isochemical rocks. The granulite contains 70% medium to coarse grained, xenoblastic to hypidioblastic plagioclase, which is normally zoned. Its composition ranges from An 40 in the core to An 35 in the rim. The larger plagioclase grains occur in a thin, irregular replacement veinlet. Fine to medium grained, xenoblastic hornblende (30%) has brown interiors and green margins. The replacement veinlet contains less hornblende. Rutile occurs quite abundantly. Garnet includes plagioclase and rutile in sieve texture. Other accessories are chlorite and epidote from hornblende, apatite, and opaques.

At the 6000 foot knob about one mile to the east the rock is fairly homogeneous quartz diorite. How far the migmatitic rocks extend east of the 5000 foot knob on the Tenas Creek-Big Creek ridge is uncertain.

All the migmatitic rocks along the ridge have recrystallized under static conditions. In most specimens such alignment of the hornblende as occurs, is mimetic after the foliation. Static recrystallization of the amphibolites was accompanied by varying amounts of soda introduction. Some amphibolites were converted into coarse grained directionless rocks of igneous aspect without much increase in the quantity of feldspar. Other rocks underwent considerable metasomatism, yet the resultant rock is only medium grained.

The isochemical amphibolites which have been preserved as intercalations, contain a maximum of 35% plagioclase, suggesting that this was the maximum amount of plagioclase present prior to feldspathization. Where feldspathization has occurred, plagioclase constitutes up to 70% of the rock.

Northern Side of the Suiattle Valley

Migmatitic schists and gneisses occur at scattered outcrops along the northern Suiattle River road east of the junction with the southern Suiattle River road and west of Downey Creek.

On the road 5.1 miles east of Buck Creek some migmatitic schists occur.

Specimen A-8-3-b is a hornblende-bearing garnet-biotite schist that contains 50% fine to medium grained, xenoblastic plagioclase with a composition of about An 35. Quartz (35%) occurs in small to medium sized, xenoblastic grains, but medium sized grains are more common. Biotite (10%) is fine to coarse grained and xenoblastic and formed synkinematically for the most part. Garnet (5%) occurs in large, anhedral porphyroblasts including quartz and plagioclase in sieve texture. It includes rare small grains of clinozoisite. A few long needles of green hornblende, apatite, and graphitic material complete the rock. This rock was probably derived from a slightly dolomitic sandy argillite, which has undergone some "concealed" soda metasomatism. The other specimens at the outcrop contain about 40% plagioclase. In specimen A-8-3-d, which contains a replacement dike of muscovite trondhjemite, muscovite has grown in the adjacent biotite schist. That some metasomatism has occurred is not surprising, for there are numerous replacement dikes in the outcrop.

On the road 4.7 miles east of Buck Creek coarse grained two mica schist contains up to 40% plagioclase, which is slightly zoned and has a composition of sodic andesine. About 4.2 miles east of Buck Creek a similar schist contains 45% plagioclase in small to fairly large, xenoblastic crystals displaying some reverse zoning. Many of the larger crystals include small biotite, quartz, plagioclase, and graphitic material that form trends. These trends were originally parallel to the foliation, and they have been rotated slightly in some cases, which indicates that some movement occurred after the growth of the grains. Fine to medium grained, xenoblastic quartz constitutes 30% of the rock. Fine to coarse grained, xenoblastic biotite (15%) is synkinematic, but crystallization lasted longer than movement. Muscovite (5%) is synkinematic and post-kinematic. Sieve textured garnet (5%) occurs in fairly large, anhedral to subhedral porphyroblasts. Greenish clinochlore from biotite, apatite, and opaques are accessories.

About 1.2 miles west of Buck Creek a garnet-biotite-plagioclase schist (specimen A-11-1-b) occurs along the road. The outcrop contains numerous pegmatite and aplite dikes. This specimen comes from directly adjacent to a trondhjemite dike. It contains 60% fairly fine grained, xenoblastic, slightly zoned plagioclase. The actual percentage of plagioclase may be lower, for a large quartz segregation is present. Outside the segregation, quartz constitutes only 10% of the rock. Biotite (20%) is in small to medium sized, xenoblastic crystals and displays alignment mimetic after the foliation. Large, subhedral garnet porphyroblasts include quartz, plagioclase, biotite, rutile, and opaque minerals. Light olive green clinochlore has been retrogressively derived from biotite. Graphitic material (5%) is included in the other minerals, but especially in the plagioclase. Muscovite, iron-poor epidote, and pyrite are accessory. Another schist specimen from the same outcrop is definitely isochemical and contains only 15% plagioclase.

Three miles west of Buck Creek quartz dioritic hornblende gneiss crops out. It contains 50 to 60% fine to fairly coarse grained, anhedral to subhedral, plagioclase. It has normal and oscillatory zoning. One crystal measured has the following zones: An 45 in the core, An 31 in an intermediate zone, and An 34 in the rim. Quartz (20 to 35%) occurs in small to fairly large, anhedral crystals. Synkinematic and late-kinematic biotite (10 to 15%) is in part derived from hornblende. It has some prehnite intergrown with it, which accounts for part of the calcium from the original hornblende. Green hornblende (5%) occurs in small to large, anhedral to subhedral crystals. Pinkish garnet is found in small to medium sized, anhedral crystals. Accessories are apatite, sphene, pyrite, and pyrrhotite. These rocks have a granoblastic gneissose texture.

An inclusion (specimen A-12-1-c) in the gneiss contains 45% fine to coarse grained, xenoblastic plagioclase with a composition of about An 36. Some of the crystals are very large porphyroblasts. They are heavily sericitized. The larger crystals include hornblende, biotite, prehnite, quartz, and plagioclase. Quartz (25%) occurs in small to medium sized, xenoblastic grains. Sutured borders are common on the larger crystals. The quartz includes scattered grains of hornblende. Fine to medium grained xenoblastic green hornblende crystallized late and post-kinematically and displays alignment mimetic after the foliation. Biotite (5%) has been derived from retrogressive alteration of hornblende and occurs intergrown with prehnite. This rock does not contain as much plagioclase as the associated gneiss, and it contains less biotite and more hornblende. It represents an intermediate stage in the production of the quartz dioritic hornblende-biotite gneiss from an amphibolite. Additional influx of soda, allowing more plagioclase to form, accompanied by a small amount of potash to biotitize more of the hornblende, would convert the inclusion into rock like the surrounding gneiss. The porphyroblastic development of the plagioclase and the incipient biotitization of the hornblende indicate that soda and potash metasomatism have played a part in the formation of the inclusion. Unfortunately the original rock is not preserved in the outcrop.

In the outcrops which were studied along the northern side of the

Suiattle River valley, metasomatism seems to increase from Downey Creek west to the edge of the mesozonal unit, which is bordered by the Straight Creek fault (see below). East of Downey Creek the rocks are isochemical, between Buck Creek and Downey Creek some of the schists are feldspathized and west of Buck Creek metasomatic migmatitic gneisses occur.

As has been mentioned in previous chapters, the mica schists with high plagioclase content (above 35% An 35) are believed to contain introduced soda, since most argillaceous sediments contain less soda than is required for the formation of so much plagioclase of that composition. The texture of many of the rocks indicates plagioclase recrystallized post-kinematically and later than most of the other constituents.

South of Bench Lake

On the ridge between Bench Creek and Downey Creek migmatitic gneisses occur at least up to an elevation of 5000 feet. Unfortunately there is no outcrop along the Downey Creek trail, and there is a considerable gap between this locality and the rocks observed on Buckindy and the ridge east of Kindy Creek. The gneisses resemble those on the 7000 foot peak east of Kindy Creek two miles to the north (see Chapter IIIC3f below). Quartzites, lime silicate schists, and amphibolites are conformably interbedded.

At about 3000 feet elevation on the ridge is exposed a microcline-bearing trondhjemitic gneiss (specimen D-14-1-a) containing 60% fine to coarse grained, anhedral plagioclase that is normally zoned with a range from An 35 in the core to An 23 on the rim. It includes quartz and biotite. Fine to fairly coarse grained, anhedral quartz constitutes 25% of the rock. Microcline (5%) replaces plagioclase starting from the grain boundaries. Biotite (10%) is late-kinematic and post-kinematic and has been partially altered to green penninite. Clinozoisite is associated with biotite, which suggests that the biotite may have been derived from hornblende. Muscovite occurs in scattered, medium sized to fairly large crystals and was derived from biotite and plagioclase when the microcline formed. Orthite, garnet, apatite, sphene, and sericite are the other accessories. The sericite is late. Some remnants of mortar occur around the edges of the grains; so shearing probably lasted quite long during the crystallization of this rock.

Specimen D-14-2 from about 3300 feet elevation on the ridge is a two mica trondhjemite containing 70% fine to coarse grained, anhedral plagioclase that includes quartz, garnet, and biotite. It has a composition of about An 24 and displays some normal zoning. Fine to coarse grained, anhedral quartz (20%) partially replaces plagioclase and includes garnet, plagioclase, and biotite. A few grains of potash feldspar occur between the plagioclase grains. Biotite (10%) is partially altered. Muscovite has been derived from plagioclase and biotite. Some of its crystals are skeletal. Garnet is found in small, euhedral to subhedral grains. Some epidote is associated with the biotite, Zircon is the other accessory. Some apparent cataclastic texture occurs around the edges of the larger grains. The small grains causing this texture may be either recrystallized mortar or relicts from an earlier fine grained stage in the evolution of the rock. The rock as a whole has a granoblastic texture.

The metasomatized rocks below Bench Lake were derived from hornblende (?) mica schists and underwent metasomatism accompanied by considerable late-kinematic and static recrystallization. Mainly soda was introduced, but some potash may have been added. Silica may also have been introduced locally. The associated rocks were resistant to metasomatism and retained their isochemical character.

Post-Kinematic, Crosscutting Replacement and Mobilized Dikes in the Mesozonal Schists

Throughout the mesozonally metamorphosed rocks of the Green Mountain unit post-kinematic, crosscutting replacement and mobilized bodies occur. They are best displayed on the ridge north of Huckleberry Mountain, especially east and south of Boulder Lake. Road cuts along the north side of the Suiattle River valley also reveal a number of these bodies. They are relatively sparse on the 6622 foot peak on the Downey Creek-Buck Creek ridge and on Green Mountain.

In some localities, such as just south of Huckleberry Lookout, crosscutting replacement dikes of migmatitic material are present. Because feldspathization has not been so strong, the rock in the dike can megascopically be determined to have been derived from the country rock, for it contains much biotite and garnet and grades into the adjacent garnet-biotite schist. Similar relationships were observed in dikes south of the next col north of the lookout. There, intrusive, as well as replacement dikes were observed. Some of the pegmatites contain relict quartz segregations, which are identical to those in the adjacent schist. The finer grained dikes grade into the pegmatite dikes, and the more leucocratic of the finer grained rocks have a similar composition to the coarser grained dikes. Some of the pegmatite dikes have banding parallel to their walls. These bands mainly consist of layers of differing grain size.

On the north side of the knob southeast of Boulder Lake occurs a biotite-quartz diorite dike which contains numerous pegmatitic areas. The contact of the dike with the schist is in part quite straight and sharp, and in part irregular and gradational. Where the contact is irregular, there occur non-rotated inclusions of the country rock (garnet-biotite schist) which still have the same orientation as the adjacent schist. The dike has a migmatitic appearance due to its pegmatitic areas and an irregular distribution of the biotite.

On the north side of the col east of Boulder Lake numerous granitic and pegmatitic dikes are present. Early dikes 3 to 6 inches wide are cut by later ones 4 to 6 feet wide. Some of the larger granitic dikes contain areas of pegmatite. Some dikes have irregular borders, and some sharp, straight borders. The few inclusions of schist observed in the dikes do not deviate from the trend of the adjacent country rock.

On the summit of Green Mountain several quartz dioritic dikes occur. One of them contains a zone of garnet and biotite parallel to the foliation of the country rock. This zone represents a less feldspathized layer of schist. A quartz diorite dike containing a concordant schist inclusion occurs west of the first knob west of the summit of Green Mountain.

On the ridge from the Suiattle River to Downey Mountain trondhjemitic bodies occur, but they are poorly exposed in the forest. At about 3500 feet elevation a two mica quartz dioritic rock with trondhjemitic areas was observed. Some of the outcrop contains clusters of mica, and locally the mica is aligned giving the rock a gneissose structure. No contacts were observed.

Some dikes have dilated the country rock and are intrusive; others are definitely of a replacement origin because they completely lack any signs of dilation. However, in many individual dikes no conclusive evidence is available as to whether dilation took place, and their mode of emplacement had to be determined on the basis of other features.

On the northern Suiattle River road about a tenth of a mile west of Sulphur Creek a large pegmatite dike is exposed. It has a migmatitic aspect with irregular areas where fine grained biotite occurs in greater abundance than in other areas of the rock. It has sharp concordant, as well as discordant, contacts, and contains haphazardly oriented, that means rotated, inclusions of schist. The borders of the schist inclusions are in part sharp and in part irregularly feldspathized. This body is interpreted as a mobilized dike of migmatitic material probably derived from the schists nearby because of its similarity to the replacement dikes.

The late, crosscutting replacement and mobilized bodies in the schists of the Snowking area are characterized by their acidic composition. Mafics (usually biotite) average 5% of the rock; oligoclase and quartz are the main constituents, and muscovite and potash feldspar are the minor ones.

The dikes and pods are quartz dioritic to trondhjemitic in composition. They contain 45 to 70% plagioclase, which varies considerably in composition in different dikes. The range is from An 35 to An 13. Quartz makes up 10 to 40% of the rocks. A few contain potash feldspar in quantities up to 20%. Where any age relationship is indicated, the potash feldspar is usually later than the other minerals; it replaced plagioclase and quartz starting from the grain borders. Myrmekite occurs in some of the specimens containing potash feldspar. Microscopic plagioclase-quartz intergrowths are also found in one specimen (A-8-3-d) which contains no potash plagioclase but only oligoclase. The dikes contain 0 to 10% biotite. Muscovite is present in similar quantities. Often it is late and appears to be derived from biotite and plagioclase. In a few specimens hornblende constitutes up to 10% of the rock. Accessories are garnet, epidote, clinozoisite, chlorite, apatite, rutile, sphene, zircon and opaque minerals. Early epidote occurs included in the quartz and plagioclase, and late epidote is found associated with biotite and plagioclase. The association of biotite and epidote suggests that these minerals may have been formed by alteration of hornblende. In some other places late epidote minerals occur as alteration products of plagioclase.

Textures vary from a mosaic-like texture in the finer grained bodies to a coarser granoblastic texture. In specimen A-15-2, a trondhjemite from the Grade Creek road, the texture is neither granoblastic nor igneous in character. It contains fine to coarse grained, anhedral to euhedral plagioclase crystals, the larger ones including smaller quartz and plagioclase grains. Quartz is fine to coarse grained and anhedral. Muscovite is fairly coarse grained and subhedral, while biotite occurs in fairly small, irregular shreds. None of the borders of this body are exposed. In some of the bodies large porphyroblasts of plagioclase, quartz, and/or potash feldspar have developed.

Near the first knob south of the col south of Mt. Chaval are some trondhjemite dikes and replacement patches in the quartz diorite. In thin section (specimen A-31-2-a) in one place it is evident that the trondhjemite has been mobilized, for the fine grained biotite and chlorite are aligned parallel to the contact with the coarse grained quartz diorite and perpendicular to the rather weak gneissose structure in this latter. The texture of the trondhjemite is granoblastic. Medium grained, anhedral plagioclase includes smaller grains of the other minerals. Since the larger plagioclase sometimes includes fine grained, aligned biotite, recrystallization probably took place after movement. Two healed fractures that partially control alteration of the plagioclase transect the specimen.

These bodies were derived from post-kinematic granitization of the country rock by the same agents that feldspathized the migmatitic rocks nearby. However, access of the granitizing agents to the country rock was controlled by joints. This is indicated by the altogether sharp and straight contacts on some of these bodies and the partly sharp and partly irregular and gradational contacts on others. That many of the dikes were formed by in situ replacement of the country rock is shown by the gradational and irregular borders just mentioned, by relict schist bands oriented parallel to the adjacent country rock, and by oriented, non-rotated schist inclusions, and by lack of dilation of the country rock. Locally the granitized material became mobilized causing flow structure, rotation of inclusions, and dilation of fissures.

In connection with these dikes, but quite different from them, a dike of quartz labradorite porphyry observed in the katazonal schists on the Snowking-Chaval ridge should be mentioned. In the field the rock is fairly dark, fine grained, and directionless. It resembles the adjacent schist, except for its directionless character. However, the dike has intruded the schists, for it includes pieces of schist in haphazard orientation. In thin section (specimen D-40-3) the rock contains 55% fine to medium grained, subhedral to euhedral plagioclase with the composition An 55. Some oscillatory zoning occurs. The plagioclase includes some biotite. Small, anhedral biotite flakes (5%) tend to be in clusters. Small to fairly small, anhedral quartz grains sometimes occur in mosaic areas. Accessories are a colorless amphibole with an extinction angle of 18° and pyrrhotite. A fine grained groundmass of quartz, plagioclase, and biotite constitutes 40% of the rock. This matrix has a metamorphic texture, while the rock as a whole has an igneous texture.

The origin of this rock is uncertain. The megascopic similarity of the intrusive rock with the country rock suggests derivation by mobilization of a portion of the country rock. However, thin sections of schist from the country rock studied have a mineral composition indicating that the country rock is considerably poorer in calcium than the dike rock. The amphibolites are calcium-rich, but richer in mafics than the dike (see Chapter IIIB4 above). No specimen of the directly adjacent country rock was collected. If, on the other hand, the dike were of igneous origin, the texture of the matrix and the presence of quartz as phenocrysts associated with such a calcic plagioclase would be difficult to explain. One would have to postulate considerable contamination by the predominantly quartz-rich country rock while the dike rock was still in a fairly liquid state.

Granitic Rocks of the Snowking Massif

General Statement

The Snowking massif constitutes the central portion of the area, and it extends from Razor Back Mountain on the north to the 6108 foot peak east of Grade Creek on the west and to Buckindy and the knob east of Boulder Lake on the south. No eastern limit was reached in the area mapped. The massif consists of granitic rocks, principally quartz diorite, trondhjemite, and granodiorite, which are in part of a migmatitic and in part of an igneous appearance in the field. Parts of the southern portion of the massif were described above in the chapter on migmatitic gneisses.

The massif comprises six units which differ somewhat in character though gradations occur. The southwestern part is strongly contrasted to the rest. It consists of gneissose and directionless diorite and quartz diorite of relatively homogeneous aspect, which constitute the metamorphosed and partially metasomatized igneous complex of Mt. Chaval (Chaval unit, Chapter IIIC3b). In the central and northeastern part of the massif occurs the gneissose and directionless granodiorite and trondhjemite of Snowking Mountain (Snowking Mountain unit, Chapter IIIC3c). On the west part of Snowking Mountain are quartz diorite, trondhjemite, and granodiorite which have locally become mobilized (West Snowking unit, Chapter IIIC3d). North of Illabot Creek and Snowking Mountain and west of Found Creek occur quartz diorite, trondhjemite, granodiorite, and quartz monzonite (Northern unit, Chapter IVC3e). East of Kindy Creek the rock consists of somewhat migmatitic gneissose and directionless granitic rock of varying composition with local texturally and compositionally heterogeneous zones, which often contain porphyries (unit east of Kindy Creek, Chapter IIIC3f). On Mt. Buckindy and to the north are diorites and quartz diorites of rheomorphic aspect and breccias, rheomorphic breccias, and porphyries (Buckindy unit, Chapter IIIC3g).

Chaval Unit

General Statement

The metamorphosed igneous complex of Mt. Chaval is bounded on the north by the band of katazonally metamorphosed schists and amphibolites on the Snowking-Chaval ridge (Chapter IIIB4) and the schists and ortho-amphibolites of the Illabot Creek schist zone, and on the west in part by ortho-amphibolites and possibly in part by a fault (the Straight Creek fault). Its southern boundary is determined by the northernmost outcrop of sediment-derived schist in the migmatitic gneisses occurring there. This schist outcrop is found on the southeastern slope of the east end of the Chaval ridge. The Chaval unit now consists mainly of gneissose and directionless quartz diorites and diorites with smaller amounts of hypersthene diorite. It contains numerous amphibolite inclusions in places, and also dark, fairly fine grained dikes.

Weakly Metamorphosed Igneous Hypersthene Diorite

Only slightly metamorphosed igneous rock occurs at about 5600 feet elevation on the northeast side of the 6400 foot peak west of Mt. Chaval, on the east part on the north face of that peak, and on the west peak of Chaval.

The two best examples are specimen D-41-5 from the west side of the west peak of Chaval and specimen B-38-1 from about 1 1/2 miles west of the west peak of Chaval. These rocks contain 70% anhedral to euhedral, small to large plagioclase grains that have normal and oscillatory zoning. The composition of the plagioclase ranges from An 42 to An 56. They include some hornblende and pyroxene. Hypersthene (10%) occurs in subhedral to euhedral, small to large crystals. In specimen B-38-1 some (about 5%) of the pyroxene is monoclinic, with a negative sign and an extinction

PLATE XII

Fig. 1 The principal peaks in the Chaval unit from the ridge east of Arrow Creek. Mt. Chaval on the left and unnamed peaks on the ridge west of Chaval on the right.

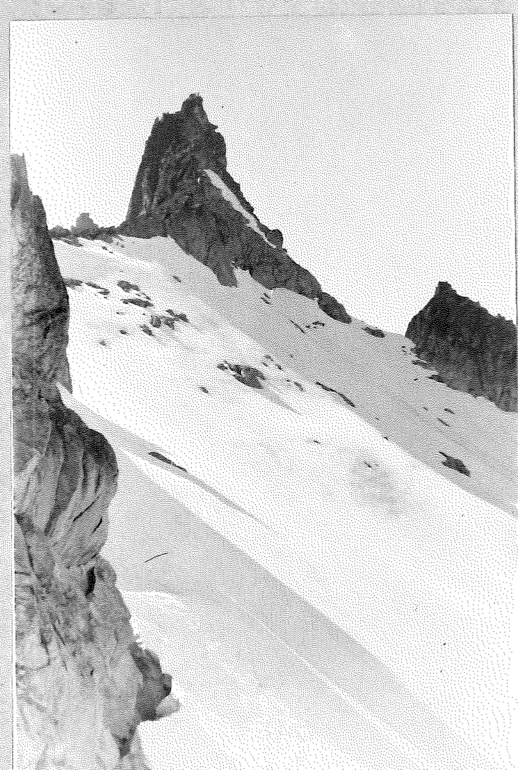


Fig. 2 Hornblende quartz dioritic gneiss on the east peak of Mt. Chaval.

angle Z∧C=30° to 42°. In both rocks brown hornblende is anhedral and varies from small to large in size. It includes and replaces pyroxene and plagioclase. Specimen D-41-5 shows this relationship well, and some of the hornblende in that specimen has sieve texture. In specimen B-38-1 a small quantity of late quartz occurs between the plagioclase crystals. In both specimens some biotite has formed from the hornblende. Apatite and opaque minerals are accessories. These rocks have an igneous texture. The well-formed pyroxene crystallized first and was followed by the plagioclase. The pyroxene was altered to hornblende, either in a late-magmatic phase or during regional metamorphism.

Specimen B-39-1 from the east part of the north face of the peak west of Chaval is similar except that metamorphism has affected the rock more strongly. Sutured borders are common in the plagioclase grains. Quartz replaces plagioclase and hornblende. Hornblende (30%) is colorless in some places. Adjacent to and in cracks in hypersthene occurs a fine grained, fibrous alteration product that may be actinolite. The outcrop from which this specimen comes contains veinlets rich in plagioclase, which appear to have formed by replacement.

In specimen D-41-5 from the summit of the west peak of Chaval only one small crystal of hypersthene remains. Most of it has been altered to hornblende (20%), which is brown and grades within individual crystals to a later, colorless amphibole. Both the brown and the colorless portions have the same extinction angle. The colorless areas have a patchy distribution. Biotite (5%) occurs in large, anhedral crystals and includes colorless amphibole and plagioclase. Quartz replaces plagioclase, hornblende, and biotite.

Specimen B-39-1-b from the east part of the north face of the peak west of Chaval is quite similar to specimen D-41-4. Hornblende (10%) occurs in small to large, anhedral crystals and grades from brown in the main body of the grains to blue-green at the margins. Colorless amphibole (either tremolite, colorless hornblende, or some undetermined low temperature amphibole) with the same extinction as the hornblende occurs in patches. Some small grains of augite remain in the patches of colorless amphibole. Plagioclase (60%) is found in large, anhedral to subhedral crystals with oscillatory zoning in a normal trend. Its composition ranges from An 53 to An 36. A small amount of retrogressive chlorite and clinozoisite has formed from hornblende. Quartz, sphene, apatite, and magnetite are accessories. The rock has a texture half way between granoblastic and igneous. Practically all the mafics have recrystallized, whereas most of the plagioclase has not and displays the same texture as the plagioclase in the typically hypersthene diorite.

Gneissose and Directionless Quartz Diorites and Diorites

The bulk of the Chaval complex is made up of biotite-bearing hornblende quartz diorite and hornblende diorite. The rocks contain 50 to 75% plagioclase (average 60%) ranging in composition from An 55 to An 21 (estimated average An 37). Normal and oscillatory zoning is very common in the plagioclase. The crystals are anhedral to subhedral and mostly quite large, although they range in size from small to large. Often they include scattered crystals of hornblende, quartz, and smaller plagioclase. In the rocks of the Bluebell Creek-Arrow Creek ridge the plagioclase is heavily altered. In specimen C-46-1 from 3000 feet in elevation the plagioclase is albite, and the grains are filled with alteration products. A few newly formed albite crystals containing no alteration products occur.

Hornblende makes up 10 to 35% of the rock (average 20%). It occurs as small to large, anhedral to subhedral crystals, often with sieve texture. Its color varies from brown to green. Most of the entirely brown hornblende occurs in the rocks on the western part of Mt. Chaval and the 6400 foot peak to the west. Much of the hornblende has brown cores and green margins. The quartz diorites on the lower part of the Bluebell Creek-Arrow Creek ridge contain green hornblende. Quite often the hornblende is altered to a colorless amphibole with the same extinction angle as the colored hornblende, and the two amphiboles intergrade.

These rocks contain 0 to 20% quartz (average 10%) as small to medium sized, anhedral grains. In many places the quartz replaces the other minerals from the intergranular network. In the vicinity of the well-preserved igneous hypersthene-diorite the rock contains little quartz.

Biotite makes up 0 to 15% of the rock (average 5%) and in most cases, at least, it has been derived from the hornblende. Prehnite and epidote are often associated with it.

Chlorite occurs in amounts up to 20% and averages about 10% of the rock. It has been derived by retrogressive alteration of the hornblende and biotite. Grains having birefringence and absorption gradational between that of biotite and that of chlorite are common. Often epidote and prehnite are associated with chlorite, as they are with biotite.

Prehnite commonly is present in small quantities intergrown with biotite and chlorite. It has been derived by the retrogressive alteration of the hornblende, and it substitutes for epidote. Sometimes it is also derived from plagioclase. Occasionally prehnite occurs in veinlets.

Epidote minerals are common accessories and are derived from plagioclase and hornblende. The rocks on the ridge between Bluebell and Arrow Creeks show quite strong retrogression and consistently contain considerable quantities of chlorite, prehnite and epidote.

In two localities (specimen D-8-2 from the north side of the 5100 foot knob on the Arrow Creek-Illabot Creek ridge, and specimen B-42-1 from near the summit of the 6108 peak east of Grade Creek) a few small grains of potash feldspar occur. In the latter specimen a trace of myrmekite is present.

Carbonate (up to 15%) and garnet occur in a few specimens. Common accessories are sphene, apatite, and opaque minerals. Rutile and zircon occur less frequently.

The textures of these rocks are generally granoblastic and partly sutured. A few specimens collected adjacent to rocks with well-preserved igneous texture contain predominantly subhedral plagioclase which resembles that of the igneous hypersthene diorite. The textures generally become more granoblastic with increasing distance from the well-preserved igneous textured rocks. In some rocks the only igneous texture preserved are just a few plagioclase grains which resemble those in the igneous hypersthene-bearing rocks.

The diorites and quartz diorites tend to be weakly gneissose on the Bluebell Creek-Arrow Creek ridge, on the 6108 foot peak east of Grade Creek and the ridge to the east, on the eastern part of Mt. Chaval and adjacent to the contact with the schists on the Snowking-Chaval ridge. However, in the last locality the shearing causing the alignment occurred late in the crystallization of the rock, as is shown by recrystallized mortar around the larger grains.

Concordant, partially feldspathized amphibolite inclusions are abundant on the eastern part of Mt. Chaval. The majority of them are lens shaped and are several inches long. In places larger amphibolite bands

6108 foot peak east of Grade Creek in the vicinity of 4500 foot elevation. The evidence examined indicates that the diorite and quartz diorite were formed by metasomatic metamorphism of igneous rock. The question is how extensive was the original body of hypersthene diorite. We know it did not extend beyond the present quartz diorite, for the amphibolites bordering the dioritic rocks are much more basic; they contain 50 to 70% hornblende, while the hypersthene diorite contains 20 to 40% mafics. The amphibolites could have formed by metamorphism of either a very mafic diorite or gabbro, or a basic andesite or basalt.

To form the diorite with its metamorphic texture, only recrystallization of the igneous diorite was necessary. To form the quartz diorite, silica had to be introduced. In many specimens quartz definitely replaces the other minerals. In the amphibolites soda, besides silica must have been introduced during recrystallization to produce quartz diorite.

However, the amphibolitic inclusion found on the first knob east of the 6400 foot peak west of chaval within the area of the more igneous textured rocks and described above is difficult to explain. It may have been an inclusion in the original igneous rock. If it were a relict of the original material from which the rock formed, the hypersthene diorites should have to be interpreted as having a metamorphic deriviation, and the author has seen no evidence for this.

Relict Dikes

On Mt. Chaval and the 6400 foot peak to the west, dikes of dark, fine grained rock occur. They have very irregular margins, and they include areas of diorite. Also pieces of dike rock are included in the diorite. Sometimes projections of dike rock are connected with the main part of the dike only by narrow septa. In places adjacent to the dike the diorite contains more mafics than the normal diorite.

Specimen B-40-2, a hornblende oligoclase microdiorite, from the knob west of the col west of Chaval contains 45% fine to medium grained, euhedral to subhedral hornblende with Z∧C=20° and the absorption Z=light green, Y=light greenish tan, and X=very light greenish tan. Its color is somewhat patchy. Medium grained, anhedral plagioclase (50%) has the composition An 20. It includes some hornblende. Epidote has formed by the retrogressive alteration of the plagioclase and hornblende and chlorite has formed by alteration of the hornblende. Together the epidote and chlorite make up 5% of the rock. Sphene and opaques are accessories.

A dike rock from the base of the north face of the peak west of Chaval is a hornblende microdiorite (specimen B-38-2) containing 50% hornblende in small to fairly small, subhedral to euhedral needles. It is mostly brown, but its color grades into light green in some crystals. Fine grained, anhedral plagioclase (40%) fills in between the hornblende. Colorless penninite (10%) occurs in small to medium sized splotches. Rutile is the accessory.

These rocks have the texture of an igneous dike rock, yet their field relations indicate that they cannot be simply later igneous dikes. The fact that the dioritic rock includes pieces of the dike rock shows that the dioritic rock was emplaced after the dike rock. The irregular, but thin, unbroken configuration of the dikes and the inclusions of granitic rock in them indicates that the dikes are not inclusions in an intrustion. The best explanation of these dikes is that they were intruded before or during metasomatism and that they have been partially feldspathized under static conditions. Thus they are relict dikes (Armstrong, J.E., 1950; G. E. Goodspeed, 1955, p. 147).

PLATE XIII

Fig. 1 Relict dike in hornblende diorite on knob west of col west of Mt. Chaval. Note the undisturbed projections of dike into the diorite and the patches and irregular projections of diorite in the dike.

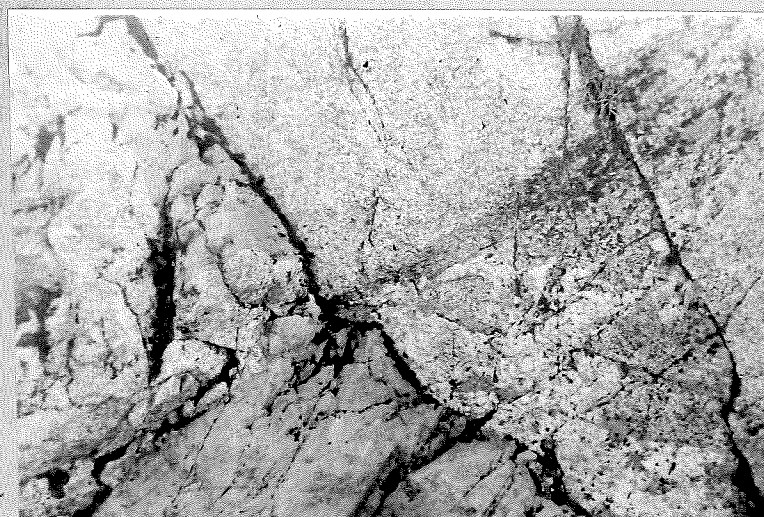


Fig. 2 Relict dike in the hornblende diorite at base of north face of peak west of Mt. Chaval.

On the east peak of Chaval occurs a plagioclase hornblende dike with chilled margins. The margins are quite contorted. Although this dike is post-metamorphic, its configuartion is not like that of a late fracture-controlled dike.

Conclusions

The dioritic rocks of the Chaval metamorphosed igneous complex are characterized by sodic andesine, hornblende, quartz, and biotite. The quartz was mostly introduced, and the biotite was derived from hornblende. The relative uniformity of the composition of the rocks and the lack of evidence for the presence of sediment-derived rock indicate that they were originally igneous rocks, which were intermediate to basic in composition. In the interior of the complex remnants of igneous hypersthene diorite indicate that part of the original rock was a pre-orogenic igneous intrustion. At the margins amphibolites grading into quartz diorites show that in part the original rock was more basic, but whether it was volcanic or plutonic is uncertain.

The rocks were metamorphosed under at least mesozonal conditions. In the adjacent amphibolites the metamorphism was synkinematic and static. In the gneissose quartz diorite it was also synkinematic and static, but during the static phase soda metasomatism may have taken place, and there was definitely silica introduction. Deformation did not penetrate the area where the well-preserved hypersthene diorites occur, and during the main metamorphism temperatures were probably so high that the mineral assemblage of the igneous rocks was not far enough from equilibrium to cause a complete recrystallization.

Snowking Mountain Unit

<u>General Statement</u>

Within the Snowking massif on the ridge between Found and Kindy Creeks, on the east peak of Snowking, on the main ridge of Snowking from the east peak to the col south of the southeast peak, and on the ridge north to the 6000 foot knob southeast of the 6735 foot peak at the head of Boulder Creek occurs gneissose and directionless quartz diorite, trondhjemite, granodiorite, and quartz monzonite which constitute the Snowking Mountain unit. The contact of Snowking Mountain unit and the Snowking massif with the Cascade valley schist zone occurs just north of the 5800 foot knob on the Found Creek-Kindy Creek ridge. The contacts of this unit with adjacent units of the Snowking massif were observed on the 6000 foot knob southeast of the 6735 foot peak at the head of Boulder Creek, on the ridge between the east and west peaks of Snowking, on the shoulder of Snowking towards Mt. Chaval, and on the south side of the col south of the southeast peak of Snowking. These contacts with other units of the Snowking massif will be discussed in the sections about the other units.

<u>Contact Relationships</u>

Near the bottom of the south side of the 5000 foot knob on the ridge between Found Creek and Kindy Creek the contact of this unit of the Snowking massif with the mesozonal portion of the Cascade valley schist zone is exposed. Just outside the contact in biotite-hornblende schist, occurs a dike of biotite-hornblende-plagioclase gneiss with its foliation parallel to that of the schist. Its borders are sharp in overall aspect but irregular in detail. Just a few yards to the south the schist grades into porphyroblast schist and gneiss. This gradation takes place over a distance of only a few yards. The foliation of the schist and the gneiss are parallel.

The dike (specimen C-26-5-a) consists of plagioclase (45%) in anhedral crystals which are, except for a few large porphyroblasts, small to medium sized. The porphyroblasts include a considerable quantity of hornblende, which in part is aligned, forming internal foliation trends (s_i). The plagioclase is normally zoned, and its composition ranges from An 32 to An 28. Small to medium sized, anhedral quartz grains make up 10% of the rock. The larger grains include biotite, hornblende, and quartz. Biotite (15%) forms small to large, anhedral to subhedral flakes and includes some quartz. At least some of it has been derived from hornblende. Hornblende (30%) occurs in medium to large, anhedral to subhedral crystals and includes some quartz. It is actinolitic and has the absorption Z=light drab green, Y=light brownish green, and X=very light tannish. The biotite and hornblende crystallized post-kinematically, and they display weak alignment mimetic after the foliation. Clinozoisite, light green clinochlore, sphene, apatite, and opaques are accessories. This rock differs from the adjacent schist mainly by its larger grain size and its somewhat larger proportion of plagioclase (10% more).

The porphyroblast schist and gneiss in the transition zone consist of 45 to 60% fine to coarse grained subhedral plagioclase with normal and oscillatory zoning. It varies in composition from An 35 to 22. It often forms large porphyroblasts that include smaller grains of the other minerals. The proportion of feldspar porphyroblasts in the rock varies. In some places the schist contains only scattered porphyroblasts. In other places the rock is an "augen" gneiss, in which the "augen" are actually aggregates of quartz and feldspar. Small to large, anhedral quartz grains make up 20%

PLATE XIV

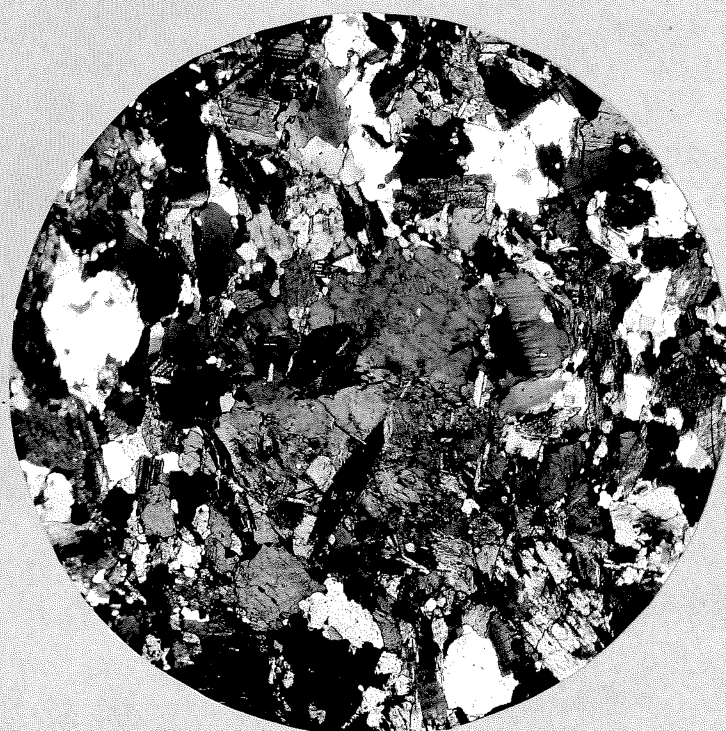


Fig. 1 Plagioclase porphyroblast in biotite-hornblende-plagioclase gneiss in migmatite zone adjacent to the northern contact of the Snowking massif on the Found Creek-Kindy Creek ridge. (specimen C-26-5-a) 13x, crossed nicols

of the rock. Biotite (10 to 20%) occurs in small to large, anhedral crystals and is in part derived from hornblende. In most of the rocks studied it is late-kinematic and post-kinematic, but it is synkinematic in a few. Fine to coarse grained, anhedral to subhedral green hornblende (10 to 20%) formed late kinematically and post-kinematically. It includes some quartz and plagioclase. Chlorite is retrogressive after biotite. Clinozoisite, sphene, apatite, zircon, orthite, rutile, and opaques are accessories. In one specimen (C-26-5-c), which contains synkinematic biotite, some zones of mortar occur.

One band in the gneiss at this locality is much more leucocratic than the rest. It is a granodioritic muscovite gneiss (specimen C-26-5-d) and consists of 35% small to large, anhedral plagioclase grains which have a composition of about An 15. The larger grains include quartz. Small to large, anhedral quartz crystals make up 50% of the rock. Some of the quartz occurs in segregations. Microcline (10%) forms small, anhedral grains except for a few larger crystals which include quartz. Muscovite (5%) occurs as medium sized, anhedral flakes, sometimes in sheaf-like aggregates. Clinozoisite is an accessory. Generally the grain size of the rock is small, but most of the larger crystals display porphyroblastic development. The rock appears to be a recrystallized mylonite.

Field Description of the Rocks of the Snowking Mountain Unit

In the field the rocks of the main body of the Snowking Mountain unit are generally medium grained, leucocratic, and contain varying amounts of muscovite and biotite. On the 5800 foot knob east of the lower Found Lake they are coarse grained. They are strongly to weakly (mostly weakly) gneissose along the ridge east of Found Creek to the east summit of Snowking Mountain and in a narrow band at the northern boundary of the unit.

The gneissose structure parallels the regional trend of the schists outside the contact except at outcrops a few hundred yards inside the contact where the strike is perpendicular to the contact. No exposures were observed between those outcrops and the contact, where schist and gneiss are parallel. Over a distance of several hundred yards towards the interior of the massif the attitudes gradually swing around and become parallel to the contact and the schists on the outside.

Aplite and pegmatite dikes are common on the ridge west of Found Creek and near the southeast peak of Snowking. On the 5800 foot knob east of the lowest Found Lake, replacement dikes and patches of finer grained, more leucocratic gneiss occur. Many are straight sided and probably controlled by fractures. Some are intrusive, for they have dilated their walls, and gneissose structure is absent. Northwest of the southeast peak of Snowking the aplite veinlets in places make up 10% of the rock, and they were mainly formed by replacement, as is shown by the lack of dilation of their walls and, locally, by their irregular and gradational borders. The aplites cut schist inclusions. Some coarser grained pegmatitic veinlets on the southeast peak of Snowking reach a thickness of a foot.

On the south facing slope west and northwest of the southeast peak of Snowking is exposed a zone containing numerous inclusions of dark colored schist, which stand out against the leucocratic granitic rocks. The zone extends northwest about half way to the 6700 foot knob where the ridge towards Mt. Chaval joins the main Snowking ridge. These inclusions are up to 80 feet long. The schists are strongly folded within the individual inclusion; so their attitudes, which vary, do not show definitely whether they have been displaced by the granitic rock. They are partially feldspathized and have gradational borders. In some places the schist can be

PLATE XV

Fig. 1 General view of the zone of schist inclusions in the Snowking Mountain unit on the southeast peak of Snowking.

Fig. 2 Schist inclusion in the Snowking Mountain unit on the southeast ridge of Snowking.

PLATE XVI

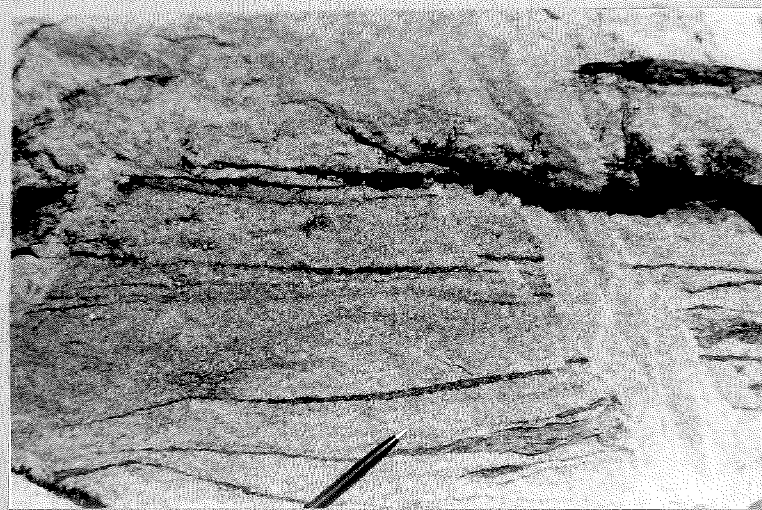


Fig. 1 Relict schist partings in directionless trondhjemite cut by replacement dike. On the southeast ridge of Snowking in the Snowking Mountain unit.

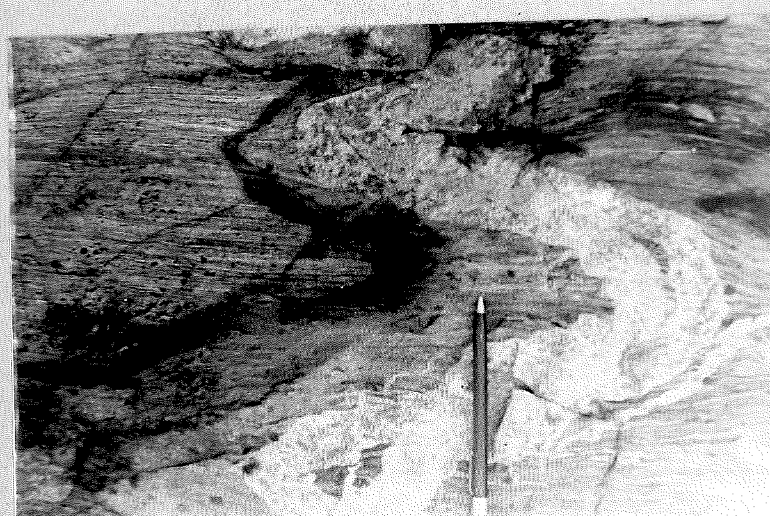


Fig. 2 Replacement veinlet of aplite in schist inclusion in the Snowking Mountain unit. Note the undistrubed inclusions of schist in the dike.

PLATE XVII

Fig. 1 Relict fold outlined by schist partings in the Snowking Mountain unit southeast of the east peak of Snowking.

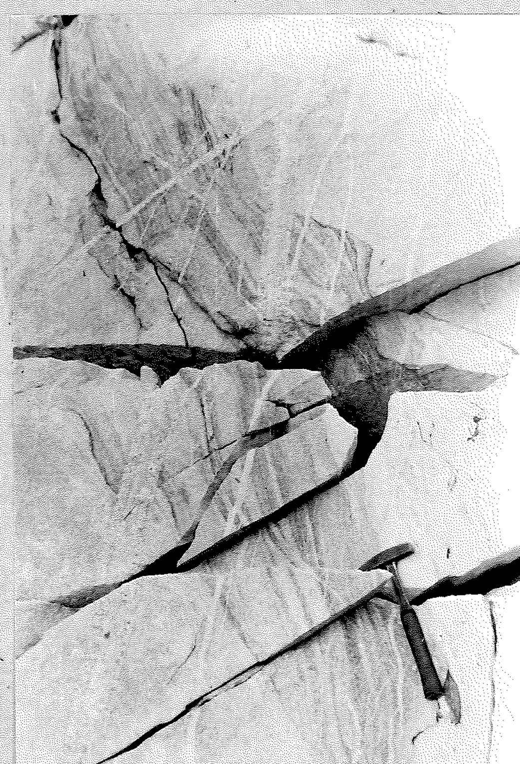


Fig. 2 Feldspathized schist relict in Snowking Mountain unit on the southeast ridge of Snowking.

PLATE XVIII

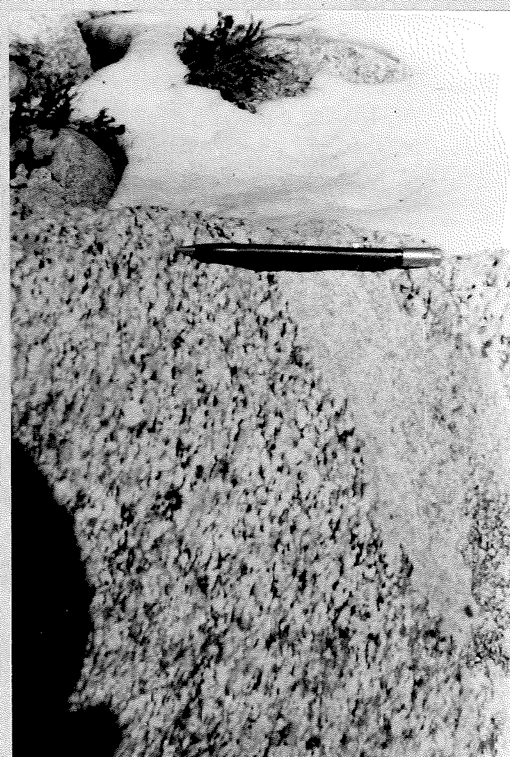


Fig. 1 Replacement stringer of granodioritic gneiss in quartz dioritic gneiss in Snowking Mountain unit on 5800 foot knob on Found Creek-Kindy Creek ridge.

traced into the granitic rock for several feet in the form of thin biotite partings.

Several specimens from the schist inclusions studied contain 30 to 50% sodic andesine to calcic oligoclase, 10 to 20% biotite, and 30 to 45% quartz. One specimen (A-57-1) from near the summit of the southeast peak of Snowking contains 10% hornblende and some garnet.

On the southeast side of the east peak of Snowking some relict schist partings were observed occurring in directionless granitic rock. They form a tight, almost isoclinal fold.

Petrographic Description

The granitic rocks of the Snowking Mountain unit contain 35 to 70% (average 55%) plagioclase which has normal oscillatory zoning. The oscillatory zoning is superposed on a normal trend. The composition ranges from An 34 to An 13. In individual crystals the maximum difference in composition between the core and the rim is usually about 10% An. The crystals are small to large, anhedral, and less commonly subhedral. The larger crystals often display crenulated borders, and they tend to include smaller grains of the other minerals except for potash feldspar. Quartz constitutes 15 to 30% of the rock (average between 20 and 25%). It is in small to large, anhedral grains, and often the larger ones include smaller grains of the other minerals. Potash feldspar, usually microcline, makes up from a few to 30% of the rock. It occurs in small to large, anhedral crystals that replace the other minerals, starting from the intergranular network. Plagioclase is the mineral most often replaced by microcline. Practically all the rocks contain myrmekite adjacent to some of the microcline. In addition to the vermicular intergrowths that characterize true myrmekite, the quartz often occurs in small blebs in the plagioclase.

A few to 15% biotite (average 10%) occurs in fairly small, anhedral flakes. The only exception is the knob east of lower Found Lake where the biotite varies from small to large in size and is subhedral in a few cases. In the gneissose rocks it is late-kinematic to post-kinematic and mimetic. Muscovite makes up 0 to 10% of the rock (average less than 5%) and occurs in small to medium sized, anhedral flakes, which have been derived from biotite and plagioclase. It formed later than all the other minerals except the potash feldspar, with which it was contemporaneous. A few grains of hornblende occur in the rocks on the knob east of the lower Found Lake. Epidote minerals are a common accessory, and they are often associated with the micas, which perhaps suggests the former presence of hornblende. Chlorite is retrogressive after biotite. Common accessories are sphene and apatite. Less common are zircon, tourmaline, orthite, and opaques.

Textures are granoblastic and typically metamorphic. Only in a few specimens does the plagioclase tend to develop better form, and in these exceptional cases the texture is less typically metamorphic without, however, becoming typically igneous either. Apparent cataclastic texture is extremely common. It is not true cataclastic texture because it consists of small grains inherited from an earlier finer grained (perhaps cataclastic) stage in the evolution of the rock, rather than of late grains formed by the breakdown of earlier, larger crystals.

A specimen (C-60-1) from the north side of the col south of the southeast peak of Snowking is an andalusite- and biotite-bearing leucocratic quartz monzonitic granulite. It contains 35% fine to medium grained, anhedral plagioclase, An 13 to 18 in composition, which includes quartz and biotite. Small to medium sized, anhedral quartz grains make up 30% of the

PLATE XIX

Fig. 1 (left) Andalusite and biotite-bearing leucocratic quartz monzonitic granulite from the Snowking Mountain unit. Fine grained andalusite and biotite (specimen C-60-1) 21x, plane light.

Fig. 2 (right) Crossed nicols.

Fig. 3 Microcline engulfing plagioclase and quartz grains in biotite granodiorite of the Snowking Mountain unit (specimen C-30-3) 20x, crossed nicols.

rock. Potash feldspar (30%) is fine to medium grained and anhedral, and it replaces plagioclase and quartz starting from the grain boundaries. Some microperthite is present. Biotite occurs in small, anhedral flakes which tend to be in aggregates. Andalusite in small, anhedral and skeletal crystals is associated with biotite. Fibrous sillimanite (fibrolite) has been derived from biotite. Accessories are muscovite, zircon, orthite, and a bright green, isotropic mineral in tiny grains (manganosite ?). The presence of andalusite indicates that this rock must have been derived from a shaly sediment with alumina excess.

On the slope northwest of the southeast peak of Snowking splotches of coarse grained biotite gneiss occur, and they have a foliation parallel to that of the gneissose portion of the unit. One specimen (A-57-2-a) shares both rock types, and in thin section the main difference between the two types is that the coarse grained gneiss contains 55% quartz in large porphyroblasts that replace plagioclase, whereas in the fine grained rock quartz constitutes only 20%. Some of the quartz in the fine grained rock is also late. In the coarse grained part of the section biotite occurs in aggregates and in larger crystals than in the fine grained portion. Aggregates of biotite are concentrated at the border between the two portions. In fact the change from evenly distributed biotite in the fine grained rock to irregular, unevenly distributed biotite concentrated in larger crystals and aggregates in the coarse grained rock defines the border most clearly. A few larger plagioclase crystals occur in the coarse grained rock, but most of the plagioclase has about the same size and shape as that in the fine grained rock. Both rocks have granoblastic textures, and both are quartz dioritic in composition. The exact relationship between the coarse grained gneiss patches and the dominant country rock is not clear. That the patches are gneissose and concordant with the main body of gneiss would suggest that they were relicts from an earlier stage in the development of the fine grained rocks. However, the development of the later quartz and the collective crystallization of the biotite suggest the opposite.

Just north of the col south of the 5800 foot knob east of the lower Found Lake is exposed a zone where the rock has been hydrothermally altered (specimen C-28-1-c). The plagioclase has been altered to albite and sericite. Biotite has become chlorite, some of which has a deep green color. In places the chlorite forms radiating fibers in quartz. Some tourmaline occurs. Remnants of mortar are present.

The aplites studied in thin section are more leucocratic, finer grained, and richer in potash than the surrounding rock. One specimen (C-27-1-b) from about 5200 feet elevation on the north side of the 5800 foot knob east of lower Found Lake contains 55% fine to coarse grained, anhedral microcline, which includes quartz and plagioclase. Quartz (30%) occurs in small to large, anhedral grains. Normally zoned plagioclase (10%) with a composition of about An 20 has some crenulated borders indicating metamorphic crystallization. Biotite is aligned. Chlorite and epidote complete the rock. Myrmekite is present. The rock is a true granite in composition.

Two specimens of dikes from within the gneissose portion of the unit have gneissose structure. Muscovite (10%) rather than biotite, which is present in only minor quantities, is the principal aligned mineral. In the gneissose dikes, which are quartz monzonitic in composition, quartz constitutes 40 to 50% of the rock, yet it is fine to medium grained and anhedral and does not display replacement features. In one veinlet of granodioritic composition containing only 15% quartz, a large quartz crystal includes a microcline grain.

Conclusions

The evidence favors the conclusion that the rocks of the Snowking unit were formed by the feldspathization of biotite schists and hornblende biotite schists. The unit is characterized by rather heterogeneous composition due to varying amounts of potash feldspar and muscovite. Practically all the rocks have granoblastic textures. They show no hints of former igneous textures or minerals. Their structure is generally concordant with that in the adjacent schists. Relict schist bands are present.

The contact with the schists of the Cascade valley is migmatitic, but the clearly mixed zone is narrow. The bend in the foliation just inside the contact seems best explained as a local feature of the original schist structure.

West Snowking Unit

General Statement

The West Snowking unit consists of biotite quartz diorite, biotite-hornblende-quartz diorite, trondhjemite, and granodiorite. It occurs on the northwest ridge of Snowking Mountain down to the col south of the 5900 foot knob on the Otter Creek-Illabot Creek ridge. Possibly the lower part of the ridge would be assigned to the Snowking Mountain unit (see Chapter IIIC3c above) on more thorough study. Its eastern border is on the peak between the east and west peaks of Snowking and on the 6900 foot knob west of the junction of the ridge to Chaval with the main ridge of Snowking. On the southwestern border of the unit is the narrow schist zone on the Chaval-

Snowking ridge. This schist zone may continue to the northwest down Illabot Creek. To the south and southeast the West Snowking unit must adjoin the Buckindy unit (see Chapter IIIC3g below), but this contact was not observed.

Contact Relations

On the peak between the east and west peaks of Snowking, in the field the contact between the Snowking Mountain unit and the West Snowking unit shows the West Snowking unit intruding the Snowking Mountain unit. Some blocks of Snowking Mountain unit rocks with fairly fine grained mafics are included in the rocks of the West Snowking unit, which have coarse mafics. The blocks have sharp borders. A fine grained, basic dike in the Snowking unit is cut by the West Snowking unit, and fragments of the dike occur in the west Snowking unit. Also variously oriented inclusions of partially feldspathized amphibolite and dike rock occur in the West Snowking rock. Although the contact is sharp in its overall aspect, it is gradational in detail.

In thin section a specimen (C-31-3-a), a quartz hornblende gabbro, from the margin of the West Snowking unit contains 45% plagioclase with very strong normal zoning, the composition of which ranges from An 80 to An 22. It occurs in medium sized, anhedral to euhedral crystals that include plagioclase, biotite, and hornblende. Quartz (25%) is in medium to large, anhedral grains that are late and include hornblende. Dark green hornblende occurs in small to medium sized, anhedral to euhedral crystals. The larger ones include some plagioclase. Biotite (5%) has been derived from hornblende. Some green penninite with very low birefringence is retrogressive after hornblende and biotite. Apatite, sphene, and opaque minerals are the accessories. The texture of the rock has an igneous aspect.

A specimen of partially feldspathized dike rock (specimen C-31-3-b) contains 60% plagiocalse with normal zoning and a compositional range from An 49 to An 20. The plagioclase consists of small to medium sized, anhedral to euhedral crystals that include hornblende and plagioclase. A few large, subhedral crystals occur, and they tend to incorporate hornblende at their margins. Small, mostly euhedral, olive green hornblende makes up 30% of the rock. It includes a few plagioclase grains. Quartz (5%) occurs as medium to fairly large porphyroblasts that replace plagioclase. Biotite (5%) and associated epidote were derived from hornblende. Green penninite is from biotite. Apatite, sphene, and opaque minerals are accessories. This rock, which is a microdiorite, has been somewhat feldspathized and silicified.

Specimen C-31-3-c, a potash feldspar bearing trondhjemite, from the same locality is an inclusion of the Snowking Mountain unit within the margin of the West Snowking unit. It contains 60% fine to coarse grained, anhedral to euhedral sodic andesine, which includes plagioclase, quartz, and potash feldspar. The included potash feldspar has a different configuration than the other included minerals. It forms long sutured, sinuous grains that suggest it is the mineral doing the replacing. The other included minerals are in roughly equidimentional anhedra. Quartz (30%) occurs in small to large, anhedral crystals that tend to fill between the plagioclase. Potash feldspar (5%) fills in between and replaces the quartz and plagioclase. Green penninite (5%) is the mafic, and it was derived from biotite. A few biotite relicts are present. Muscovite, epidote, apatite, orthite, zircon, and opaque minerals are accessories. This rock has an igneous texture except for the inclusions within the larger, euhedral plagioclase grains, which look as if they crystallized first.

At 18 inches on the Snowking Mountain unit side of the contact occurs a biotite granodiorite (specimen C-31-3-d). Its plagioclase (50%) is in medium sized, anhedral to subhedral crystals, and it includes plagioclase, quartz, biotite, and potash feldspar. Again some of the potash feldspar inclusions appear to be late replacement patches, but quite a few of them are not distinctive. Quartz (30%) occurs in medium sized, anhedral grains which have a slight tendency to fill in between the plagioclase grains. It includes plagioclase, quartz, and biotite. Potash feldspar (10%) fills in between and replaces plagioclase and quartz. Biotite and retrogressive green penninite make up 10% of the rock and are in small to large, anhedral to subhedral flakes. Some fibers of secondary rutile occur in the chlorite. Sphene, apatite, zircon, and opaque minerals are accessories. The texture of the rock has a somewhat igneous appearance, but metamorphic features are also present insofar as the plagioclase is not especially well formed, and as the larger grains of quartz and plagioclase include smaller grains of the other minerals.

The field evidence definitely indicates that the West Snowking unit has intruded the Snowking Mountain unit at this locality. The West Snowking unit here consists of more basic rock than the Snowking Mountain unit. It contains plagioclase of more calcic composition and a larger quantity of mafics. The principal mafic in the West Snowking unit at this locality is hornblende, while in the Snowking Mountain unit it is biotite. The rock of the West Snowking unit must have been quite hot to allow the calcic cores of the plagioclase to form. However, the inclusions in the well-formed crystals throw some doubt on whether it was ever a true melt. The leucocratic rock of the Snowking Mountain unit adjacent to the contact developed textures of an igneous aspect and may have been partially melted. This heating and intrusion took place during the main metamorphism and metasomatism because the potash feldspar in the Snowking Mountain unit partially participated in it.

On the knob west of the junction of the main Snowking ridge with the Snowking-Chaval ridge the relationship between the Snowking Mountain unit and the West Snowking unit is not as clear. The contact is gradational over several inches, and the large hornblende and biotite grains of the rocks of the West Snowking unit disappear gradually in the direction of the Snowking Mountain unit, which contains no hornblende and finer grained biotite. Dikes and pods of rock with coarse mafics occur in the rock with the finer mafics, and these bodies have gradational boundaries.

Specimen D-1-1-a, a potash feldspar-bearing biotite quartz diorite, from the transitional rock, contains 75% normally zoned plagioclase varying from An 45 to An 33 in composition. Some superposed oscillatory zoning is present. The plagioclase occurs in small to large, anhedral to euhedral crystals, which include quartz, hornblende, and biotite. Small to large, co-anhedral quartz grains (10%) tend to fill in between the plagioclase, and they include biotite. Some late replacement quartz occurs. Potash feldspar (5%) also tends to fill between the plagioclase crystals. Biotite (10%) occurs in small to medium sized, anhedral to euhedral crystals which include quartz, plagioclase, and opaque minerals. Although most of it is brown, some is bright green. Some epidote is associated with it. Chlorite, hornblende, sphene, apatite, zircon, and opaques are accessories. The texture is igneous except that the larger plagioclase crystals are not the best formed.

A biotite quartz diorite (specimen D-1-1-b) from one of the dikes with coarse grained mafics contains 70% andesine in small to large, anhedral to euhedral crystals, which include biotite, hornblende, quartz, and opaque minerals. Quartz (15%) occurs in small to medium sized, anhedral grains. Potash feldspar tends to fill in between and replace plagioclase. Biotite (15%) is found in fairly small to fairly large, anhedral to euhedral crystals. Some large crystals include quartz in sieve texture. Hornblende occurs in tiny, anhedral grains included in plagioclase. Zircon and apatite are accessories. The texture is quite igneous.

The specimen studied from the closest part of the main Snowking Mountain unit is from the top of the 6900 foot knob, and it (specimen A-56-2) is a leucocratic quartz monzonite with a well-developed granoblastic texture.

Field Description of the Rocks of the West Snowking Unit

The rocks of the main body of the West Snowking unit consist of biotite and biotite hornblende quartz diorite, trondhjemite and granodiorite. In the northern part of the unit the mafics tend to be fine grained, while to the south, especially on the Snowking-Chaval ridge, they are coarse. There hornblende crystals are up to 1/2 inch long.

On the lower part of the northwest ridge of Snowking quite a few large schist inclusions crop out. The exposures are not good enough to observe very well their relation to the granitic rock. In one place where the boundary of a schist inclusion was observed, the schist had been statically somewhat recrystallized. Some float containing variously oriented small schist inclusions occurs on the west side of the ridge N 13° E of the summit of Chaval. As was mentioned above, the rock in this area might belong to the Snowking Mountain unit.

Mafic inclusions occur west of the west peak, in the rocks in talus at the east end of the low part of the Snowking-Chaval ridge, in various places on the west side of the mountain, and on the north side of a little tarn southeast of the southwest-facing glacier on Snowking. Two general types of inclusions occur. In one variety the mafics are finer grained, and feldspar porphyroblasts are present. The other type appears to be a concentration of mafics.

At about 5500 feet elevation of the east side of the Snowking-Chaval ridge the hornblende in the rock has a faint lineation.

Petrographic Description

The number of specimens studied from the West Snowking unit is relatively small, and they vary considerably in their textures; so it is difficult to make generalizations about the main body of the unit. The hornblende bearing portion of the unit occurs on the Snowking-Chaval ridge, and the rocks in that area contain up to 10% green hornblende.

At about 5600 feet elevation on the northwest ridge of Snowking the rock, a two mica granodiorite, has a granoblastic texture and is very similar to the typical rock of the Snowking Mountain unit.

At about 6800 feet elevation on the northwest ridge of Snowking the rock is also a two mica granodiroite (specimen A-52-2) containing 55% normally zoned plagioclase ranging from An 28 to An 21 in composition. Oscillatory zoning is superposed on the normal zoning. The plagioclase occurs in small to large, anhedral to subhedral crystals, which have irregular rims. It includes biotite and quartz. Quartz (25%) is in part later than the plagioclase and includes biotite and earlier quartz. Late microcline (15%) occurs in the intergranular network and replaces the plagioclase. Myrmekite is present. Biotite forms anhedral flakes that are mostly retrogressively altered to green penninite. The texture is granoblastic, but the larger plagioclase grains exhibit some late euhedral tendencies that suggest increased freedom of crystallization late in the history of the rock.

On the west summit of Snowking the rock is a potash feldspar bearing biotite quartz diorite (specimen A-52-3) which contains 65% plagioclase generally displaying normal zoning with minor oscillations. One crystal ranges in composition from An 55 in the core to An 11 in the rim. In another crystal oscillations are well developed, and four definite zones were measured. From the core outward they are An 32, An 26, An 43, and An 12. Generally the crystals are small to large and anhedral to subhedral, but a few of the large ones are quite euhedral despite the presence of margins that are irregular in detail. They include a few biotite and quartz grains. Quartz (20%) occurs mainly as small, anhedral grains, but a few large anhedral crystals have sutured borders and include plagioclase. Potash feldspar (5%) is in small to fairly large grains that appear to be late. Biotite (5%) occurs in small, anhedral flakes. Both clinochlore and penninite are the products of the retrogressive alteration of biotite. Also they occur with carbonate in what appear to be pseudomorphs of poorly shaped hornblende crystals. A small fragment of hornblende is included in a plagioclase crystal. A grain of definitely early clinozoisite occurs included in a small quartz and a small plagioclase grain, all of which is included in a large quartz crystal. Pyrite, magnetite, and apatite are accessories. This rock has an apparent cataclastic texture. The observed relations between the mineral grains indicate this rock has a dominantly crystalloblastic texture with a late superposed tendency towards an igneous-appearing texture as shown by some of the large, late plagioclase porphyroblasts.

Between the west summit and the intrusive contact with the Snowking unit, the rock is a potash-feldspar bearing biotite-hornblende-quartz diorite "porphyry" (specimens C-31-2-a&b). It contains 60% plagioclase which is normally zoned with superposed oscillations. The plagioclase varies

PLATE XX

Fig. 1 "Potash feldspar-bearing biotite hornblende quartz dioritic porphyry" from the mobilized portion of the West Snowking unit near intrusive contact with the Snowking Mountain unit. Plagioclase "phenocrysts" have grown from finer grained groundmass and are porphyroblasts. (specimen C-31-2-a) 12 x, crossed nicols.

Fig. 2 "Biotite hornblende quartz dioritic porphyry" from mobilized portion of the West Snowking unit near intrusive contact with the Snowking Mountain unit. Plagioclase porphyroblasts in finer grained groundmass. (specimen C-31-2-b) 20x, crossed nicols.

from An 53 to An 35 in composition. It occurs as small, anhedral grains in the groundmass to large, euhedral porphyroblasts that include much groundmass at their margins. Quartz (20%) occurs in crystals varying from small, anhedral grains in the groundmass to large, anhedral porphyroblasts that include groundmass minerals. Potash feldspar (less than 5%), sometimes microperthite, tends to fill in between and replace plagioclase and quartz. Green hornblende (10%) is found in small, anhedral to large, subhedral to euhedral crystals. It includes considerable quantities of small quartz and plagioclase. Biotite (more than 5%) occurs in small, anhedral flakes in the groundmass. A few larger crystals are late and include other minerals. The biotite was at least partially derived from hornblende. Epidote is associated with biotite and is also from hornblende. Green penninite is the product of retrogressive alteration of biotite and hornblende. Apatite, zircon, sphene, and opaque minerals are accessories. The rock has an igneous overall aspect, but the details of its crystallization history are incompatible with an igneous origin. Field relations show that it is intrusive. Therefore, this is a mobilized, but not melted, rock of metasomatic descent.

On the eastern half of the ridge between Snowking and Chaval the rock is quite igneous in aspect except for one specimen of biotite granodiorite from about 5600 feet elevation. The specimen (A-53-1) contains 60% plagioclase in small to large, anhedral to subhedral crystals that are normally zoned. The grains range in composition from An 32 to An 23, and index comparisons suggest the margins may be even more sodic in composition. They have borders that incorporate smaller grains, and they include quartz, plagioclase, and biotite. Quartz constitutes 20% of the rock. Microcline (15%) occurs in small to very large crystals. Some of it is microperthite.

PLATE XXI

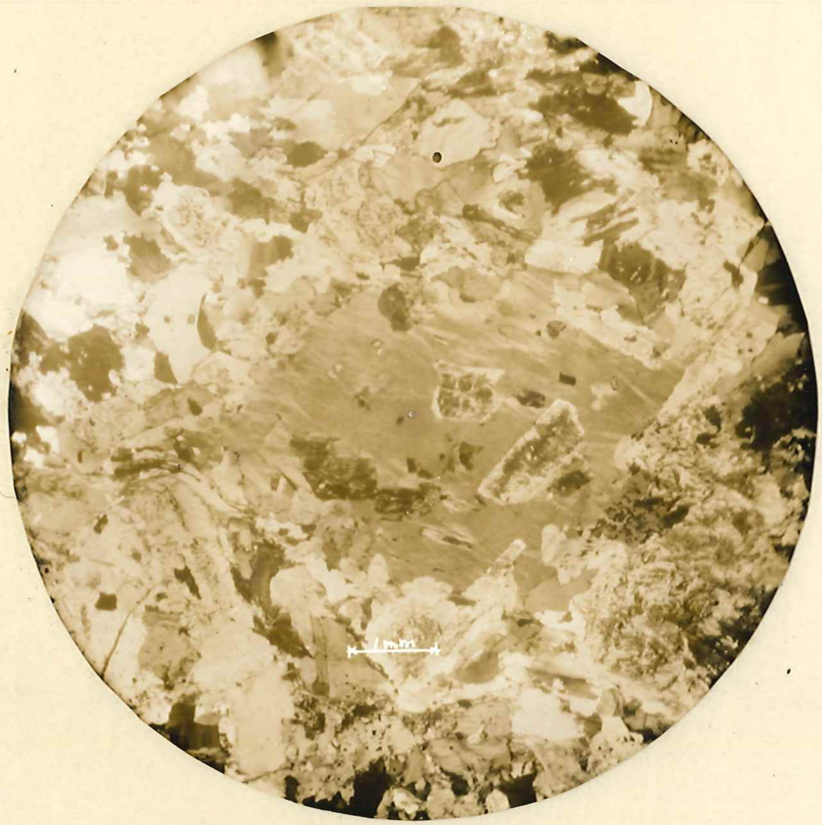


Fig. 1 Microcline porphyroblast in biotite granodiorite in West Snowking unit. (specimen A-53-1) 12x, crossed nicols.

The smaller grains occur in the intergranular network, while the large ones engulf the other minerals. Biotite (5%) forms anhedral flakes and in places occurs in aggregates of small crystals. It appears to have been sheared and recrystallized. Retrogressive chlorite is present. Late muscovite has been derived from plagioclase. Apatite, zircon, and magnetite are accessories. There are some areas of fine grained quartz and feldspar between the larger crystals, which are being incorporated by the larger crystals, thus producing an apparent cataclastic texture.

Not far west at about 5500 feet elevation a hornblende biotite quartz diorite porphyry (specimen A-54-1) is exposed. It contains 70% normally zoned plagioclase in large, euhedral to subhedral phenocrysts and gradations to small, anhedral groundmass grains. Oscillatory zoning is superposed on the normal zoning. The grains range from An 55 to An 22 in composition. They have quite a sharp sodic outer rim, which tends to incorporate the groundmass. The large crystals include earlier quartz, plagioclase, and hornblende. A few crystals are zoned relative to a non-existent center, which suggests that they may be fragments. Quartz (20%) occurs in crystals varying from large, euhedral phenocrysts to small, anhedral, groundmass grains. The larger crystals include earlier quartz and plagioclase. Hornblende (5%) forms large, subhedral crystals and in the groundmass as small, anhedral grains. It includes some quartz and plagioclase. Biotite (5%) occurs mainly as small to medium sized, anhedral flakes in the groundmass. A fairly large, euhedral crystal is present. A small portion of the biotite is from hornblende. Apatite and opaque minerals are accessories. Except for the inclusions of the small grains of the various minerals in the larger crystals, this rock has an igneous texture. Perhaps the rock has an earlier metasomatic history, the evidence for which has been all but lost during a

Some of them were derived from hornblende. Hornblende (5%) is found in small to medium sized, anhedral to subhedral crystals. In both the country rock and the inclusion the accessories are chlorite, epidote, apatite, sphene, zircon, and magnetite. The magnetite tends to occur in rather small grains in the matrix of the inclusion, whereas in the country rock it is in larger grains.

The texture of the inclusion suggests it may have been an igneous or mobilized rock. Whatever the early mafics were, they have been recrystallized into late hornblende and biotite porphyroblasts. Large euhedral plagioclase crystals have formed. A few quartz grains grew in the groundmass. The contact with the country rock is gradational over a short distance. Some features in the adjacent rock suggest it may simply be a more thoroughly recrystallized and silicified portion of the original fine grained rock.

Conclusions

The rocks of the West Snowking unit are at least in part of metasomatic origin. The main evidence for this is the granoblastic texture of those rocks in the northern part of the unit. On the Snowking-Chaval ridge the texture of the rock is generally igneous. However, some rocks with metamorphic texture occur. Between the northern rocks and the Snowking-Chaval ridge rocks those specimens studied have an intermediate texture in which the igneous tendencies developed during a late phase of crystallization. Since no break was observed between the two general areas containing these rocks of dissimilar texture, it is inferred that the igneous textured rocks of the Snowking-Chaval ridge are the products of the same metasomatic process as the rocks of the northern part of the unit, except that they have been partially melted or have contained a large enough amount of interstitial fluid to permit considerable freedom of crystallization during a late stage of their growth, as indicated by their textures. The fact that some of the rock has been mobilized may have aided the development of the late igneous texture. Mobilization might be the result of the presence of a somewhat larger amount of liquid phase than in the non-mobilized metasomatic rocks. This increase in the amount of liquid combined with movement might produce the fine grained matrix and the porphyroblasts characteristic of the mobilized rocks.

Northern Unit

General Statement

The northern part of the Snowking massif consists of coarse grained hornblende-biotite and biotite-quartz diorite, trondhjemite, granodiorite, and quartz monzonite. This unit extends south to the top of the 6000 foot knob southeast of the 6735 peak at the head of boulder Creek and south of the 5800 foot knob on the Otter Creek-Illabot Creek ridge. Its southwestern margin is somewhere on the northeast side of the Illabot Creek valley. Its contacts with the Cascade valley schist zone are fairly well exposed on the ridge south of Razor Back and on the Found Creek-Boulder Creek divide and less well exposed on the ridge west of the knob west of the upper Falls Lake, the west side of the Boulder Creek valley, and the col west of the main knob on Razor Back. On the Jordan Creek-Boulder Creek ridge and the ridge north of Razor Back the contact is not at all exposed but must be inferred from float.

Contact Relationships

On the 6000 foot knob above the lowest Granite Lake the contact between the Snowking massif and the Cascade valley schist zone is well exposed.

Granitic rock and cataclastic gneiss appear to be interbedded with and grade into quartzitic schist. In some places the quartzitic schist can be seen to change to granitic rock along its strike. Some of the attitudes in the schist and gneiss are more or less parallel to the general attitude of the schists of the Cascade valley schist zone, whereas other attitudes are generally parallel to the trend of the margin of the Snowking massif at this point. However, although the Snowking massif cuts across the general trend of the Cascade valley schist zone, the adjacent schists are concordant to the border of the massif.

Just north of the 5500 foot col between Found Creek and Boulder Creek the Snowking massif is in contact with mica schists and quartzitic schists. On the 5900 foot knob to the north is a north-south trending granitic dike that appears to be intrusive, yet is not entirely homogeneous. Farther down in the col are some rather coarse grained intrusive quartz-rich dikes. Near the bottom of the col occurs a 50 foot thick dike of rather heterogeneous granitic rock. Some of it is very leucocratic. The mafic mineral, biotite, varies considerably in its size. The adjacent schist is riddled with dikes and quite contorted. Some of the dikes have indefinite margins and contain long undisturbed fingers of schist projecting into them. Those are replacement dikes. The rest of the contact is covered, for south of the col the rock is entirely granitic.

The dike on the 5900 foot knob is a biotite quartz diorite (specimen C-12-2-a) containing 60% fine to coarse grained, anhedral to subhedral, normally zoned, plagioclase that ranges in composition from An 41 to An 24. The plagioclase includes large quantities of smaller quartz and plagioclase grains. Fine to coarse grained, anhedral quartz (25%) includes plagioclase and biotite, and the larger crystals are strongly strained. A small amount

PLATE XXII

Fig. 1 General view of terrain in the Northern unit. On the left the 6350 foot peak between Boulder Creek and the second Jordan Lake; on the right the 6400 foot peak on the Jordan Creek-Boulder Creek divide.

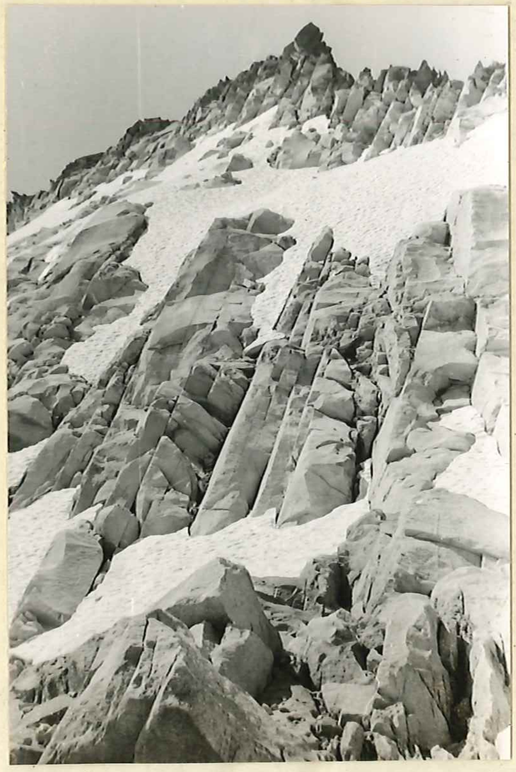


Fig. 2 Rocks of the northern unit on 6735 foot peak at the head of Boulder Creek. Jointing locally well developed.

of potash feldspar is present. Biotite (10%) includes some quartz and plagioclase and occurs in small to large, anhedral flakes. Muscovite (5%) was derived from biotite and plagioclase and is in small to medium sized, anhedral flakes. Sphene and apatite are accessories. The texture is granoblastic.

Another specimen (C-12-2-e) of the dike showing its contact with the schist is a microcline-bearing trondhjemite. Plagioclase (50%) with the composition An 20 occurs in medium to large, anhedral to euhedral crystals and includes quartz and biotite. Small to large anhedral quartz grains (40%) fill in between the plagioclase in the part of the section where the plagioclase is euhedral. Large microcline crystals replace quartz and plagioclase, and myrmekite is associated with them. Muscovite replaces quartz and plagioclase. Biotite completes the rock. This rock has some igneous features, but they formed at a late stage of the history of the rock and are irregularly distributed. The contact with the schist is sharp except in a small portion of the section where it is gradational. Some of the biotite in the dike is aligned parallel to the walls, which suggests intrusion. Perhaps the dike is an at least partially mobilized dike of metasomatically-derived material.

The rock in the dike near the col is a microcline bearing biotite quartz diorite (specimen C-13-2-b) with granoblastic texture. A small leucocratic dike (specimen C-13-2-a) within the quartz diorite dike is a quartz monzonite and contains 25% medium grained, anhedral to subhedral plagioclase with the composition An 23. The plagioclase includes some quartz. Quartz (35%) is found in medium sized, anhedral grains and tends to replace and include plagioclase. It is rather strongly strained. Microcline (35%) occurs in medium sized, anhedral crystals, and it tends to replace quartz and plagioclase. Muscovite (5%) was derived from biotite. A little biotite remains. Skeletal crystals of clinozoisite occur with the muscovite. Fragments of isotropic material (garnet ?) are present. The texture is granoblastic.

Much of the adjacent schist contains up to 10% microcline, which tends to replace quartz. It probably indicates some potash introduction since normally the schist contains no potash feldspar. The adjacent schists are mainly synkinematic, but some of them display a fairly strong post-kinematic phase which reduced the sharpness of alignment of the biotite. In one case (specimen C-13-2-f) the biotite tends to be aligned parallel to the axial planes of the fold.

The rock inside the contact is coarse grained hornblende-biotite-quartz diorite and granodiorite having generally crystalloblastic textures with idioblastic tendencies. At the bottom of the south side of the col the granitic rock includes partially feldspathized fragments of hornblende biotite schist. One specimen of schist (C-14-2) contains 55% plagioclase with the composition sodic andesine and weak reverse zoning. It is in small to medium sized, anhedral grains. Post-kinematic green hornblende, which has sieve texture with quartz and plagioclase inclusions, makes up 20% of the rock. It occurs in small to medium sized, anhedral grains. Biotite (20%) formed post-kinematically but is aligned mimetically after the foliation. Only a small amount of it appears to have been derived from hornblende. Quartz, sphene, and apatite are the accessories. The quantity of biotite that is contemporaneous with the hornblende suggests that the rock may have been derived from a shaly tuff or greywacke. The scarcity of quartz and large proportion of plagioclase indicates the possibility of considerable "concealed" soda metasomatism.

The observed features of the contact and of the adjacent rock are not entirely conclusive, but they seem to favor emplacement partially by replacement and partially by intrusion of mobilized metasomatic granitic material.

On the ridge west of the 5200 foot knob west of the upper Falls Lake somewhat scattered outcrops delineate the contact of the Snowking massif. Para-amphibolite and granitic rock crop out about 30 feet apart. The granitic rock contains what appears in the field to be gneiss zones about 1 1/2 feet wide. The zones seem to grade into the granitic rock. In the cirque to the north and somewhat to the east occurs an outcrop of quartzitic schist, and granitic rock crops out about 100 feet to the east. The strike of the schist at these localities is 5^{o} to 15^{o} west of north, whereas the general trend of the border of the Snowking massif is slightly east of north. The schist dips steeply under the massif. The supposed gneiss zone is concordant with the schist. Thus in detail the contact of the granitic rock cuts across the strike of the schist in what is interpreted to be a zigzag pattern.

At this locality the schists are dominantly synkinematic. Thirty feet from the contact the rock, a hornblende-plagioclase schist (specimen D-44-1-2) contains two bands of plagioclase that might have been partially formed by replacement. The supposed gneiss zone mentioned above is a garnet-two mica-clinozoisite quartzite (specimen D-44-1-e). In this rock the mica is synkinematic. The granitic rock is biotite quartz diorite (specimen D-44-1-e), and its original texture is somewhat masked by late shearing. Plagioclase (60%) forms medium to large, subhedral to euhedral crystals that include some biotite and smaller plagioclase. Quartz (30%)

is generally later than the plagioclase and is in medium to large, anhedral grains. It includes some biotite. Biotite (10%) occurs in small to fairly large, anhedral to subhedral crystals, and it has been somewhat sheared and strained. Retrogressive light yellowish tan penninite was derived from biotite. Clinozoisite is from plagioclase and/or hornblende. Orthite and zircon are accessories. The original texture was igneous.

On the Illabot-Jordan Creek divide the contact is not exposed and must be inferred from float in conjunction with isolated outcrops. As close as can be seen the granitic rock is adjacent to para-amphibolite and biotite schist. The attitude of the schist is N 20° W, but at this point the contact must be trending even more easterly than to the south.

On the Jordan Creek-Illabot Creek divide the rocks are generally synkinematic. However, some of them display a static phase, and late shearing may tend to obscure the effects of that static phase. The granitic rock nearest the contact is a microcline-bearing hornblende-biotite-quartz diorite (specimen B-1-3) containing subhedral to euhedral plagioclase An 20 (60%), which includes some hornblende. Quartz (20%) fills in between the plagioclase, sometimes tending to be in aggregates of sutured crystals. Microcline (5%) grew at the expense of quartz and plagioclase. Biotite (10%) occurs in medium to large, subhedral to euhedral books. Green hornblende (5%) is found in small to medium sized, anhedral to subhedral crystals. The biotite is altered to light green, light brown, and brown penninite. Also a yellow alteration product intermediate between biotite and chlorite is present. Prehnite occurs associated with biotite. Apatite is an accessory. This rock has an igneous texture except for the hornblende, which is early, but not well formed.

The nature of the contact in this area is rather a puzzle. The adjacent rocks lack any definite contact metamorphic effects, yet the granitic rock has quite an igneous aspect. If the granite was intruded into the mesozonal schists, perhaps no such effects need be expected. The zone of mesozonal metamorphic rocks adjacent to the granite is rather narrow, namely only about 1/4 mile wide, which suggests that the granite is not now in its original genetic environment. The rocks display considerable late shearing, but this shearing is hardly thorough and intense enough to indicate a fault contact.

On the Jordan Creek-Boulder Creek ridge the contact could only be determined by float. The Snowking massif here adjoins the Jordan ridge serpentine on the crest and the west side of the ridge. On the east a thin zone of mesozonal quartzitic schist borders the granite. The specimen of granitic rock collected closest to the contact (specimen C-57-2) is from about 4600 feet elevation on the ridge, and it is a microcline bearing hornblende biotite quartz diorite. The diorite has a fairly igneous texture. It contains quite large euhedral biotite which includes hornblende, quartz, clinozoisite, prehnite, zircon, apatite, and sphene. The hornblende occurs in small to medium sized, anhedral to euhedral grains. Plagioclase is in small to large, anhedral to euhedral crystals. As usual, microcline replaces and includes the other minerals.

On the west side of the Boulder Creek valley at about 2700 feet elevation just north of where a gulley spreads into a narrow slide slope south of the logged area occurs an outcrop that must be very close to the contact of the Snowking massif. The outcrop consists of quartzitic schists containing bands of leucocratic granite rock. The strike of the foliation is parallel to the trend of the margin of the Snowking massif, and it dips steeply (80° to 85°) to the southwest, or beneath the massif.

The schists contain micas that are generally post-kinematic and mimetic after the foliation, although in one specimen from this outcrop (D-28-2-c) part of the mica is synkinematic.

In specimen D-28-2-d, a contact between biotite-quartz schist and granitic rock is present. The granitic rock contains 20% fine grained, anhedral plagioclase with the composition An 10 to 15. Small to medium sized, anhedral quartz grains make up 35% of the rock. Microcline (45%) ranges from small to large in size and is anhedral. It replaces fine grained quartz and plagioclase. Epidote, muscovite, and garnet are accessories. Some myrmekite occurs. Also some pseudomyrmekite (quartz in potash feldspar) is present. The quartz in the potash feldspar appears to be a relict from an earlier true myrmekite in which the plagioclase has subsequently been replaced by potash feldspar. The rock has the composition of an alaskite. The alaskite pushes aside the biotite trends in the schist, and thus it is intrusive at this place.

The other specimens of the granitic rock from this outcrop are alaskite containing sodic oligoclase, quartz, microcline, and microperthite. The microcline is late and replaces the other minerals. One specimen (D-28-2-e) contains small, subhedral garnets included in all the other minerals. Muscovite has formed from both plagioclase and microcline, but mainly from plagioclase. The specimens have granoblastic textures.

The nearest outcrop within the Snowking massif observed in the Boulder Creek valley occurs at about 2700 feet elevation on a tributary brook that enters Jordan Creek just below the falls. The rock (specimen D-28-1) is a hornblende biotite granodiorite which contains anhedral plagioclase and hornblende and late microcline. Considerable prehnite is associated with the biotite. The texture of the rock is granoblastic.

Again the evidence for the nature of the contact is inconclusive. The small garnets in the alaskite are probably relicts from schist. The textures and field relations suggest that the alaskite dikes are mainly of replacement origin, although locally there may have been some intrusive movement due to mobilization. However, the main contact is obscured. The granitic rock inside the contact does not have any igneous features at this locality.

To the south the contact of the Northern unit with the Snowking Mountain unit is exposed on the 6000 foot knob southeast of the 6735 foot peak at the head of Boulder Creek. On the north side of the knob the coarse grained rock of the northern unit is gneissose in places, and fine grained rock like that of the Snowking Mountain unit occurs in dikes and has gneissose structure parallel to that in the coarse grained rocks. Replacement dikes of pegmatite and aplite are common, and some dikes are intrusive, as is shown by dilation of their walls. From the top of the knob replacement and intrusive dikes grade into rocks of the Snowking Mountain unit in a southerly and southeasterly direction. Some of the dikes of fine grained granitic rock have pegmatitic borders. Some have gneissose structure aligned with the structure in the coarse grained granitic rock. Some of the intrusive dikes have flow structure. In the field the evidence is that the fine grained rock is younger than the coarse grained.

The fine grained and coarse grained rocks are of similar composition, except that the coarse grained rocks contain about 15% biotite as opposed to about 5% in the fine grained. The finer grained rocks have more muscovite. The quantity of microcline varies within approximately the same limits (5 to 25% in the rocks examined) in both rock types. In the rocks sampled at the contact the composition of the plagioclase is about

10% more albitic in the finer grained ones than in the coarser grained ones. Farther inside the Snowking Mountain unit the plagioclase is somewhat more calcic.

In thin sections of the specimens collected, nothing was found to clarify the relationship of the coarse grained to the fine grained rocks. Both rock types are characterized by apparent cataclastic texture with the development of medium to large plagioclase, quartz, and microcline porphyroblasts. Not much groundmass remains. In the coarser grained rocks the large biotite crystals in some cases appear to be porphyroblasts. The process of recrystallization may have continued longer in the coarse grained rocks to produce their strikingly different aspect in the field. Yet if this is true, it is difficult to explain the occurrence of all the dikes.

Field Description of the Rocks of the Northern Unit

The rocks forming the main body of the northern part of the Snowking massif are generally coarse grained and contain large biotite crystals. On the ridges above the second Jordan Lake the grain size of the biotite varies considerably. On the ridge to the south of the lake the rock is entirely medium grained over a small area. Hornblende is fairly common in the rocks near the margin of the massif. Much of the coarse grained rock contains blobs of quartz up to 1 cm. in diameter, which sometimes stand out on a weathered surface. Several shear zones were observed in the northern unit.

On the south slope of the 5800 foot knob south of the contact on the Found Creek-Boulder Creek ridge aplite dikes 1/2 to 8 inches wide trending N 80° E and dipping 72° NW occur. Some of them cross each other at low angles, and older ones are offset; so the younger ones, at least, are intrusive.

Petrographic Description of the Rocks of the Northern Unit

The rocks of the northern unit consist of quartz diorite, trondhjemite, granodiorite, and quartz monzonite. However, the rocks have more mafics than those of the Snowking Mountain unit, and trondhjemite plays a smaller role in the northern unit. No particular areas seem to consist of predominantly one rock type. On the ridge south of the second Jordan Lake the rocks tend to be more leucocratic and contain more potash.

The rocks of this unit contain 35 to 70% plagioclase (average 55%) that usually has oscillatory zoning in a normal trend. The composition of the plagioclase ranges from An 35 to 5. Usually the composition in individual zoned crystals varies about 10% An between the core and the rim. The plagioclase crystals vary considerably in size and shape. In some rocks they are all anhedral, while in others they vary from anhedral to subhedral or euhedral. In most specimens, whether the plagioclase is euhedral or not, it includes small grains of the other minerals. In a few specimens the plagioclase crystals are euhedral and free of inclusions.

Quartz makes up 10 to 35% of the rock (average about 20%). It occurs in anhedral grains of various sizes. Quite often it constitutes aggregates of small to large, sutured, anhedral crystals. Often the larger quartz crystals replace the other minerals, usually plagioclase. Rarely it even replaces microcline. In some of the rocks with dominantly euhedral plagioclase crystals the quartz tends to fill in between the plagioclase.

Microcline (0 to 30%, average 10%) is always one of the late crystallizing minerals. It is always anhedral, but it varies in size from tiny grains between the quartz and plagioclase to large porphyroblasts that include smaller grains of the other minerals. The microcline replaces the other minerals except for late quartz and muscovite. However, in a few specimens from fairly near the contact on the Illabot Creek-Jordan Creek ridge the microcline is interstitial to plagioclase and quartz. Microperthite is common. Myrmekite is almost always associated with microcline and occurs very near or adjacent to the microcline grains. Sometimes the pattern of the quartz in the plagioclase is spotted rather than vermicular.

Biotite (0 to 20%, agerage 10%) occurs also in a variety of shapes and sizes. It varies from fine to coarse grained and from anhedral to euhedral. In a few specimens it is in euhedral books, and most of those specimens tend to contain euhedral plagioclase and interstitial quartz; in short an igneous texture. However, in many specimens even the large well-formed biotite crystals include small grains of quartz, plagioclase, and hornblende. In one specimen (C-44-3) large subhedral biotite crystals have growth borders that incorporate adjacent grains of other minerals. Thus it seems possible that igneous-looking biotite may be a product of porphyroblastic growth. The larger biotite crystals are very commonly strained. In rocks bearing hornblende, biotite is at least partially derived from the hornblende, and clinozoisite, epidote, or prehnite from the hornblende are associated with the biotite. In many rocks that do not contain hornblende, those minerals are associated with the biotite, which suggests the biotite may have been derived from some previous hornblende.

Muscovite constitutes up to 10% of the rock and is common in the rocks from the vicinity of the second Jordan Lake. It is found less frequently and in smaller quantities in the rocks near the contact, which contain some hornblende. In most specimens muscovite formed from biotite and plagioclase and less often from microcline. It occurs in small to medium sized, anhedral

PLATE XXIII

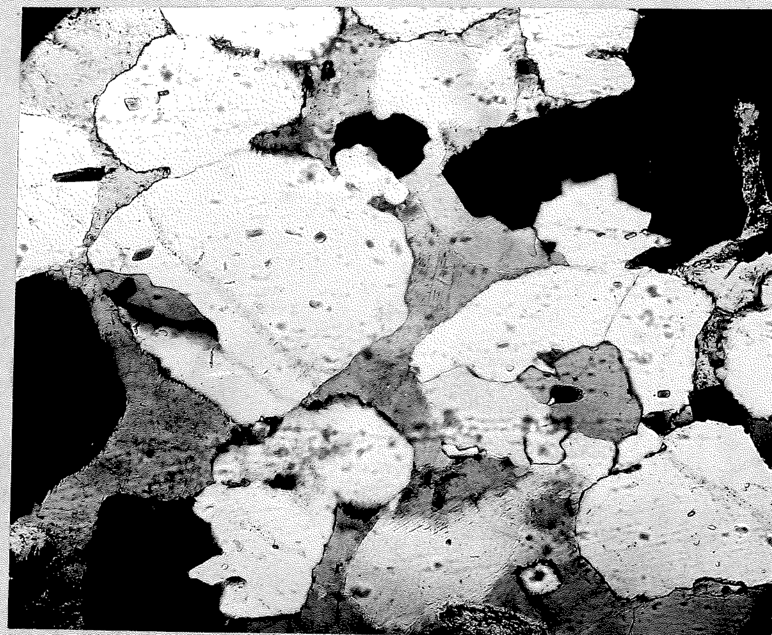


Fig. 1 Potash feldspar in the intergranular network of a recrystallized quartzitic schist from adjacent to the contact of the Snowking massif on the Found Creek-Boulder Creek ridge. (specimen C-13-2-g) 60x, crossed nicols.

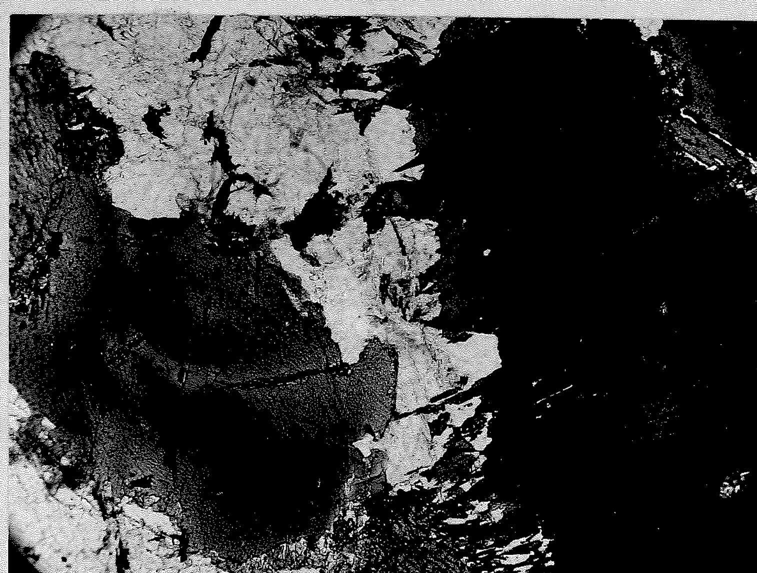


Fig. 2 Large biotite porphyroblasts in hornblende biotite quartz diorite in the Northern unit. (specimen C-44-3) 20x, plane light.

to subhedral flakes. Sometimes epidote or clinozoisite are associated with it. Probably that indicates that the muscovite was derived from biotite, which, in turn, was derived from earlier hornblende.

Hornblende is found most commonly in the rocks towards the edge of the Snowking massif, but even there it makes up only 0 to 5% of the rock. It occurs in all sizes and shapes but tends to be small to medium sized and anhedral to subhedral. Large euhedral crystals occur relatively rarely, and even in the rocks where they do occur, most of the hornblende grains are smaller and less well formed. The hornblende is green to light green and $Z \wedge C$ varies from 15° to 23°. Thus in some rocks the hornblende is actinolitic. In some specimens the hornblende includes occasional grains of quartz, plagioclase, and accessory minerals.

Clinozoisite or epidote is usually present in these rocks. Most often they are associated with biotite and sometimes with muscovite. As was mentioned above, they accompany biotite when it can be seen to have been derived from hornblende, and its association with biotite in a hornblende free rock may indicate the former presence of hornblende. When it is found with muscovite a more complex history might be inferred; 1. the biotitization of hornblende to produce biotite and the epidote mineral, 2. the alteration of biotite to muscovite with the preservation of the epidote mineral. Minerals of the epidote group, including zoisite, are often products of retrogressive alteration of the plagioclase in the rocks of this unit.

Prehnite occurs intergrown with biotite, and it probably substitutes for the epidote minerals usually derived in the biotitization of hornblende.

Chlorite is commonly present as a retrogressive alteration product of biotite. Sphene, apatite, and zircon are common accessories. Less common are orthite, carbonate, and opaque minerals.

In specimen C-37-1-b from the south side of the col south of 6735 foot peak at the head of Boulder Creek a few anhedral grains of monoclinic pyroxene occur.

In texture the rocks vary from granoblastic to igneous. There seem to be all gradations. The evidence for the age relations of the two textures as indicated in the rocks of intermediate texture and the igneous textured rocks seems to suggest that the igneous texture developed later than the granoblastic texture. The rocks with granoblastic textures contain no evidence of former igneous textures. Rocks with intermediate textures often have metamorphic features, such as growth borders and inclusions in the larger, more euhedral crystals. Some of the igneous textured rocks contain inclusions of smaller grains of the various minerals in those crystals that should have crystallized first, if the rock had an orthomagmatic origin. Only a few specimens have no features that might cast doubt on a possible igneous origin. In view of the evidence, these rocks may be considered neomagmatic. The majority of the igneous textured and intermediate textured rocks, as well as the granoblastic textured rocks contain microcline replacing the other minerals; so that feature cannot be considered critical. To a much lesser degree the same may be said of quartz. The important relationships are those of the plagioclase and mafics to each other and the other minerals of the rock.

Some apparent cataclstic texture occurs in these rocks. Cataclastic texture is fairly common, for many rocks were weakly sheared during the late part of their crystallization and after crystallization. In a few restricted zones the shearing was strong. In some rocks the microcline was formed after shearing.

Along the ridge from the 6350 foot peak north of the second Jordan Lake northwest to the 6400 foot peak on the Jordan Creek-Boulder Creek divide the rock as a whole was weakly sheared. In specimen C-41-2 from this area the plagioclase has been bent and broken and locally made into mortar. The quartz is brecciated and strung out. In specimen C-41-3 biotite is strained and bent, and quartz is strongly strained and elongated. Shear zones accompanied by mortar and muscovite and epidote occur in specimen C-41-1. Specimen C-44-1 from the summit of the 6350 foot peak north of the second Jordan Lake contains strained and strung-out quartz and bent and strained biotite. Some mortar occurs around the edges of the larger grains.

An example of a restricted and intense shear zone occurs on the Jordan Creek-Boulder Creek ridge at about 5400 feet elevation. There the shearing is very obvious in the field, and the zone has some iron stain on it. The rock (specimen C-57-4-a&b) contains quartz that has been brecciated, strung out, and partially made into mortar. Plagioclase has been heavily altered to sericite, albite, and calcite. In a few places the albite has recrystallized and has cleared itself of the other alteration products. The sericite and calcite has been distributed throughout the rock. A veinlet of albite and calcite occurs. Biotite has been altered to light green penninite (with some clinochlore) and has been bent and strung out. The chlorite has some inclusions of an opaque mineral.

On the summit of the 6400 foot knob just west of 6735 foot peak at the head of Boulder Creek occurs a shear zone in which the rock is a muscovite-albite granulite (specimen C-36-2-a) which contains 85% albite (An 8) in small, anhedral to subhedral grains. Fairly small, anhedral muscovite flakes make up 15% of the rock. Accessories are biotite, epidote, carbonate, sphene (?), apatite and zircon. The rock has completely recrystallized so that except for its occurrence in the field it would be difficult to be certain what it is. In the field the country rock, a porphyroblastic two mica quartz monzonite (specimen C-36-2-b) grades into the rock of the shear zone. Plagioclase (35%) with composition ranging from An 28 to An 11 forms fairly large, anhedral to subhedral porphyroblasts that grew from a fine grained groundmass of plagioclase, quartz, and biotite. The plagioclase includes those minerals. Quartz (30%) occurs in small to medium sized, anhedral grains, some of which have sutured growth borders. Microcline (30%) is found as small grains in the groundmass and grades to medium sized porphyroblasts that replace the groundmass. Small, anhedral biotite flakes make up 5% of the rock. Muscovite (10%) occurs in small, anhedral grains and was derived from plagioclase and biotite after the formation of the plagioclase porphyroblasts. Some small grains of clinozoisite are associated with the micas. Sphene and apatite are accessories. A crosscutting veinlet of pegmatite is present. The rock has apparent cataclastic texture. The fine grained portion was probably originally cataclastic material, as is suggested by its relation to the shear zone; this material would then have recrystallized and subsequently developed feldspar porphyroblasts.

On the ridge to the west at about 6200 feet elevation a pegmatite dike about 6 inches wide occurs in granodiorite and quartz monzonite. It has an indistinct border. The composition of the specimen (C-34-3-d) differs little from that of the country rock except that some of the country rock contains more biotite and a little less microcline. The dike contains 40% sodic oligoclase in small to large, anhedral crystals that include some quartz and plagioclase grains. Some of the crystals

PLATE XXIV

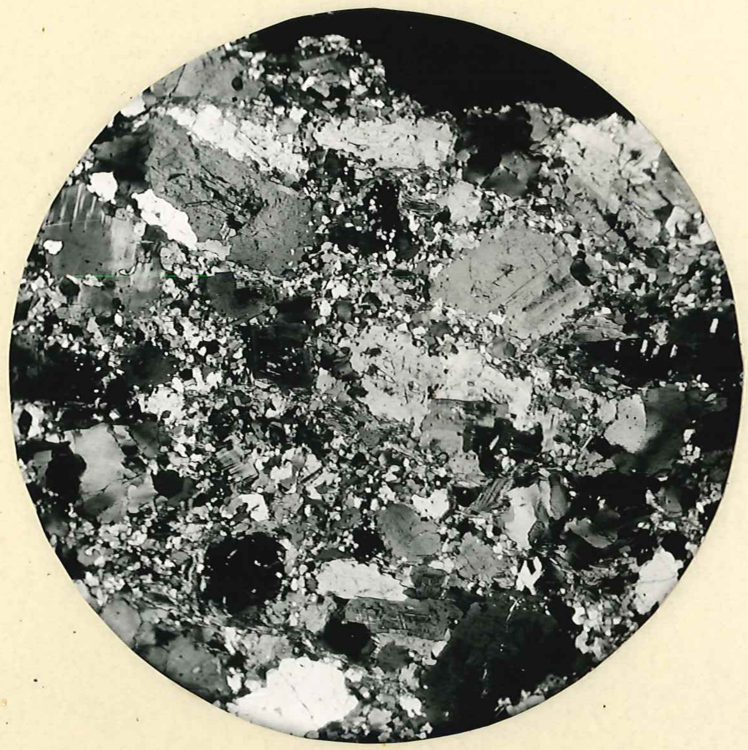


Fig. 1 Porphyroblastic two mica quartz monzonitic rock from a zone of late para-crystalline shearing in the Northern unit. Plagioclase porphyroblasts have grown in a fine grained, recrystallized cataclastic groundmass. Potash feldspar has replaced some of the fine grained quartz and plagioclase of the groundmass. (specimen C-36-2-b) 13x, crossed nicols.

have been bent and broken. Quartz (25%) occurs in small to medium sized, anhedral grains and includes quartz and biotite. It is strongly strained. Microcline and microperthite constitute 30% of the rock and are in small to large, anhedral grains, which replace and include quartz and plagioclase. Myrmekite is present. Muscovite (5%) occurs in small to medium sized, anhedral flakes. Small, anhedral biotite flakes look as if they might have been shredded. Light green penninite is retrogressive after biotite. Iron poor epidote is an accessory. Some scattered mortar occurs. The rock has a granoblastic texture. This rock appears to have been at least partially cataclastic at one time, but extensive recrystallization has left only remnants of cataclastic derived material. Perhaps the cataclasis during crystallization enabled the formation of a somewhat coarser grained rock than the adjacent country rock.

Just south of the col west of 6735 foot peak at the head of Boulder Creek a fine grained leucocratic dike 30 feet thick crops out. The adjacent rock is coarse grained and biotite-rich. Within the biotite-rich country rock a few patches of leucocratic rock occur. Also smaller dikes of leucocratic rock are found in the vicinity.

A specimen (C-40-1-a) from the large dike is a granodioritic gneiss containing 65% normally zoned plagioclase in small to fairly large, anhedral grains. Its composition ranges from An 29 to An 15. The larger crystals are sieve textured porphyroblasts including small biotite, quartz and plagioclase grains. Quartz (30%) occurs in small to medium sized, anhedral grains, some of which are strongly strained, whereas others are recrystallized. Microcline (10%) is found in small to medium sized, anhedral crystals replacing quartz and plagioclase from the grain boundaries. Small, anhedral biotite (5%) formed synkinematically with crystallization lasting longer than movement. Muscovite replaces plagioclase and quartz. Light green penninite is retrogressive after biotite. Small, early formed grains of epidote minerals are present. Sphene is the accessory. Shear zones with mortar, clinozoisite, and sericite along them pass through the rock. In this partially recrystallized cataclastic rock the plagioclase recrystallized and grew from the mortar. Microcline formed late.

The specimen (C-40-1-c) from the smaller dike is a leucocratic granodioritic, apparently cataclastic rock with porphyroblasts of sodic oligoclase grown from a fine grained groundmass. Biotite is minor and muscovite (5%) is the principal mica. Garnet and apatite are accessories.

The biotite-rich country rock (specimen C-40-1-b) is a biotite quartz monzonite. Fine to coarse grained, anhedral to euhedral plagioclase constitutes 25% of the rock. Its composition is about An 20, and it displays oscillatory zoning in a normal trend. It includes some smaller plagioclase. Quartz (20%) occurs in small to large, anhedral grains and includes plagioclase and quartz. Microcline and microperthite amount to 20% of the rock and are in small to large, anhedral crystals that tend to replace the plagioclase. Large, anhedral to euhedral biotite crystals constitute 35% of the rock. Some of them have ragged edges. They are mostly strongly strained. They include small amounts of plagioclase, quartz, and apatite. Accessories are apatite, zircon, and sphene, the latter two being associated with the biotite. A small quantity of muscovite has been derived from the biotite. Some zones of mortar occur. The unusually large amount of biotite in this rock and its location ajdacent to a large leucocratic dike suggest that this may be a local, small scale basic front. More detailed work would be necessary to prove it. The borders of the biotite crystals indicate metamorphic growth in some cases.

Conclusions

The rocks of the northern unit vary from metasomatic to neomagmatic in character, and all intergradations occur. These conclusions are made mainly on the basis of texture, for few remnants of definitely sediment-derived material were observed except in the vicinity of the contacts, and no definite mineralogical or textural relicts of an early unquestionably igneous rock were found.

The northern contact of the Snowking massif is characterized by a complex set of conditions. Only a narrow zone of mesozonal schist occurs between the massif and the epizonal schists of the Cascade valley schist zone. At the contact concordant quartzitic schist inclusions occur. The contact and the structure in the adjacent schist are generally parallel. Where exposed the contact displays both replacement and intrusive features. Small replacement and intrusive dikes of granitic material are present near the contact. No significant contact-metamorphic effects were observed.

Unit on Ridge East of Kindy Creek

General Statement

Along the ridge east of Kindy Creek as far south as to the 7000 foot summit at the head of Milt Creek, occurs a heterogeneous group of diorites, quartz diorites, granodiorites, and quartz monzonites. In This area the Snowking massif is in contact with the Cascade Valley schist zone on the north side of the 5800 foot knob on the Kindy Creek-Sonny Boy Creek ridge and on the southeast side of the head of Sonny Boy Creek. A two mile gap in observation exists between Bench Lake and the 7000 foot peak at the head of Milt Creek. However, the rock on the peak resembles the gneissose portion of the migmatitic zone at and below Bench Lake; so perhaps a gradational relationship is present between the two units.

Contact Relationships

On the north side of the 5800 foot knob on the Kindy Creek-Sonny Boy Creek ridge, the contact of the Snowking massif is fairly well exposed. In the field the rocks of the Cascade valley schist zone appear to be hornfelsized and to contain varying amounts of feldspar porphyroblasts. Sometimes these feldspathic spots seem to coalesce into rounded or angular patches of granitic rock. Granitic rock and schist appear to be intimately intermixed and to intergrade. On top of the 5800 foot knob the rock is granitic but quite variable in texture. Dike-like and irregular blocks of biotite-rich rock which sometimes includes pieces of granitic rock, also occur at that place. Immediately south of the knob the rock is still migmatitic and contains inclusions of partially feldspathized hornfelsized schist.

Under the microscope the relationships turn out to be more complex than observed in the field. At about 5300 feet elevation on the north side of the 5800 foot knob the rock is predominantly schist. Specimen B-57-1-d from the locality contains 65% sodic andesine in fairly small, anhedral crystals. Biotite (20%) is in small to medium sized flakes, and it formed late-kinematically. Medium grained, euhedral garnet makes up about 10% of the specimen. Quartz and accessories complete the rock. The large amount of plagioclase suggests "concealed" soda metasomatism.

Specimen B-57-1-a contains 55% normally zoned plagioclase in small to medium sized, anhedral grains. A few quite large porphyroblasts occur, which ave a rounded outline suggesting that at one time they may have been porphyroclasts. Composition of different grains ranges from An 60 to An 34. Quartz (10%) is found in small, anhedral grains. A stringer of recrystallized quartz occurs. Biotite (30%) forms small to medium sized, anhedral flakes that appear to have been shredded and recrystallized. Light green hornblende (5%) with an extinction angle of 20° occurs in small anhedral, somewhat fibrous, crystals that occasionally form aggregates. Retrogressive clinozoisite and muscovite from plagioclase, and penninite from biotite are present. Sphene and apatite are the accessories. In the rock occur shear zones containing mortar. It is probably a porphyroblast schist that has been sheared and somewhat recrystallized.

Specimen B-57-1-b is a hornblende-bearing biotite schist. Its plagioclase (65%) occurs in small to large, anhedral to subhedral crystals, and the larger grains have sutured borders and tend to incorporate the other minerals. Biotite (25%) is in small to fairly large, anhedral flakes. It has been partially shredded, and the shredded portions have recrystallized somewhat. Actinolite hornblende occurs in small to medium sized, anhedral crystals. Some has been altered to clinozoisite and biotite. Some remnants of mortar occur. This rock has been partially sheared and considerably recrystallized after shearing.

Specimen B-57-1-c contains 55% sodic andesine in small to large, anhedral to subhedral crystals. The plagioclase displays normal zoning, sometimes with superposed oscillatory zoning. The larger crystals are porphyroblasts and include plagioclase, quartz, biotite, and hornblende. One euhedral porphyroblast is very well zoned, and it includes finer grained matrix material. Quartz (20%) forms small, anhedral grains. Biotite (15%) was partially derived from hornblende and occurs in medium sized, anhedral crystals that formed synkinematically. Synkinematic green hornblende (10%) has brownish cores and is in medium sized, anhedral to subhedral crystals. Clinozoisite, apatite, sphene, and opaque minerals

PLATE XXV

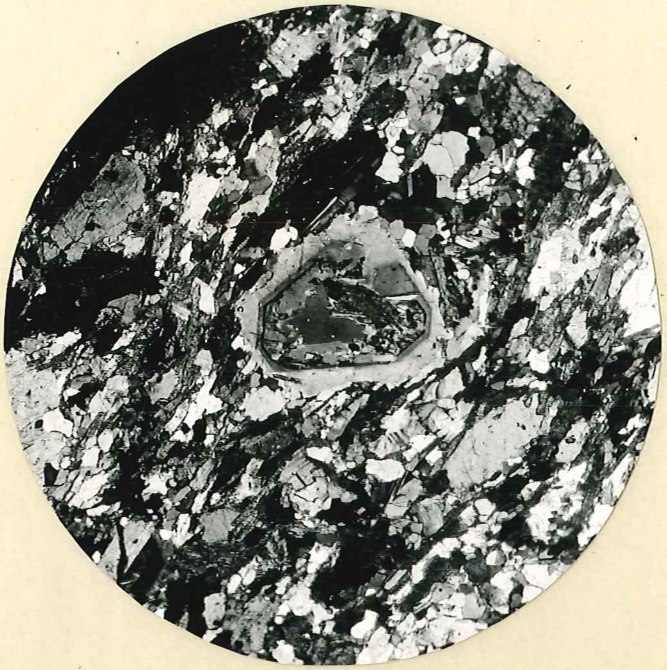


Fig. 1

Zoned plagioclase porphyroblast in biotite-hornblende-plagioclase schist adjacent to the contact of the Snowking massif on the ridge east of Kindy Creek. (specimen B-57-1-c) 13x, crossed nicols.

Fig. 2

Zoned plagioclase porphyroblast in biotite-hornblende-plagioclase schist adjacent to the contact of the Snowking massif on the ridge east of Kindy Creek. (specimen B-57-1-c) 13x, crossed nicols.

are accessories. This is a medium grade metamorphic rock that has probably undergone some soda metasomatism.

The rocks in this outcrop are incompletely feldspathized schists which partially underwent late shearing, and then recrystallized under static conditions.

At about 5600 feet elevation on the north side of the same knob the rock varies from a breccia of dominantly schist-derived material to granodioritic rock free of schist remnants. The rocks have been recrystallized to varying degrees.

Specimen B-56-1-d from this locality contains 45% plagioclase with the composition of sodic andesine. It occurs in small to large, anhedral grains that have been bent, fractured, and made into mortar. Small to medium sized, anhedral quartz grains constitute 20% of the rock. They are not strongly strained; so they probably are recrystallized. Biotite (35%) is fairly fine grained and occurs in felted aggregates. Sphene and apatite are the accessories. The rock consists of fragments of crystals, fine grained crush material, and partially crushed rock fragments. Biotite has been shredded and recrystallized. The specimen displays less recrystallization than the others collected at this locality.

Specimen B-56-1-b is a breccia that has been recrystallized to a greater degree than the above speimen. It contains 40% andesine in small to large, anhedral to subhedral crystals. Some of the grains are crystal fragments. They have been reconstituted considerably, and they include biotite. Also, biotite occurs in fractures in the plagioclase grains. Probably during recrystallization it migrated into the openings. Quartz (30%) occurs in small to large, anhedral crystals. It forms some mosaic textured areas. It penetrates plagioclase in a few places. The quartz is almost completely recrystallized, for it lacks any signs of strong strain. Biotite (30%) occurs in clusters of fine grained crystals which appear to be recrystallized shredded aggregates. Apatite is the accessory. Some mortar remains in the feldspar crystals.

Specimen B-56-1-a consists of granitic rock and partially recrystallized breccia similar to specimen B-56-1-b. The granitic rock is made up of small to large, sutured, anhedral andesine grains (90%) and chloritized biotite (10%). The plagioclase grains include fine grained quartz and feldspar. Between the granitic rock and the breccia is a zone of very fine grained feldspar and quartz (?) in which porphyroblasts of plagioclase have grown. The porphyroblasts include and incorporate the groundmass. This zone is a "porphyry" much like specimen B-56-1-g (see below). Because of the amount of recrystallization and the metamorphic aspect of the plagioclase in the coarser grained portion, it is difficult to tell how large the fine grained portion originally was, and how much of the coarse grained portion may have been derived from its late recrystallization. The fine grained area was a crush zone derived from the granitic rock. It lacks the amount of biotite contained in the predominantly schist-derived breccia. Porphyroblastic growth has given it what might be called a pseudoporphyritic texture.

The intimate mixture of granitic fragments in a schist-derived matrix in these recrystallized breccias suggests that the original rocks may have been migmatites, probably consisting of feldspar porphyroblast schist and banded gneiss. Cataclasis made the porphyroblasts into porphyroclasts, fragmented the gneiss bands, mylonitized the schist, and produced mortar and mylonite zones in the granitic fragments. Extensive recrystallization healed many of the effects of cataclasis and even reconverted the porphyroclasts into porphyroblasts. Some of the mortar and crush zones recrystallized into mosaics, and sometimes new porphyroblasts grew in the crush zones.

Specimen B-56-1-g from this locality is a leucocratic "dacite porphyry". A fine grained groundmass of quartz and plagioclase constitutes 85% of the rock. Quartz (5%) occurs in small to medium sized, anhedral to subhedral grains which sometimes form mosaic textured patches. Plagioclase (10%) with the composition An 33 occurs in anhedral to euhedral crystals varying from medium to groundmass size. They include groundmass grains and have finely sutured borders that incorporate groundmass grains. They give the rock a texture that looks porphyritic in its gross aspect but is in fact porphyroblastic.

Other granitic rocks from the same outcrop are mildly cataclastic and contain small amounts of partially recrystallized mortar. One specimen (B-56-1-f) is a biotite granodiorite. It contains plagioclase (40%) in small to large, anhedral, normally zoned crystals that include quartz and biotite. The measured compositional range of the grains is from An 28 to An 22. Small to large, anhedral quartz grains make up 45% of the rock. They include some smaller quartz grains. Potash feldspar occurs as large porphyroblasts that replace plagioclase and quartz. Some microperthite and antiperthite is present. Myrmekite also occurs. Biotite and retrogressive chlorite make up 5% of the rock. Apatite and opaques are accessories.

Neither the fragments in the breccia nor the massive granitic rocks display very clear evidence of their origin. They have crystalloblastic textures, but these textures are not especially critical in view of the evidence that late recrystallization took place after a phase of deformation which post-dates the emplacement of the granitic rock. Nor is the lack of any sign of pyrogenic minerals or igneous-appearing textures a decisive criterion in this case.

The contact on the southeast side of the head of Sonny Boy Creek is not well exposed. Just east of the col at the head of the creek occurs a breccia which contains fragments of schist in granitic matrix. In some places the schist fragments have not been rotated, and they include replacement patches and stringers of granitic rock. At about 5700 feet elevation on the ridge to the northeast more breccia occurs. North beyond this point is an outcrop of biotite gneiss, and at about 5800 feet elevation occurs biotite hornblende schist.

Specimen C-1-2-a from the first outcrop is a partially recrystallized quartz-dioritic breccia. Normally zoned plagioclase ranging from An 27 to An 11 in composition makes up 35% of the rock. It occurs in small to large, anhedral grains, and it includes quartz, plagioclase, chlorite, and biotite. Quartz (45%) forms small to large, anhedral grains. It includes quartz, plagioclase, biotite, and chlorite. In part it is strongly strained, but in part it is free from strain. Green penninite from biotite and hornblende constitutes 15% of the rock. Some biotite relicts are present. Hornblende (5%) grades from a green to a colorless variety without any change in extinction angle. A few grains of potash feldspar occur. Sphene, apatite, and opaque minerals are accessories. A few mortar zones occur. The fragments in the breccia consist of amphibolite and schist.

A specimen of amphibolite from the breccia (specimen C-1-2-b) is a hornblende-plagioclase granulite containing 60% plagioclase with reverse zoning and a composition ranging from An 22 to An 30. It occurs in medium sized, anhedral to subhedral grains and has pavement texture. Small to medium sized, anhedral green hornblende (35%) includes sufficient quartz and plagioclase to be sieve textured. Quartz (5%) is partially late, replacing plagioclase and filling in between its grains. Biotite from hornblende and chlorite from hornblende and biotite occur. Sphene, apatite, and opaque minerals are accessories.

Both replacement and intrusive movement took place at this northeastern contact of the Snowking massif. The granitic matrix of the breccia lacks definite evidence of igneous origin. No specimen of the immediately adjacent rock was studied. In the field the rock inside the contact has gneissose structure that trends at about right angles to the contact and the regional trend.

Field Description of the Rock Comprising the Unit East of Kindy Creek

In the field the granitic rock of the ridge east of Kindy Creek varies considerably. Some of it is equigranular, and some contains large quartz and feldspar crystals. Sometimes large feldspar, biotite, and/or hornblende crystals occur in a rather fine grained matrix forming a rock one would call a porphyry if it did not grade to equigranular rock. The quantity of biotite and hornblende varies, as does their combined amount. Gneissose structure which roughly parallels the regional trend, occurs in certain zones.

Several shear zones occur, and they are somewhat mineralized. On top of the next low rise south of the 5800 foot knob on the Kindy Creek-Sonny Boy Creek ridge, a mineralized zone about 80 feet wide contains disseminated pyrrhotite. The rock there is rather nondescript.

On the first knob south of the junction of the ridge at the head of Sonny Boy Creek with the Kindy Creek-Sonny Boy Creek ridge, another mineralized zone occurs. It contains pyrite in fractures and disseminated throughout the rock. The zone contains what appear in the field to be blocks of mineralized hornfels that are about 8 inches in diameter.

These mineralized areas appear to be in shear zones that extend from Mt. Buckindy northeast towards Boston and Buckner mountains north and northeast of Cascade Pass, which is northeast of the Snowking area.

In several localities, a rock believed to be hornfels in the field appears to grade into porphyroblastic hornfels and granitic rock.

On top of the 5800 foot knob on the Kindy Creek-Sonny Boy Creek ridge, the granitic rock contains dike-like and irregular bodies of biotite-rich rock. This rock sometimes includes fragments of granitic rock. The dike-like bodies are similar to the relict pseudodikes of Goodspeed (1955 p. 147).

Petrographic Description

In thin section the rocks of this unit display varying mineral compositions and textures. Mineral percentages fall within the following ranges: plagioclase, 30 to 75%; quartz, a few to 40%; potash feldspar, 0 to 40%; biotite, 0 to 15%; and hornblende 0 to 30%. Also present are chlorite, garnet, epidote, and accessory apatite, sphene, zircon, orthite, rutile, and opaques. Some specimens contain as much as 10% opaque minerals. The plagioclase is usually normally zoned and in some cases very strongly so. Extremes of composition are An 67 and An 7. On the average, however, it is sodic andesine. The average rock type is a potash feldspar-bearing quartz diorite. Textures vary from cataclastic to granoblastic and to porphyritic and igneous-appearing. To attempt to illustrate the variations and some of the processes active in the genesis of these rocks, it is necessary to give detailed description of a number of specimens.

On the top of the 5800 foot knob on the ridge between Kindy Creek and Sonny Boy Creek six different specimens of granitic rock were collected.

PLATE XXVI

Fig. 1 Biotite granodioritic gneiss on the 7000 foot peak at the head of Milt Creek in the unit east of Kindy Creek.

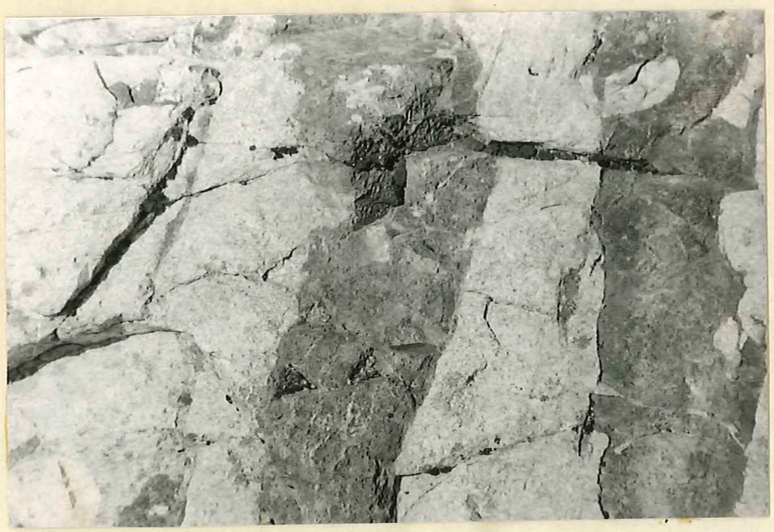


Fig. 2 Relict pseudodikes on the 5800 foot knob on the ridge east of Kindy Creek.

Specimen B-56-2-a is a potash-feldspar-bearing quartz diorite. Plagioclase with strong normal zoning and superposed oscillatory zoning makes up 50% of the rock. Its average composition is about An 35. It occurs in small to large, subhedral to euhedral crystals that include quartz, garnet, biotite, and hornblende. Some of the crystals lack uniform extinction, probably because they were derived from the coalescence of a number of smaller grains. Quartz (35%) occurs in small to large, anhedral to subhedral crystals that include plagioclase, garnet, biotite, and quartz. Some grains are strongly strained. Potash feldspar (5%) tends to replace quartz and plagioclase from the intergranular network. Biotite (10%) occurs in small to medium sized, anhedral to subhedral flakes. The larger ones are strained. A few anhedral grains of dark green hornblende occur. Small, euhedral garnet crystals tend to be retrogressively altered to biotite. Retrogressive chlorite from biotite and accessory zircon complete the rock. Between the grains a small amount of fine grained material is present, and it is either relict mortar or matrix. The development of the large crystals, especially the euhedral plagioclase, took place late in the crystallization history of the rock. Thus the igneous features in the texture are late; early features are entirely crystalloblastic. A mild late cataclasis is superposed.

Specimen B-56-2-b is a "biotite dacite porphyry". Plagioclase (65%) occurs in medium to large, subhedral to euhedral crystals that have normal and oscillatory zoning. Its composition averages sodic andesine. The crystals include quartz, plagioclase, biotite, and hornblende. They are fractured somewhat. Quartz (10%) is found in anhedral to euhedral, small to large grains. It includes biotite and fine grained quartz and feldspar. The larger grains are strongly strained. Biotite (10%) tends to occur in fine to medium grained aggregates in the matrix. A fine grained groundmass of quartz, plagioclase, biotite, and hornblende constitutes 15% of the specimen. Retrogressive light green penninite was derived from hornblende and biotite. A little epidote occurs with biotite that may have been derived from hornblende. Zircon, sphene, and apatite are accessories. This rock is characterized by a considerable number of inclusions in the well-formed quartz and plagioclase and a groundmass that does not have an igneous aspect. Perhaps the groundmass has a cataclastic origin, and the large crystals have at least in part grown as porphyroblasts in it.

Specimen B-56-2-c, still from the same locality, is a cataclastic biotite quartz diorite. It contains 60% small to large, anhedral plagioclase that is normally zoned in the range between An 28 and An 20. The plagioclase grains include biotite, quartz, and plagioclase. Quartz (30%) occurs in small to large, anhedral grains. Some are strongly strained. The larger ones have rather round outlines. In mortar some recrystallized blebs of quartz occur that have delicate projections into the adjacent material. Biotite (10%) is in small to medium sized flakes. Some of the fine biotite appears to consist of recrystallized shreds. A few grains of potash feldspar and myrmekite occur. Sphene, apatite, zircon, and opaques are accessories.

Specimen B-56-2-d is a biotite quartz diorite that has a granoblastic texture, but late formed, igneous-appearing, large, euhedral plagioclase crystals occur. Again evidence of cataclasis fairly late in the history of the rock is present in the form of mortar remnants and broken and partially healed plagioclase crystals.

Specimen B-26-2-e from the same locality is a hornblende biotite diorite porphyry. It contains 40% plagioclase in small to large, anhedral to euhedral crystals that have normal and oscillatory zoning. In one case reverse zoning was observed. The average composition is sodic andesine, and the range in composition is roughly from An 40 to An 20. The plagioclase includes quartz, plagioclase, biotite, and hornblende. It has been sheared and in some cases broken down into subindividuals. Quartz (10%) occurs in small to medium sized, anhedral to subhedral grains. Much of it occurs in mosaic textured areas that appear to be derived from recrystallized cataclastic material. About 30% of the rock consists of a very fine grained cataclastic groundmass of quartz and plagioclase. Biotite (10%) occurs as medium sized, strained crystals and as shreds derived from the shearing out of larger biotite flakes and the alteration of hornblende. Green hornblende (5%) forms small to medium sized, anhedral to subhedral grains that are often sheared and altered to biotite. Very small grains occur in the groundmass and are included in the plagioclase. Zircon is the accessory. The early history of this rock is somewhat obscured. The two latest events are rather strong shearing producing the fractured feldspars, and a period of recrystallization which mainly affected the quartz. Whether the fine grained groundmass was entirely produced during the latest shearing is open to question, for it is so fine grained that it seems as if the larger crystals should have been broken and strung out into separate fragments more than they are.

Specimen B-26-2-f from the same locality is a partially recrystallized quartz dioritic mylonite. Normally zoned calcic oligoclase constitutes 40% of the rock. It occurs in small to large, anhedral grains, sometimes with sutured borders. The grains include quartz, plagioclase, and biotite. Quartz (30%) forms small to large, anhedral to subhedral crystals, a few of which are strongly strained. Biotite and retrogressive light green clinochlore occur in fairly fine grained aggregates and medium sized, anhedral flakes. A few grains of potash feldspar are present. Mortar makes up about 25% of the rock, and there are all gradations in grain size from the largest crystals to the mortar matrix. Apatite and opaques are accessories. This rock has undergone considerable recrystallization after shearing, so that mosaic textured areas and porphyroblasts were formed.

A specimen (B-56-2-g) of one of the biotite-rich rocks from this locality mentioned above contains 90% biotite in a felted mass of fairly small crystals. Plagioclase and quartz (10%) are in small, anhedral grains and include biotite. A band of quartz forms a sharp border for the inclusion. In the adjacent quartz diorite a few small areas of similar textured biotite and plagioclase occur, and they tend to grade sharply into more feldspar-rich, coarser grained rock. The biotite-rich rock is a basic segregation.

The rocks from the summit of the 5800 foot knob on the Kindy Creek-Sonny Boy Creek ridge, which have been described above (specimens B-56-2 a to g), have been sheared and recrystallized to varying degrees. Their only igneous appearing features are products of the recrystallization and accompanying crystal growth that took place late in their history, often in the presence of a fine grained cataclastic groundmass. We can only guess at what conditions favored the late development of large euhedral porphyroblasts in some rocks containing a fine groundmass and not in others. Perhaps it was the presence of a large quantity of intergranular fluids or an influx of soda or a combination of these two factors.

Just south of the 5800 foot knob mentioned above, the rock contains inclusions. Specimen B-57-2-a contains some of these inclusions and is a quartz dioritic breccia. The fragments contain about 45% small to fairly small, anhedral, quite light green, hornblende and 5% magnetite. Very fine grained feldspar and quartz (?) makes up about 45% of the rock except in some places where larger crystals have grown. Some of these crystals have a radial habit and a multiple twinning that lacks the sharpness of the usual plagioclase twinning. They look like a zeolite, yet the properties ascertained were not diagnostic. They could be either plagioclase or stilbite, and the former seems more likely. Sphene constitutes about 5% of the fragments. The matrix contains about 20% hornblende, which occurs in slightly larger, but similarly shaped, crystals as in the fragments. Calcic oligolcase in small to medium sized, anhedral crystals makes up 60% of the matrix. The larger crystals have sutured borders, indicating porphyroblastic growth. Quartz (20%) forms small to medium sized, anhedral crystals. Sphene and opaques are accessories. Throughout the matrix patches of fine grained rock that is similar to the larger fragments except not so hornblende-rich, occur. The boundary between the fragments and the matrix is sharp in some places and entirely gradational in others. The impression obtained is that the matrix is recrystallized and somewhat granitized rock of the type found in the fragments.

Specimen B-57-2-b from the same locality looks like a breccia on a cut surface but in thin section fine grained crush material forms the groundmass throughout. Small to medium sized, anhedral, green hornblende makes up 20% of the section. In the areas that appear to be a rock fragment the hornblende constitutes a larger portion of the rock and is finer grained than elsewhere. Also opaques make up about 5% of those areas. Sphene (10%) occurs throughout the rock in small to medium sized, anhedral to subhedral crystals. A quartz segregation is present. The plagioclase (?), sometimes with the radiating habit mentioned above, makes up about 15% of the rock. This appears to be a somewhat recrystallized cataclastic rock.

Specimen B-57-2-c from the same locality is a cataclastic hornblende quartz basalt porphyry. Plagioclase (45%) occurs in small to large, subhedral to euhedral crystals that have normal and oscillatory zoning. Their composition varies from An 60 to An 46. Plagioclase also occurs in small to large, anhedral grains in leucocratic, granoblastic areas. Green hornblende (15%) forms large, anhedral to euhedral crystals and gradations to small grains, sometimes in aggregates, in the groundmass. Some of the large crystals include small plagioclase grains and have finely sutured borders that indicate metamorphic growth. Quartz (10%) occurs in medium to large, anhedral grains. A very fine grained groundmass of quartz and feldspar constitutes about 30% of the rock. Apatite, sphene, and opaque minerals are the accessories. Some of the larger sphene crystals include plagioclase grains and portions of the groundmass. The leucocratic inclusions consist mainly of quartz and plagioclase. They are much better defined in the hand specimen than in the thin section. In the latter the boundaries are partly gradational, and they contain areas of fine grained, almost matrix-like, material. The coarser grained portions have enough small grains to suggest that they may be derived from recrystallized matrix. Yet the leucocratic character of the fragments indicates that they may not have been derived from the immediately adjacent matrix unless some silica metasomatism has been active only in patches. The well-shaped plagioclase and quartz have an igneous appearance. The large late hornblende is definitely porphyroblastic. The matrix looks like very fine mortar.

On the top of the next small rise on the ridge to the south a mineralized zone occurs. Specimens B-58-1-a, b, and c were collected from this zone. Specimen a is a chloritized and mineralized hornblende labradorite porphyry. The plagioclase (45%) occurs as small to large, subhedral to euhedral phenocrysts which include some quartz and plagioclase. The phenocrysts have fairly weak normal zoning and superposed oscillatory zoning. In one crystal reverse zoning was observed. The compositional range is from An 62 to An 35, the larger crystals tending to be more calcic. Quartz (5%) occurs in medium sized, subhedral phenocrysts that include a few small plagioclase grains. Light green penninite with carbonate and opaques forms pseudomorphs after hornblende phenocrysts. The opaque is pyrrhotite, and it is disseminated in small to medium sized grains. It replaces the mafics. A fine grained groundmass of quartz and feldspar makes up 40% of the rock. Sphene is an accessory. This rock has definitely an igneous type of texture. The inclusions in the phenocrysts carry just a suggestion of a possible earlier metamorphic chapter, preceding the igneous chapter in the history of this rock.

Specimen b is similar except that the plagioclase phenocrysts are not so well developed or as calcic. They are more altered. Also a very large euhedral quartz phenocryst has a ragged border engulfing the matrix and quite a few inclusions of matrix material that indicate a metamorphic derivation.

Specimen c is a similar porphyry in which the plagioclase has been heavily sericitized and the mafic (hornblende) chloritized to a rather light green penninite. Iron was apparently set free and perhaps in part introduced, and fine grained stilpnomelane instead of sericite formed in the adjacent plagioclase. Pyrrhotite also formed in small to large disseminated grains often associated with chlorite; so sulphur must have been available.

Specimen B-58-1-d is from the same locality, but from outside the mineralized zone. It is a similar igneous appearing porphyry which differs

PLATE XXVII

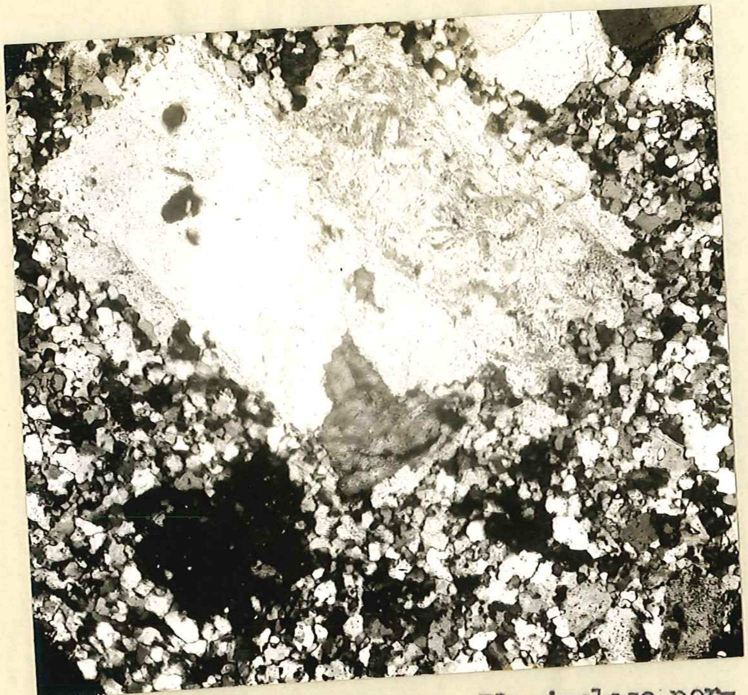


Fig. 1 "Dacite porphyry". Plagioclase porphyroblast grew in fine grained, recrystallized cataclastic groundmass. Marginal portion of the unit east of Kindy Creek. (specimen B-56-1-g) 55x, crossed nicols.

Fig. 2 Large quartz "phenocryst" in "dacite porphyry" cut by shear. Mortar in shear zone similar to groundmass of "porphyry". The quartz "phenocryst" has replaced part of the mortar. In Unit east of Kindy Creek. (specimen B-58-1-b) 55x, crossed nicols.

only by a somewhat less calcic composition of its plagioclase and certain textural details. It contains medium to large, subhedral to euhedral plagioclase phenocrysts (50%) ranging in composition between An 55 and An 43. They are normally zoned, sometimes with superposed oscillatory zoning. A few have oscillatory zoning without any systematic compositional change except for a sodic rim. The crystals include other minerals, and on close examination many have borders indicating metamorphic growth even in cases where no sodic rim is present. A few large, late quartz porphyroblasts are present, and they include plagioclase and groundmass grains. Brownish green hornblende (5%) occurs in medium sized to large, subhedral to euhedral crystals and also as small anhedral grains in the groundmass. Some of the larger ones include plagioclase. They are altered to a somewhat bluish green amphibole and to a colorless amphibole, both of which in some places exhibit optical continuity with the unaltered crystals. In other places the retrogressive amphiboles have recrystallized into aggregates of smaller grains. Biotite (10%) has been derived from hornblende, and it occurs in small to large, anhedral flakes. The larger ones are conspicuously porphyroblastic, for they engulf and include adjacent minerals. A fine grained groundmass of quartz, plagioclase, biotite, and hornblende make up 30% of the rock. Apatite and opaque minerals are the accessories.

Specimen e is even more igneous-appearing. The plagioclase phenocrysts generally lack irregularities and inclusions along their borders, although they do contain quite a few inclusions of the other minerals. Hornblende is found in well-formed phenocrysts, although it has rather numerous plagioclase inclusions. The groundmass consists of recrystallized quartz and plagioclase in small, sutured, anhedral crystals that include much very small biotite.

On the first knob south of the junction of the Kindy Creek-Sonny Boy Creek ridge and the Sonny Boy Creek-Milt Creek divide occurs another mineralized zone. Specimen B-60-1-a from this zone contains 65% plagioclase, partially with normal zoning, which has the composition of about An 43. It is in medium sized to large, subhedral to anhedral grains, and it includes biotite and quartz. It is considerably altered to kaolin, sericite, and clinozoisite. Anhedral quartz grains (10%) replace plagioclase somewhat. Some quartz is strongly strained. Biotite (15%) occurs as fine grained, anhedral flakes that are the product of alteration of a mineral (hornblende ?) or of shredding and recrystallization of former biotite grains. In places it grows into the plagioclase. Pyrite with minor magnetite makes up 10% of the specimen, and they are disseminated throughout the rock replacing the other minerals. A few small grains of lightish, somewhat blue-green amphibole with an extinction angle of about 20° occur between the opaques and biotite. They are later than the biotite and were probably formed when calcium was released at the opaque mineral replaced plagioclase. The calcium reacted with the biotite to form the amphibole. A few grains of iron-rich epidote occur in a similar fashion. Some green penninite is also later than the opaque minerals. Rutile, apatite, and sphene are the accessories. A little apparent cataclastic texture is present.

In another nearby mineralized zone the rock contains 35% small, anhedral quartz. No plagioclase was identified with certainty, but patches of sericite account for 25% of the rock, and they may represent former plagioclase grains. Potash feldspar (35%) occurs in fairly large crystals that replace quartz and plagioclase (?). Fine grained brown and green biotite makes up 5% of the rock. Pyrite is disseminated in small to large, anhedral blobs. This is a cataclastic rock which has undergone potash metasomatism, mineralization, and hydrothermal alteration.

In the former of these two last mentioned mineralized zones, blocks of mafic rock (called hornfels in the field) occur. Specimen B-60-1-b from one of them contains 50% quartz and plagioclase which is very fine grained at the margin of the mafic rock and somewhat coarser away from its margin. The larger grains are filled with tiny biotite flakes. Biotite (35%) occurs as fine grained flakes throughout the rock and as aggregates of fine grained crystals. It probably has been shredded and recrystallized. Pyrite and magnetite (5%) are disseminated, although they have a slight tendency to be associated with the biotite clusters. Epidote, sphene, and apatite are the accessories.

Specimen B-60-1-c from the adjacent granitic rock is a "biotite-quartz monzonite porphyry" containing plagioclase (30%) in medium to large, anhedral to euhedral phenocrysts. They include biotite, quartz, and plagioclase and have sutured borders that incorporate groundmass grains. They have normal and superposed oscillatory zoning, and their composition varies from An 35 to An 20. Quartz (30%) occurs mainly as small, anhedral grains in the groundmass. However, some anhedral to euhedral phenocrysts are present, and they include and incorporate other minerals at their margins. Potash feldspar (35%) occurs as small, anhedral grains in the groundmass, some of which are microperthite. Biotite (5%) forms small to medium sized anhedral flakes. Some of the larger ones are obviously porphyroblasts. A few tiny grains of hornblende occur in the groundmass. Sphene and opaques are accessories. This rock has a crystalloblastic texture.

Another specimen of adjacent granitic rock (B-60-1-d) contains

PLATE XXVIII

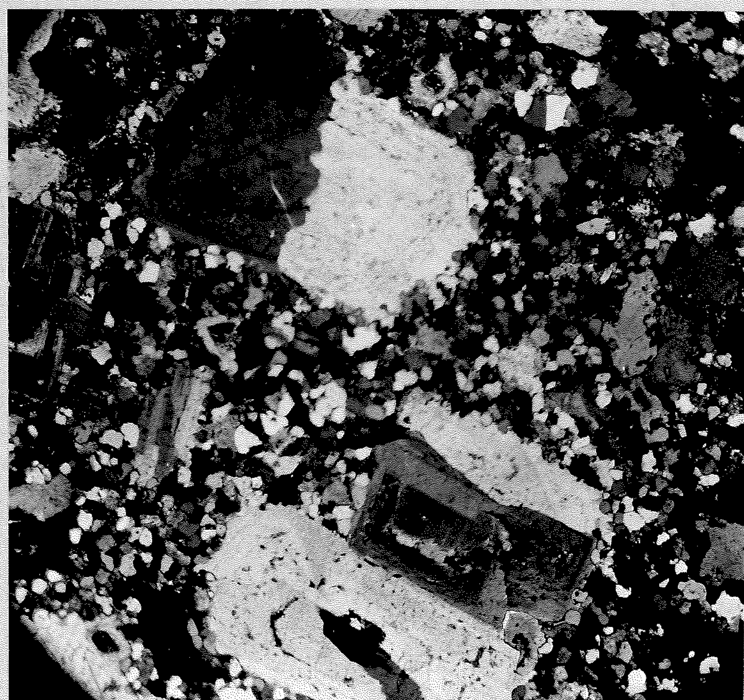


Fig. 1 "Biotite quartz monzonite porphyry". Plagioclase "phenocrysts" are porphyroblasts. Unit east of Kindy Creek. (specimen B-60-1-c) 18x, crossed nicols.

normally zoned plagioclase (60%) with superposed oscillatory zoning. Its composition ranges from An 55 to An 10. It occurs in small to large, anhedral to euhedral crystals. Quartz (20%) is found in small to large, anhedral grains. Some are large porphyroblasts that replace plagioclase. Potash feldspar (5%) replaces quartz and plagioclase along the intergranular network. Small to medium sized, anhedral to subhedral biotite flakes make up 10% of the rock. They include plagioclase. A small amount of biotite was derived from hornblende. Green hornblende (5%) occurs as medium sized, anhedral to subhedral crystals. A small amount of green penninite is retrogressive after biotite. Epidote, sphene, apatite, magnetite, and pyrite are accessories. The rock has an igneous texture somewhat modified by late quartz growth.

A short distance south of the above described outcrop is one in which a rock that in the field appeared to be porphyroblastic hornfels, grades into granitic rock. Specimen B-61-1-a has a sharp gradation between the dark, fine grained rock into a rock with large feldspar and hornblende crystals in a fine grained matrix. Plagioclase makes up 65% of the rock and occurs in medium to large, euhedral phenocrysts and small, anhedral to subhedral grains in the groundmass. The larger crystals have compositions ranging from An 60 to An 36. The largest ones are the most calcic. Some normal and oscillatory zoning is present. One phenocryst includes many small anhedral hornblende crystals. A few rounded quartz grains occur that look like zenocrysts except that on parts of their margins they include groundmass material. Green hornblende (30%) occurs in small to large, anhedral to euhedral crystals. In the fine grained portion of the specimen it is mainly fine grained, while in the porphyritic portion it tends to be concentrated in large crystals. Many of the crystals include plagioclase. One very large crystal has plagioclase in its core, a central zone of fine opaque and small plagioclase inclusions, and a sutured border that indicates metamorphic growth. The interior zone has a light brown absorption. Other hornblende grains have similar irregular borders. In the fine grained portion the hornblende exhibits some alignment. Euhedral and subhedral magnetite make up 5% of the rock. A few grains of potash feldspar and myrmekite occur in the groundmass of the porphyritic part, which consists of plagioclase, hornblende, and biotite. A small amount of retrogressive green penninite was derived from hornblende. Apatite and sphene are the accessories. The more equigranular part of the specimen contains more hornblende, and, except for a very few of the largest hornblende crystals, it is not at all metamorphic in aspect. The contact between the fine grained microdioritic portion and the hornblende labradorite porphyry is gradational.

Specimen B-61-1-b from the same locality is a rock whose texture is intermediate between the microdiorite and the porphyry of specimen B-61-1-a. The larger hornblendes have a porphyroblastic aspect, and many of the larger plagioclase crystals include small hornblende. Some of the plagioclase grains have sutured borders.

In the field the rock types described in the last two paragraphs appear to grade into granitic rock like that of specimen B-61-1-c, a "biotite-labradorite-quartz diorite porphyry". However, the latter rock is quite different in texture and somewhat different in composition. It contains plagioclase (75%) which occurs in fairly small to large, anhedral to euhedral crystals. They have normal zoning with oscillatory zoning superposed. Their composition varies from An 67 to An 22. Some crystals have a zone of alteration in an originally more calcic core. The plagioclase includes biotite and plagioclase. Quartz (15%) is in large to fairly large, anhedral grains that include plagioclase, quartz, and biotite. The larger crystals are late porphyroblasts. Biotite (10%) occurs in small to medium sized, anhedral flakes, which are sometimes in aggregates. Some of the aggregates have a shape which suggest that they may be pseudomorphs after hornblende. Some of the biotite has a greenish tinge. A few small grains of potash feldspar occur in the intergranular network. Retrogressive green penninite from biotite is present. Accessories are zircon, apatite, pyrrhotite, and pyrite. The texture of this rock is generally granoblastic, but late igneous-appearing features exist, such as the development of the euhedral plagioclase. Not much in this rock suggests that it was derived from the rock type of specimens a and b. Potash introduction could have caused biotitization of the hornblende. However, without an intermediate specimen to bridge the gap such an interpretation is far-fetched; it seems more probable that this rock was derived from an originally more biotite-rich type.

Specimen B-61-1-d from the same locality is rather similar to specimen c. The plagioclase is less calcic. Hornblende is present. Biotite forms some almost euhedral porphyroblasts. More potash feldspar occurs. This is another rock in which the plagioclase has at a late stage developed a euhedral tendency. The potash feldspar and much of the quartz are of late replacement origin.

On a flat place at 6100 feet on the Kindy Creek-Sonny Boy Creek ridge occurs a biotite-hornblende-quartz diorite (specimen B-59-5) that clearly displays a late igneous-appearing texture superposed on a previous crystalloblastic texture. This rock contains small to large, anhedral to euhedral plagioclase (50%) that has normal zoning with superposed oscillatory zoning.

The composition of the plagioclase varies from An 62 to An 35 and averages a calcic andesine. The plagioclase includes hornblende, plagioclase, and quartz. Quartz (10%) occurs in small to large, anhedral to euhedral crystals. The larger ones include quartz, plagioclase, hornblende, and biotite and are late porphyroblasts. Green hornblende (10%) is found in small to large, anhedral to subhedral crystals. Some of the larger ones have sutured borders and include plagioclase, thus indicating they are products of metamorphic growth. Biotite (10%) occurs in small to large, anhedral to euhedral crystals. Again plagioclase is included, and some of the larger crystals are obviously porphyroblasts. One striking example has sieve texture and is very ragged in outline. A few small grains of potash feldspar occur. A small amount of retrogressive green penninite from biotite and hornblende is present. Sphene, apatite, and magnetite are accessories. There is a fairly fine grained matrix of quartz, plagioclase, biotite, and hornblende, from which the larger, well-formed grains crystallized. The matrix is considerably coarser grained than the very fine mortar-like matrices of many of the rocks described above.

At about 6000 feet elevation on the Kindy Creek-Sonny Boy Creek divide occurs a leucocratic quartz monzonite (specimen B-59-4). It contains plagioclase (30%) varying from An 16 to An 7 in composition. The plagioclase occurs in medium to large, subhedral crystals that include rare grains of plagioclase, biotite, and quartz. Quartz (25%) forms medium to large, anhedral grains. Perthite (40%) occurs in medium to large, anhedral to subhedral crystals that include some quartz and plagioclase. In many places it appears to have formed from plagioclase crystals. Biotite (less than 5%) is found in small to medium sized, anhedral to subhedral flakes. Light green penninite and chlorite-biotite intermediate minerals were derived from biotite. Oxidized opaques and rutile are accessories. The texture is somewhat igneous-appearing.

Other rocks studied on this ridge are biotite gneisses containing sodic andesine and calcic oligoclase and up to 15% late potash feldspar. They contain remnants of an earlier fine grained rock that has been mainly incorporated in the larger plagioclase and quartz grains; this fine grained material may have been recrystallized mortar. The texture and mineralogy of these gneisses is similar to that of the gneiss in the migmatite at Bench Lake and to the south (Chapter IIIC1f above).

Conclusions

The rocks of the ridge east of Kindy Creek are characterized by heterogeneity. Some are igneous-appearing, and one would expect to find them occurring as dikes in the more metamorphic-textured rocks. Yet in the field no sharp boundaries were observed. This might be due to lack of really clean exposures, but it seems unlikely that no intrusive contacts should be observed if the numerous zones containing igneous-appearing rocks were made up of truly intrusive dikes. However, in many cases the igneous aspect of the rock can be seen to be a product of late metamorphic crystallization, and all gradations occur from cataclastic rocks to "porphyries". The interpretation of these rocks definitely remains open, and perhaps more intensive field study would be desirable. In the opinion of the author this ridge represents a cross section of complex plutonic processes. Varying amounts of cataclasis, recrystallization, and probably metasomatism took place. The cataclasis (perhaps just the latest cataclasis), the effects of which we see, tended to be concentrated in fairly restricted zones. It took place before the rocks had finished crystallizing, and it permitted certain mineral grains a greater freedom of crystallization than they would have had without it, thus giving rise to euhedral porphyroblasts of the various minerals, especially plagioclase. Associated with the cataclasis there may have been mobilization, but at this level it was incipient or gradational from the outside of the cataclastically deformed zone inward; so it did not produce obvious intrusive relationships with the wall rock. At a higher level it might have become truly intrusive. In other words, this may have been the birthplace of some mobilized rock that could have been squeezed upward and intruded.

Very few criteria for the nature of the original rock exist. The evidence indicates that the textures and minerals that we see in the rocks now, were produced mainly by metamorphic rather than igneous processes. The few inclusions that do occur and were studied are cataclastic, probably argillite-derived, rocks like those near the contact, and one is microdiorite. Near the 7000 foot peak at the head of Milt Creek the gneiss had some partings of biotite schist. The gneiss there is similar to the metasomatic migmatitic gneiss near Bench Lake; so it may be of similar origin.

Buckindy Unit

General Statement

The Buckindy unit consists of breccia, quartz diorite, and labradiorite-bearing but rather leucocratic rocks, which will be referred to as dioritic. This unit extends from between the two 7300 foot peaks on the southern part of Buckindy Mountain to the south side of the col south of the southeast peak of Snowking. Its western boundary must lie somewhere in the brush and timber-covered valley of Buck Creek, for no similar rocks occur on the ridge north of Huckleberry Mountain. Its eastern boundary is uncertain, but the unit does not extend to the 7000 foot peak at the head of

Milt Creek. It is possible that the zones of heterogeneous rocks on the ridge east of Kindy Creek may be a continuation of elements of the Buckindy unit.

Contact Relationships

The southern contact of the Buckindy unit which is also the main southern contact of the Snowking massif is exposed on the two southern 7300 foot peaks of Mt. Buckindy. Here, the contact consists of a breccia made up of fragments of schist and trondhjemite dikes. Towards the Green Mountain unit, the breccia disappears and passes into non-brecciated schist with regular structures. The adjacent part of the Green Mountain unit consists of garnet biotite schist and para-amphibolite. The biotite in the schist crystallized late-kinematically and post-kinematically (specimen B-51-1-a&b), but in the amphibolite the hornblende did not crystallize post-kinematically to any extent. This contact should be examined in more detail.

The northern contact of the Buckindy unit which lies within the comprehensive Snowking massif, is exposed on some slabs just south of the col south of the southeast peak of Snowking. There the Buckindy unit is in contact with the Snowking Mountain unit (see above, Chapter IIIC3c). The Buckindy unit here consists of gray rock with medium grained biotite and hornblende, whereas the Snowking Mountain unit is a rather white rock containing fine grained biotite. Adjacent to the rock of the Snowking Mountain unit, the rock of the Buckindy Mountain unit contains small feldspar porphyroblasts and irregular patches and dikes of rocks of the Snowking unit. The rock of the Buckindy unit contains mafic inclusions of amphibolite and dike rock, and in many places these inclusions remain in the marginal parts of the Snowking unit. These features indicate that the Snowking unit here has been formed by replacing the rock of the Buckindy unit.

Petrographic description of the rocks at the northern contact.

At its northern contact the Buckindy unit is a biotite labradorite rock (specimen C-60-2-a) which contains 70% plagioclase in medium sized, anhedral to euhedral crystals which have normal and superposed oscillatory zoning. They range from An 63 to An 45 in composition. In some cases they have narrow rims of more sodic composition. The crystals include biotite, hornblende, quartz, and plagioclase. One has sieve texture with small plagioclase grains. Small to medium sized, anhedral quartz crystals (15%) both fill in between and replace the other minerals. Biotite (15%) occurs in small to medium sized, anhedral to subhedral flakes that replace and include plagioclase and quartz. In some places biotite has invaded the calcic plagioclase, and more sodic plagioclase (oligoclase) has formed later. Green hornblende occurs in small, anhedral to euhedral grains. Epidote, apatite, zircon, and opaques are accessories. The texture is igneous-appearing except for the many inclusions in the plagioclase.

One specimen (C-60-2-c) shows a contact between the Buckindy and the Snowking rock. The more mafic (Buckindy) portion of the specimen is essentially similar to the specimen just described. The leucocratic (Snowking) portion is a biotite trondhjemite which contains plagioclase (55%) in small to large, anhedral crystals. They are normally zoned and range in composition from An 30 to An 21. They include biotite, plagioclase, and quartz. Quartz (40%) forms small to large, anhedral grains that include biotite, plagioclase, and quartz. Small, anhedral biotite flakes make up 5% of the rock. Some retrogressive green penninite from biotite is present. Apatite is the accessory. Some areas of fine grained material occur between the larger crystals. The rock has a granoblastic texture. In detail the contact between the two rock types is somewhat irregular and gradational in this specimen. The biotite in both rocks is similar. However, in the Buckindy rock most of the biotite is later than the plagioclase, while in the Snowking rock it is earlier than the plagioclase. The plagioclase in the more mafic rock shows a tendency to break down into mosaic textured areas of sodic andesine. All these features suggest that the leucocratic trondjhemite has formed by replacement of the more basic Buckindy rock.

Description of the Rocks of the Buckindy Mountain Unit

General Description. Due to their heterogeneity it is not easy to give a general description of the rocks of the Buckindy unit. Because of rugged terrain there is a gap in my traverses which makes it convenient to divide the unit into a northern and a southern portion. The southern portion extends from the southern contact **northward** to the junction of the Horse Creek-Buck Creek ridge with the main ridge of Buckindy mountain. The northern portion extends from the northern contact southward to a pronounced ridge that separates the tributaries of Kindy Creek draining the north side of Mt. Buckindy, from those draining the east side of the 6700 foot summit on the Snowking-Buckindy ridge. (The topographic map contains some errors in this vicinity).

South Portion of Buckindy Unit: Field Description. The southern part of the unit, which was studied on the high ridge that constitutes Buckindy Mountain, consists of breccia and quartz diorite. The quartz diorite varies considerably in texture. Buckindy Mountain has a strong, rusty color due to the weathering of finely disseminated sulphides, mainly pyrite with rare grains of pyrrhotite, chalcopyrite, and bornite. The sulphides occur in fractures and are disseminated throughout the rock.

On the northern part of the mountain, breccias form several rugged, grey spires. Only in one place along the ridge breccia was observed to occur without forming a spire. The spire just north of the junction of the Horse Creek-Buck Creek ridge with Buckindy is called "Buckindy Tower" by mountaineers who have seen it from a distance. The breccia occurs in irregular zones which contain shear planes that strike N 15° E and dip 75° SE. The breccia consists of rounded fragments of granitic rock and crystal fragments of quartz and feldspar in a light green cataclastic matrix. A tower a little south of the ridge junction mentioned above, is made up of fragments of granitic rock 4 to 6 inches in diameter and relatively little matrix.

Just north of the 7300 foot peak on Buckindy Mountain a trondhjemite dike occurs in the quartz diorite. The exposure is too iron stained to ascertain its mode of emplacement. Just south of this point, some biotite-rich partings were observed in the quartz diorite. They are aligned parallel to the regional trend.

In the field much of the rock has a cataclastic look. Just north of the 7300 foot peak north of the contact of the Snowking massif, a discontinuous body of porphyry occurs in a sheared-appearing rock.

Petrographic Description. In thin section this portion of the Buckindy unit is characterized by granodioritic and quartz dioritic compositions and a variety of textures varying between cataclastic, granoblastic, and igneous.

The specimens studied from the breccia zones (specimens B-48-1 a&c) contain 55 to 60% small to large, anhedral to subhedral sodic andesine grains. The plagioclase tends to be rather heavily altered to sericite and carbonate. Some of the crystals are bent. Some include grains of the other minerals. Quartz (20 to 30%) occurs in small to large, anhedral to subhedral grains. Green penninite (10%) occurs in small to large pseudomorphs

PLATE XXIX

Fig. 1 "Buckindy Tower", composed of breccia, in the southern portion of the Buckindy unit.

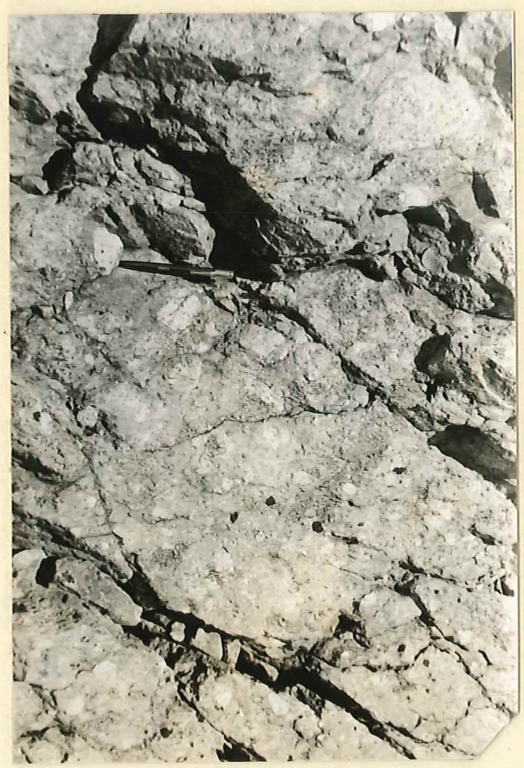


Fig. 2 Breccia zone in the southern portion of the Buckindy unit.

after biotite and hornblende. Many chlorite grains include small grains of sphene (?). Microcline (5 to 10%) is found in small to large, anhedral crystals that replace quartz and plagioclase. It tends to be concentrated in leucocratic granodioritic fragments, which have a granoblastic texture. It also occurs in the recrystallized groundmass. The fragments have both sharp and gradational borders. The groundmass consists of mortar. Recrystallization has affected both the groundmass and the crystal fragments, tending to make their fragmental nature less obvious.

At the junction of the ridge between Horse Creek and Buck Creek with the main Buckindy ridge a biotite-quartz diorite (specimen B-27-2-a) is exposed. Placioclase (75%) with normal and oscillatory zoning and a composition of An 32 occurs in small to large, anhedral to subhedral grains. The larger crystals include smaller plagioclase grains. Quartz (15%) forms small to large, sutured, anhedral crystals that replace the plagioclase. Biotite (10%) consists of large crystals that are partially broken down to smaller ones and of small flakes that occur in aggregates. Some retrogressive green penninite was derived from biotite and grows into the plagioclase in places. Epidote occurs with biotite. Often pyrite is also associated with biotite. Orthite and apatite are accessories. Some mortar occurs along shears and between the grains. The rock has a sutured granoblastic texture.

On Buckindy about S 65° E from Hurricane Peak the rock is a quartz-biotite-labradorite porphyry. Specimen B-49-1-b contains 30% large, euhedral plagioclase phenocrysts and some gradations to groundmass size. Their composition is about An 56. They have normal and superposed oscillatory zoning. They include some small feldspar grains. Large to small, euhedral quartz phenocrysts (5%) include some feldspar grains. Light green penninite (10%) forms pseudomorphs after biotite phenocrysts. A few biotite phenocrysts remain. Biotite also occurs as fine grained, anhedral flakes in the groundmass and makes up about 15% of the rock. The quartzo-feldspathic portion of the groundmass constitutes 40% of the rock. Apatite, sphene, and pyrite are accessories.

Specimen B-49-1-a from the same locality is an altered and more mineralized sample of the same rock type. The plagioclase is heavily altered to sericite and carbonate. Muscovite and sericite (15%) occur as pseudomorphs after biotite and as radial growths associated with chlorite. Also, they tend to replace quartz. Pyrite has replaced biotite. Light green clinochlore and light tan penninite grow into the plagioclase somewhat.

In the col between the 7311 foot peak and the peak to the south a leucogranodiorite (specimen B-50-1) occurs as a dike in a biotite-quartz diorite that is mineralized along its fractures. The leucogranodiorite contains 40% normally zoned plagioclase ranging from An 30 to An 8 in composition. It occurs in medium to large, anhedral grains, includes earlier quartz, and has sutured borders. Quartz (40%) of similar shape and size includes earlier quartz and plagioclase, and the larger grains replace the plagioclase. Microcline (20%) occurs in small to large, anhedral grains and replaces quartz and plagioclase from the intergranular network. Some myrmekite is present. Green and light brownish penninite forms pseudomorphs after biotite. A small amount of biotite remains. Some clinozoisite is associated with the biotite and chlorite. Muscovite, which may be from biotite, occurs. Apatite is the accessory. The texture is granoblastic.

The next peak south consists of cataclastic-appearing rock with scattered mineralization (specimen B-50-2-a). It is severely fractured. In thin section the rock consists of quartz (50%), muscovite and sericite (30%), and carbonate (20%). Apatite and a light brown chlorite with a very low birefringence are accessories. This is a recrystallized cataclastic rock that has been hydrothermally altered.

In the altered rock occurs a discontinuous body of biotite diorite porphyry (specimen B-50-2-b). It contains plagioclase (25%) in large, euhedral to subhedral phenocrysts that grade to groundmass size. The plagioclase has normal and superposed oscillatory zoning and a composition that ranges from An 43 in the core to An 2 in the rim in extreme cases. The plagioclase includes quartz, plagioclase, and biotite. Biotite (15%) occurs in fairly fine grained, anhedral flakes, sometimes in aggregates. Bright green penninite (5%) is derived from biotite. A groundmass of quartz and plagioclase makes up 55% of the rock and has a crystalloblastic texture. A small amount of potash feldspar replaces the plagioclase phenocrysts. Magnetite, pyrite, orthite, epidote, and sphene are accessories. The texture is igneous-appearing, but the inclusions in the phenocrysts and the crystalloblastic groundmass suggest that the rock did not crystallize from a melt.

Northern Portion of the Buckindy unit: General Description. The northern part of the Buckindy Mountain unit is better exposed (deglaciated but somewhat iron stained slabs) than the southern part. It is complex, and a more detailed study would no doubt reveal much about plutonic processes.

Relations are so complicated in some outcrops that in the field it was difficult to describe them without resorting to interpretation, which was not always borne out by the subsequent petrographic study.

Despite the varied aspect of the rocks in the field, study reveals

PLATE XXX

Fig. 1 General view of the northern part of the Buckindy unit. Outcrops described occur below the small glacier in the middle of the photograph and near the right foreground. Note recent moraine. North face of Buckindy Mountain in the background.

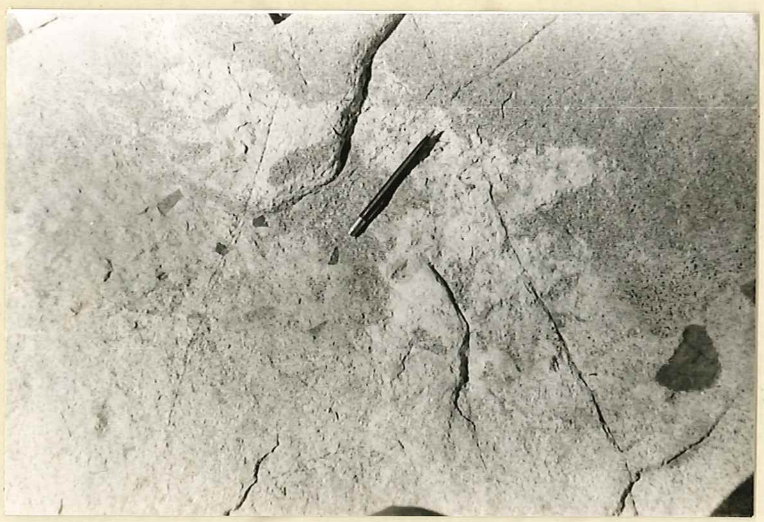


Fig. 2 Rock of the Snowking Mountain unit (light colored) replacing rock of the Buckindy unit (dark colored). The dark inclusions in the Snowking rock are inherited from the Buckindy rock.

that they have a fairly uniform quartz dioritic composition whereas they vary considerably in texture. The author will discuss individual outcrops separately rather than attempt to cover them in generalizations.

Outcrop area (1). On the deglaciated slabs southeast of the col below the southeast peak of Snowking, hornblende-biotite-quartz diorite with coarse grained mafics occurs as sharply bordered patches in a rock in which the mafics are finer grained. Gradually in a southerly direction the rock with coarse mafics takes the place of the rock with finer mafics, through an increase in the number of more fine grained patches. Gradational boundaries between the patches containing coarse grained mafics and the surrounding rock containing fine grained mafics also occur.

Outcrop area (2). Just south of outcrop area (1) a dark appearing rock with fine grained mafics has patches or fragments of rock with more coarse grained mafics in it. Some rocks of intermediate aspect (partially with coarse mafics) became mobilized and flowed around the patches or fragments of rock with the coarse grained mafics. The mobilized rock has flow structure and a fine grained matrix. In some places a gradation exists between the rock with coarse grained mafics and that with the fine grained mafics. Patches, replacement dikes, and fracture-controlled veinlets of a more leucocratic-appearing rock occur. The grain size of the mafics in the leucocratic rock varies.

Petrographic Description. The rock interpreted in the field as earliest at outcrop (2) is a biotite-quartz-dioritic porphyroblastic granulite (specimen C-61-1-c). It contains small to large, anhedral to subhedral plagioclase (55%), which has normal and minor superposed oscillatory zoning. The composition of the grains varies in an extreme case from An 55 in the core to An 33 on the rim. The larger crystals tend to

PLATE XXXI

Fig. 1 Patches with coarse grained mafics at outcrop area #1 in the northern part of the Buckindy unit.

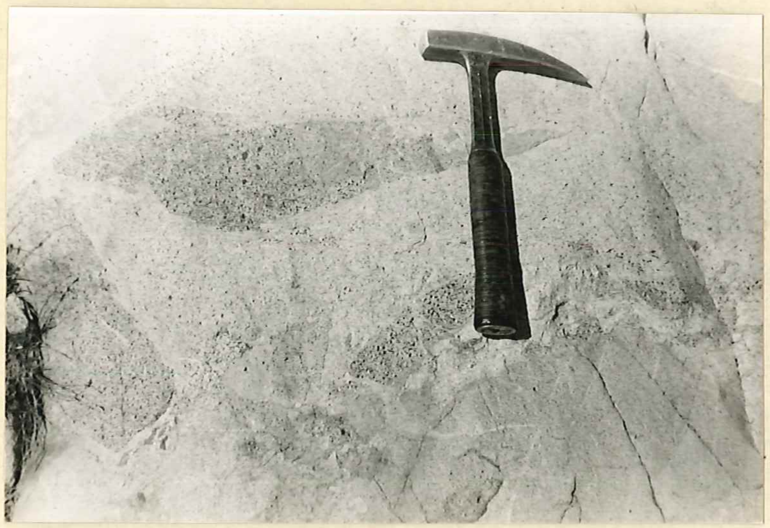


Fig. 2 Breccia at outcrop area #2 in the northern part of the Buckindy unit.

be more strongly zoned and to have more calcic cores. They include scattered grains of quartz, hornblende, and biotite, and their margins are highly irregular. They have grown from a mosaic-textured groundmass of plagioclase, quartz, and biotite. Quartz (35%) occurs in small to medium sized, anhedral grains and includes plagioclase and biotite. Biotite (10%) forms fairly small, anhedral to subhedral flakes throughout the rock. A few small, anhedral grains of hornblende occur. Retrogressive green penninite from biotite is present. Apatite, sphene, and opaques are accessories.

The rock of an intermediate aspect (specimen C-61-1-b) is composed of biotite, hornblende, quartz, and labradorite. Although it doesn't fit the traditional rock classification, it will be referred to as a diorite because of its leucocratic character. Plagioclase (70%) occurs in medium to large, subhedral to euhedral crystals that have normal and superposed oscillatory zoning. In one extreme case, the composition of a grain ranges from An 81 in the core to An 30 on the rim, but most of the grains determined are sodic labradorite. Plagioclase crystals include biotite, hornblende, quartz, and plagioclase. Some grains have a mottled pattern to their extinction due to partial conversion of their inner, calcic portion to a more sodic plagioclase. Quartz (10%) forms small to medium sized, anhedral crystals, some of which replace plagioclase. They include hornblende, plagioclase, and biotite. Green hornblende is found in small to fairly large, anhedral to subhedral grains. Often it occurs in large aggregates of small crystals. Some of the small crystals have a light, rather bluish green absorption. The hornblende includes quartz and plagioclase, and sometimes those minerals form sieve texture in it. Numerous grains of opaque minerals are also included. Biotite (10%) forms small to medium sized, anhedral to subhedral flakes. Some of it was derived from hornblende. It includes plagioclase. Retrogressive green penninite from biotite and clinozoisite from hornblende occurs. Apatite, sphene, zircon and the opaques pyrite, pyrrhotite, and magnetite (?) are accessories. The rock has quite an igneous aspect, except for the mafics which formed both early and late during the development of the rock.

The mobilized rock is a "labradorite porphyry" (specimen C-61-1-d). It contains 70% plagioclase in large, subhedral to euhedral phenocrysts and small anhedral to subhedral grains in the groundmass. The phenocrysts have normal and some superposed oscillatory zoning. Their composition ranges from An 80 to An 55, and some have more sodic margins. They include a few hornblende grains. The groundmass plagioclase has normal zoning and the composition of sodic andesine. Some of the groundmass grains have sutured borders, are somewhat larger than most, and have a subhedral outline. Quartz (20%) occurs as small, anhedral crystals in the groundmass. Green hornblende forms aggregates of medium sized, anhedral to subhedral grains. In the groundmass it occurs as small, anhedral grains. It includes quartz and plagioclase. Biotite (10%) is found in small, anhedral to subhedral grains throughout the groundmass, and it occurs also in medium sized crystals associated with the hornblende aggregates. Apatite, sphene, and opaques are the accessories. The groundmass has a mosaic texture, and perhaps it is recrystallized cataclastic material.

The rock thought in the field to have been the last formed, is a biotite-hornblende-quartz diorite (specimen C-61-1-a). It contains 70% andesine in small to large, anhedral to euhedral crystals (mostly anhedral and subhedral). The plagioclase grains have some fairly strong normal zoning and some oscillatory zoning. Some grains have more calcic interiors,

PLATE XXXII

Fig. 1 Labradorite porphyry at outcrop area (2) in the northern portion of the Buckindy unit. Mobilized rock showing flow structure in the field. Mosaic textured groundmass. (specimen C-61-1-d) 18x, crossed nicols.

PLATE XXXIII

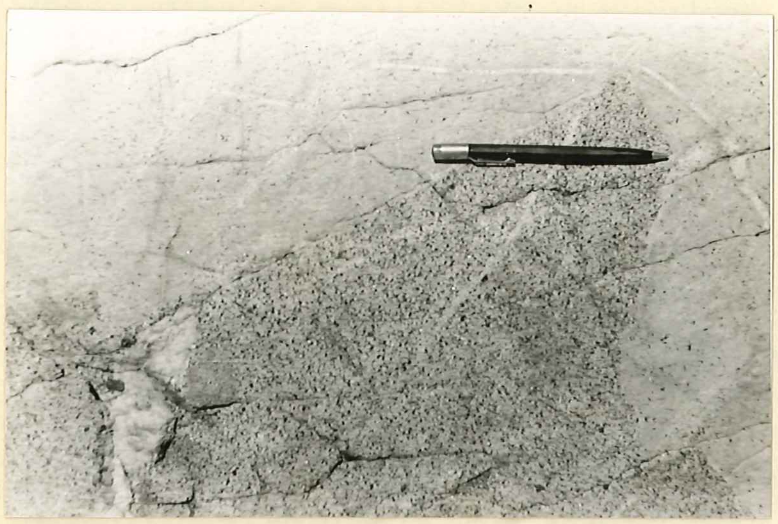


Fig. 1 Rheomorphic breccia in outcrop area #2 in the northern part of the Buckindy unit.

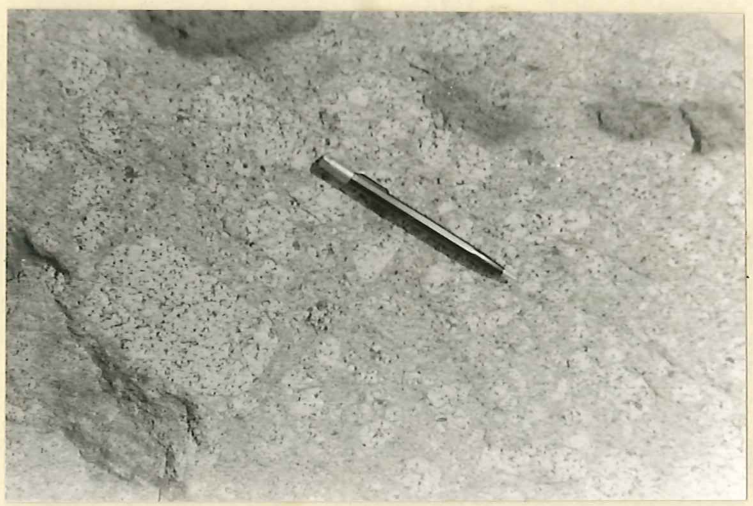


Fig. 2 Breccia at outcrop area #5 in the northern part of the Buckindy unit.

but many of them have a mottled extinction pattern, indicating that the calcic interiors have been incompletely altered to andesine. The plagioclase includes quartz and hornblende. Medium grain, anhedral quartz makes up 10% of the rock. It replaces and includes plagioclase and hornblende. Fine to coarse grained, anhedral hornblende (10%) includes quartz and plagioclase. It has highly irregular and sutured borders and tends to incorporate adjacent minerals. Biotite (10%) forms small to large, anhedral flakes. It was at least partially derived from hornblende. It grows in the intergranular network and tends to incorporate the other minerals. Retrogressive green clinochlore from biotite is present. Zircon, apatite, and opaques (mostly pyrrhotite) are the accessories. The texture of the rock is crystalloblastic. The porphyroblastic character of the mafics is conspicuous.

The author does not understand exactly how the petrographic features of specimens a, b, and c fit in with the field observations, especially from a compositional point of view. The rock thought to be the earliest has a metamorphic texture, more quartz, and less mafics than the other rocks. The rock judged in the field to have formed latest has late-crystallized mafics that might indicate some iron and magnesium metasomatism. The rock believed to represent an intermediate stage between the two has as many, and probably somewhat more mafic minerals than the later formed rock. Texturally it might represent an intermediate period of crystallization under fluid-rich and/or high temperature conditions favorable for the development of igneous appearing plagioclase. The later formed rock perhaps has a similar history, but its crystallization continued longer into a period in which conditions in the rock permitted less freedom of crystallization.

Outcrop area (3). On a deglaciated slab on the east side of the ridge, about 400 feet below the north side of the col which lies between the 6200 foot summit and the 6700 foot peak on the Snowking-Buckindy ridge, occurs a granitic rock that contains some large, almost euhedral biotite and hornblende, but mainly fine grained mafics. Some patches and zones of fine grained rock with fine grained mafics occur and they grade into the rock with coarse and fine grained mafics.

Petrographic Description. The rock with both the coarse and fine grained mafics (specimen D-2-1) is a biotite hornblende granodiorite. It contains plagioclase (60%) in small to large, anhedral to euhedral crystals that have normal and superposed oscillatory zoning. The plagioclase ranges in composition from An 35 to An 25. Many of the larger plagioclase grains have sutured borders, are anhedral, and include earlier biotite and hornblende. Quartz (15%) forms small to fairly large, anhedral crystals, and it includes plagioclase. Potash feldspar (15%) occurs in small, anhedral grains that tend to replace plagioclase and quartz. It is especially abundant in the fine grained zones. Green hornblende with an olive tinge, is found in small to fairly large, anhedral crystals. The larger ones include quartz and plagioclase. Biotite (5%) forms small to large, anhedral to subhedral crystals. Some of it is from hornblende. The large crystals include quartz and plagioclase and have ragged borders engulfing adjacent minerals. Retrogressive green penninite from biotite, apatite, sphene, and zircon complete the rock. Zones of fine grained recrystallized mortar occur, and some large crystals have grown in those areas. The cataclasis was paracrystalline. It formed a zone that was especially favorable for late potash introduction. The texture of the rock is generally granoblastic.

Outcrop area (4). At a ridge that trends east from the south side of the col between the 6200 foot summit and the 6700 foot peak on the Snowking-Buckindy ridge, a mineralized and fractured zone occurs in the rock.

Petrographic Description. Specimen D-2-2 from this locality is a hornblende biotite quartz diorite. Plagioclase (75%) occurs in normally zoned, fairly small to large, subhedral to euhedral crystals. Oscillatory zoning is superposed on the normal zoning. Its composition varies from An 45 to An 37. The plagioclase includes quartz, hornblende, biotite, and epidote. Some euhedral crystals have anhedral inner zones. Some have irregular borders containing quite numerous inclusions, and thus these crystals appear to have grown from the groundmass. Quartz (10%) forms small to fairly large, anhedral grains and includes plagioclase. Some late large ones include portions of the groundmass. Hornblende (less than 5%) is found in small to medium sized, anhedral grains. Often it forms aggregates of fairly small crystals. One aggregate looks like a pseudomorph after a former large hornblende crystal. Biotite (10%) also tends to form aggregates of small to fairly large, anhedral flakes. Retrogressive green penninite from biotite and hornblende is present. Apatite, sphene, and opaques (mainly pyrrhotite) complete the rock. Pyrrhotite is disseminated and sometimes is found as thin films in fractures. The plagioclase is quite igneous in its overall aspect, but some of its features indicate that metamorphic growth may have played an important role in its formation. The mafics are of metamorphic origin.

Outcrop area (5). Below the small glacier on the east side of the 6700 foot peak on the Snowking-Buckindy ridge occurs a breccia. Some fragments in the breccia do not have sharp borders. The matrix looks as if it contains individual feldspar crystals or small aggregates of quartz and feldspar.

Petrographic Description. In thin section the rock adjacent to the breccia is a biotite quartz diorite (specimen D-3-1-a). It contains plagioclase (70%) in small to large, anhedral to euhedral, normally zoned crystals. Superposed oscillatory zoning occurs. The grains include quartz, biotite, and hornblende. Much of the plagioclase has sutured borders. Quartz (20%) is found in small to medium sized, anhedral grains, and it includes biotite and plagioclase. Potash feldspar occurs in a small horsetail-structured veinlet that passes through the specimen. Small to medium sized, anhedral hornblende includes some quartz and plagioclase. Biotite (10%) forms small to large, anhedral to euhedral crystals. Some of it is derived from hornblende. It tends to occur in aggregates. The large crystals include quartz and plagioclase and have ragged and sutured borders that tend to incorporate adjacent grains. Prehnite occurs with biotite. Retrogressive green penninite was derived from biotite. Apatite, sphene, zircon, and opaques are accessories. In the vicinity of the potash feldspar filled veinlet much of the rock is quite fine grained. Small scattered areas of fine grained material occur throughout the rock. This material may be remnants of recrystallized mortar. In the author's opinion, many of the larger grains grew from the mortar, which was produced by an earlier phase of shearing.

The specimen of the breccia studied (specimen D-3-1-b) contains a sharply bordered fragment of leucocratic granitic rock and several indistinct areas of a rock that is more coarse-grained than the matrix. The matrix, defined as all of the rock except the leucocratic fragment, contains plagioclase in small to large, anhedral to euhedral crystals which have strong normal zoning and a compositional range from An 80 to An 30. Some grains are fragments of crystals. The plagioclase includes quartz, biotite,

PLATE XXXIV

Fig. 1 Biotite hornblende granodiorite from outcrop area (3) in the northern portion of the Buckindy unit. Fine grained area consists of recrystallized mortar and contains a higher proportion of potash feldspar. (specimen D-2-1) 18x, crossed nicols.

Fig. 2 Biotite quartz diorite from outcrop area (5) in the northern portion of the Buckindy unit. Zone of late-crystalline shearing has undergone more recrystallization than in Fig. 1. (specimen D-3-1-a) 18x, crossed nicols.

and hornblende. Quartz (20%) occurs in small to fairly large, anhedral to subhedral grains that include plagioclase, biotite, and hornblende. A few small, anhedral grains of potash feldspar occur. Biotite (10%) forms small to fairly large, anhedral to subhedral flakes that often include plagioclase. Again the larger crystals have a very obvious porphyroblastic habit. Small, anhedral, green hornblende occurs scattered throughout the rock. Apatite and opaques (mostly magnetite) are accessories. The coarser grained areas probably contained more and larger crystal fragments than the rest of the rock. All the minerals have recrystallized and grown considerably, so that fine grained recrystallized mortar makes up only a minor portion of the rock. The rock fragment is a leucocratic quartz monzonite with a granoblastic texture, and it is quite unlike the matrix, which has a texture that developed under conditions permitting considerable freedom of crystallization.

Outcrop area (6). Southeast of outcrop area (5), more breccia occurs. Narrow bands with coarse grained mafic grade into rock with somewhat finer grained mafics. Also, the bands grade into patches and into better defined fragments of rock with coarse grained mafics.

Petrographic Description. The only specimen collected from this outcrop is from the matrix of the breccia (specimen D-3-2). It is quite similar to the matrix in specimen D-3-1-b described above. It has a seriate porphyritic texture, and the large feldspars and even the groundmass are quite igneous-appearing. The plagioclase phenocrysts contain rare inclusions of hornblende and plagioclase. The mafics, however, are not igneous-appearing. Hornblende forms small to fairly large, anhedral crystals. Biotite occurs mainly in small, anhedral flakes, but a few large, euhedral porphyroblasts with numerous inclusions and ragged borders incorporating adjacent

PLATE XXXV

Fig. 1 Indistinct stringers of coarse grained rock in outcrop area #6 in the northern part of the Buckindy unit.

grains are present. This rock was probably at least partially melted.

Outcrop area (7). On the ridge which separates the northeast side of the cirque north below Buckindy from the cirque east below the 6700 foot peak on the Buckindy-Snowking ridge, the rock is rich in disseminated pyrite. Its mafics are medium grained. A rock with somewhat finer grained mafics is also present. The relationship between the two could not be seen on the weathered surface of the ridge.

Petrographic Description. Specimen D-4-1 from this locality is a hornblende biotite quartz diorite which contains plagioclase (75%) in small to large, subhedral to euhedral crystals with normal and superposed oscillatory zoning. The composition of the plagioclase averages calcic andesine. Many of the larger crystals have a mottled appearance due to the presence of partially altered more calcic plagioclase. The plagioclase includes hornblende, biotite, early and late epidote, and later formed chlorite and opaque minerals. Quartz (10%) forms small to medium sized, anhedral grains. It fills the interstices of the plagioclase crystals and also tends to replace them to a limited extent. Some large late crystals occur. Olive green hornblende (5%) is found in small to fairly large, anhedral crystals that include plagioclase. The larger ones have highly irregular outlines, include considerable plagioclase, and incorporate plagioclase grains at their margins, and thus are obviously porphyroblasts. Some slightly bluish green amphibole with the same extinction angle occurs as a retrogressive mineral. Biotite (10%) forms small to medium sized, anhedral to subhedral grains. Some of it is retrogressive after hornblende. It has the same features as the hornblende that indicate it is a product of metamorphic growth. Iron-rich epidote, mostly retrogressively derived from hornblende and plagioclase, occurs. A few grains of epidote, however,

PLATE XXXVI

Fig. 1 Hornblende biotite quartz diorite from outcrop area (7) in the northern portion of the Buckindy unit. Biotite and hornblende of various sizes and shapes. Rather large hornblende porphyroblast on the left. (specimen D-4-1) 18x, plane light.

Fig. 2 Crossed nicols. Plagioclase subhedral to euhedral.

appear to be early. Disseminated pyrite and magnetite make up 5% of the rock. Retrogressive green penninite was derived from biotite. Apatite is the accessory. The texture of the rock is quite igneous-appearing except for the mafics.

The rock with the finer grained mafics is a "biotite diorite porphyry". Plagioclase (80%) occurs in small to fairly large, anhedral to euhedral crystals. It has normal and superposed oscillatory zoning. Several crystals have a marked calcic zone near their margins. One crystal has the composition An 37 in the core, An 63 in the calcic zone, and An 33 on the rim. Many crystals include biotite, and the phenocrysts tend to have numerous biotite inclusions near their borders. Biotite (10%) forms small anhedral flakes. Iron-rich epidote is associated with biotite. A few small grains of green hornblende occur. Pyrite, zircon and apatite are the accessories. The texture has an igneous-appearing aspect, but the inclusions in and the borders of some of the plagioclase grains raise considerable doubt that it crystallized from a melt. A leucocratic veinlet that contains very little biotite but has a texture similar to that of the rest of the section, transects the specimen.

Outcrop area (8). A few specimens were collected from talus along the Buckindy-Snowking ridge. In one place the talus contains segregations of hornblende crystals that reach a maximum length of 2 inches. In some cases the hornblende appears to form the matrix of a breccia-like rock with granitic fragments.

Petrographic Description. Specimen D-5-1-c from part of the breccia-like rock contains a hornblende-plagioclase petmatite, fractures filled with hornblende, and fragments of fine grained rock in addition to coarse grained hornblende quartz diorite. It consists of plagioclase (70%) with normal and superposed oscillatory zoning. The plagioclase ranges from An 60 to An 30 in composition. It occurs in small anhedral to fairly large, euhedral crystals. Some crystals have been partially converted from a calcic plagioclase to a sodic andesine, and their extinction has a mottled pattern. The larger crystals are porphyroblasts that have grown in a fine grained groundmass. Quartz (10%) occurs in small to fairly large, anhedral grains that include plagioclase and hornblende. It tends to replace plagioclase. Hornblende occurs in small to fairly large, anhedral crystals. It has an extinction angle of 18°, and the pleochroism: Z=lightish drab green, Y=brownish green, and X=yellowish tan. The large crystals include quartz and plagioclase. The hornblende fills fractures. In the fine grained parts, hornblende makes up 40% of the rock. A small amount of biotite from hornblende is present. Sphene and opaques are accessories. The rock has an apparent catcalstic texture. The fine grained portion of the specimen looks as if it might originally have been a recrystallized cataclastic rock. The border between the fine grained portion and the coarse grained portion is in part gradational and in part sharp. The coarse grained portion has a granoblastic texture, which has only a few igneous-appearing features, such as several euhedral plagioclase crystals. In the coarse grained portion are occasional aggregates of smaller crystals which suggest that the coarse grained portion might be derived by recrystallization of the fine grained mortar.

Conclusions

The Buckindy unit deserves more intensive field and petrographic study. The unit as a whole has, relatively speaking, the most pronounced igneous aspect of any of the units of the Snowking massif. The rock has been worked over by so many processes that it is difficult to determine the nature of the original material. The author believes that what we see now is not the products of the simple crystallization of a silicate melt, but of perhaps the re-consolidation of partially melted rock that was formerly in a solid state. This opinion is based on the relationships between the minerals in the rocks. Euhedral minerals, which, if judged merely on the merit of their shape, should be early, contain inclusions of anhedral minerals, which if judged on the merit of their shape alone, should be late, both judgments, of course, being based on the assumption of a simple igneous crystallization. The actual relationships, then, indicate that such a simple assumption does not do justice to the observed facts. To be specific, hornblende and biotite partially occur both as inclusions in large euhedral plagioclase crystals and as late porphyroblasts. No remnants of possible early, definitely pyrogenic, minerals occur. Even if the rocks had crystallized from a true melt, the mafics would have mostly formed when the rock was in a solid state. There is no evidence that the hornblende was derived from the breakdown of former minerals, as one would expect if the porphyroblasts were products of endomorphic processes in a rock that crystallized from a melt. The early mafics do not have an igneous aspect. The author suggests that they may be remants from an earlier metamorphic chapter in the history of the rock. Perhaps the late mafics were derived from the collective crystallization of early mafics during a late stage of the crystallization of the rock. Another possibility is that the rock underwent some iron and magnesium metasomatism.

In several places petrographic study suggests that at least some of the igneous appearing rocks have been derived from recrystallization of a cataclastic rock. This applies especially to the breccia zones north of

Mt. Buckindy. There the matrix has developed quite an igneous appearing texture, and the presence of foreign leucocratic fragments, and locally, of flow structure indicates that some movement has taken place. This is a "rheomorphic breccia" as defined by Goodspeed (1952, p. 457, 467). In the north part of Buckindy Mountain the breccia partially recrystallized to form a granoblastic rock. Perhaps heat and/or the amount of liquid in the rock made the difference.

Generally speaking, the Buckindy unit is rheomorphic in aspect. Movement occurred at least locally. Paracrystalline and late-paracrystalline shearing took place within the unit, producing rheomorphic and partially recrystallized breccias, "porphyries", and incompletely recrystallized cataclastic rock. The breccia at the southern contact may be due to this shearing, although because of insufficient observations intrusion is not ruled out as a cause of its formation. Some later marginal metasomatism and recrystallization occurred where the Buckindy unit borders the Snowking Mountain unit.

The area occupied by the Buckindy unit was probably a focus of tectonic actitivy during crystallization of the rock. In the northern unit, the West Snowking unit, and especially in the unit east of Kindy Creek similar rocks occur in restricted zones, which in some cases are quite obviously zones where shearing occurred during the crystallization of the rock. This process gave rise to "porphyries" and rocks of igneous aspect. In the Buckindy unit these processes were active throughout the unit, although they may have lasted longer in certain zones.

Conclusions and Interpretaion of the Snowking Massif

The Snowking massif is a complex plutonic mass. The Chaval unit consists of metamorphosed and metasomatized hypersthene diorite and probably other igneous rocks of basic and intermediate composition. The Snowking Mountain unit is made up of late-and post-kinematically granitized biotite and hornblende-biotite schists. The Northern unit consists of metasomatic and neomagmatic rocks which intergrade. The West Snowking unit contains metasomatic rocks, some of which have developed an igneous appearing texture in a late part of their history and have been locally mobilized. The unit on the ridge east of Kindy Creek is a complex of metasomatic gneiss and recrystallized cataclastic rock. In certain zones cataclastic rock has recrystallized to "porphyry" and other igneous appearing rocks. The term "porphyry" is used in referring to rocks containing a fine grained quartzo-feldspathic groundmass and large, mostly euhedral porphyroblasts, which in these rocks are plagioclase, sometimes accompanied by quartz. Mineralization has occurred in some of these zones. The rocks of the Buckindy unit are of rheomorphic aspect. They consist of breccias, equigranular granitic rocks, porphyries, and "porphyries". During the late part of their complex history many of these rocks have attained an advanced stage of evolution concomitant with the development of igneous textures. This advanced stage of evolution is interpreted as representing partial liquefaction. However, some of the massive granitic rocks have not attained this stage and have remained granoblastic, and the same is true of some of the breccias and cataclastic rocks. Some of the rocks which on textural evidence are interpreted as having been partially liquefied have moved and thus can be described as rheomorphic. No large scale movement, however, can be proved. Most of this mobilized rock may still be very near the site of its formation.

The genesis of the Snowking plutonic complex appears to have combined metasomatism, cataclasis, recrystallization under varying conditions, probably partial liquefaction in certain portions of the massif, and at least a certain amount of mobilization in parts of the massif. However, the various processes have considerably overlapped in time, and they have not even acted in any definite and uniform sequence. In each of the various component parts of the Snowking massif, we tend to see most clearly the effects of that process which has terminated the evolution of that particular component part.

For instance, in the Snowking Mountain unit and the Chaval unit cataclasis is earlier than most of the metasomatism, whereas cataclasis is later than metasomatism in the Buckindy unit and in certain zones within the unit which occupies the ridge east of Kindy Creek. However, it is possible that an early cataclasis has occurred also in the two latter units and that its traces have been erased by more recent events. Where partial liquefaction has occurred, this process, recorded by the subsequent crystallization, always has been the latest stage in the evolution of the rocks. Where mobilization has occurred, it is later than metasomatism. Only some of the mobilized rocks have also undergone partial liquefaction. In mobilized rock bodies which were partially liquefied the time relation between these two processes varies. In the eastern part of the West Snowking unit mobilization seems to have been later relative to partial liquefaction than in portions of the Buckindy unit and in certain zones of "porphyry" and porphyry in the unit east of Kindy Creek.

In the West Snowking unit igneous-textured areas developed and mobilization took place without being preceded or accompanied by strong cataclasis of the pre-existing rocks, while in both the Buckindy unit and locally in the unit east of Kindy Creek such cataclasis was more important, especially in the production of the "porphyries". In those rocks the fine grained quartzo-feldspathic groundmass in which the phenocrysts grew was formed by cataclastic breakdown of pre-existing rocks. Some of the more equigranular rocks may have been produced in the same manner. In those equigranular rocks cataclasis may have occurred somewhat earlier in relation to the end of crystallization than it did in the rocks that became "porphyries". Another factor influencing the grain size of the final product may be the degree of mobilization and the time of its occurrence. Whether cataclasis has taken place prior to or as a result of mobilization is difficult to determine, but certainly they are intimately related. Mobilization of a mostly solid rock often takes place by "cataclastic-plastic flow" (Misch, 1952b). The rocks of the Snowking area clearly demonstrate that such a process must have occurred. Mobilization also has given rise to "porphyries" of metamorphic aspect that grade into porphyries of igneous aspect. This throws doubt on the origin of many porphyries associated with granitic complexes in regionally metamorphosed terranes.

Within the plutonic complex the contact relationship between the Snowking Mountain unit and the Buckindy unit indicates that metasomatism and crystallization continued longer in the former than in the latter. The Snowking Mountain unit is much richer in soda and potash than the Buckindy unit. There is no conclusive evidence for alkali metasomatism in the Buckindy unit. If at all, it can have occurred only during an early stage of evolution of this unit and must have been obscured by subsequent events.

The zones of cataclastic rock and "porphyry" in the unit east of Kindy Creek may be finger-like extensions of the Buckindy unit.

and northeast.

The northeastern contact of the Snowking massif is migmatitic on the ridge between Kindy and Found Creeks. On the ridge east of Kindy Creek the contact is formed by a former migmatite zone which has been sheared and recrystallized and thus been converted into a breccia with a schist matrix. At the head of Sonny Boy Creek the contact zone consists of migmatite and breccia.

Post-Metamorphic Igneous Rocks

Downey Mountain Trondhjemite

The southwestern marginal part of a trondhjemite body of undetermined size was observed on Downey Mountain.

A contact between the trondhjemite and the schists of the Green Mountain unit is well exposed on the south side of the 5900 foot summit of Downey Mountain. At this place the contact trends 30° E. The contact is sharp, and amphibolite occurring in the wall rock appears to have recrystallized somewhat. The amphibolite contains small leucocratic replacement stringers and pods. A dike composed of a hornblende-rich, fine grained, rock cuts the amphibolite and continues into the trondhjemite. However, at the contact between the trondhjemite and amphibolite the dike is offset a few feet. About 25 feet inside the contact the dike ends. Near the contact, inclusions are rare in the trondhjemite, but farther inside the trondhjemite, inclusions of partially feldspathized amphibolite are common. They are roughly elliptical, and they tend to be aligned in a direction somewhat east of north. Their long axes plunge to the northeast. They are probably derived from the dike rock.

About 3 inches from the contact a specimen of hornfelsized amphibolite (specimen C-22-2-b) was collected. It contains 80% small, anhedral

PLATE XXXVII

Fig. 1 Contact of Downey Mountain trondhjemite with amphibolite just south of the summit of Downey Mountain.

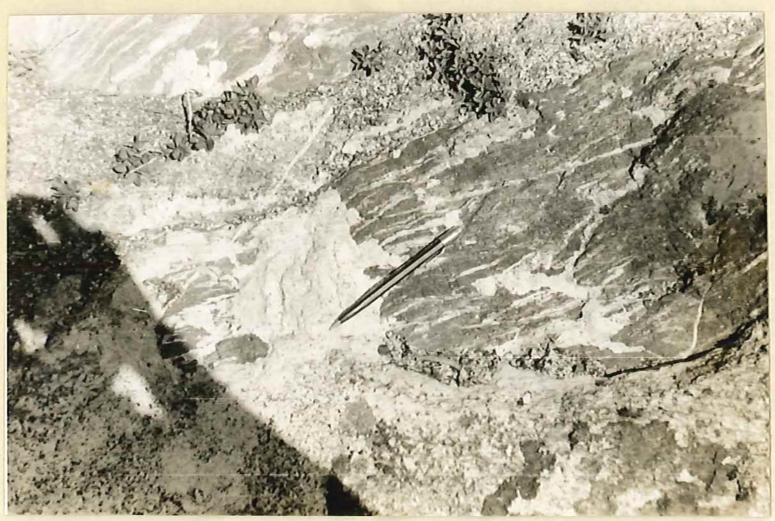


Fig. 2 Feldspathic replacement pods in amphibolite adjacent to the Downey Mountain trondhjemite.

to subhedral hornblende grains that have a fairly light green absorption, except for a brownish tinge in their rims. Plagioclase (20%) has a composition of An 37 and occurs in small, anhedral to subhedral grains. It tends to be concentrated in bands. Both reverse and normal zoning are present. Sphene and opaques are accessories. In areas where hornblende is sparse, this mineral partially retains its original alignment.

Specimen C-22-2-d contains the contact of the trondhjemite with the amphibolite. The granitic rock contains plagioclase (65%) in medium to large, anhedral to euhedral, normally zoned grains. It tends to be anhedral adjacent to the contact and euhedral away from it. Quartz (35%) occurs in small to fairly large, anhedral crystals. Green hornblende is found in medium sized, subhedral to euhedral crystals in the trondhjemite adjacent to the contact and in small, anhedral to subhedral grains in the amphibolite. Biotite from hornblende occurs in the amphibolite and is found as medium sized, subhedral crystals in the granitic rock. Adjacent to the contact, quartz replaces plagioclase, and the trondhjemite has a granoblastic texture, whereas just about a half inch away the Downey Mountain trondhjemite has an igneous texture. Some hornblende which was derived from the amphibolite and subsequently recrystallized, occurs directly adjacent to the contact.

The main trondhjemite (specimen C-22-1) contains plagioclase (80%) in medium to large, subhedral to euhedral crystals. It has normal and superposed oscillatory zoning and ranges from An 36 to An 12 in composition. It includes a few grains of quartz, plagioclase, and hornblende. Quartz (10%) occurs in medium to large, anhedral grains. Biotite (10%) forms small to fairly large, subhedral to euhedral crystals. Some was derived from hornblende. Green hornblende occurs in small to large, anhedral to subhedral grains. One large hornblende crystal has been replaced by plagioclase along its margin. Retrogressive light green penninite from biotite is present. Some prehnite occurs in the biotite. Apatite, sphene, zircon, and orthite are accessories. The texture is igneous.

A sample of a feldspathized inclusion (specimen C-21-1-b) contains plagioclase (55%) in small to medium sized, subhedral to euhedral crystals with normal and superposed oscillatory zoning. The plagioclase ranges from An 37 to An 22 in composition. It includes hornblende and biotite. Quartz replaces plagioclase. Green hornblende (30%) occurs in small, anhedral to large, subhedral crystals and tends to form clusters. One large crystal has sutured borders and is altered to rather euhedral biotite. Biotite (15%) is found in small to medium sized, anhedral to euhedral flakes and was derived from hornblende. Apatite, zircon, and opaques are accessories. In texture and composition the rock looks very much like a feldspathized dike rock.

At the locality where the Downey Mountain trondhjemite was observed, it is an igneous intrusion. The adjacent rock has been hornfelsized. Some replacement dikes and pods occur adjacent to the contact. The main body has no chilled borders but has a zone of granoblastic textured rock about 1/2 inch wide at the contact. The lack of pyrogenic minerals and the scattered inclusions of various minerals in the euhedral plagioclase suggest that this rock is of neomagmatic rather than orthomagmatic origin. The rest of the body should be mapped and studied.

Dacitic Porphyry Dikes

In the Green Mountain unit, especially on Green Mountain and in the adjacent part of the Suiattle River valley, occur scattered porphyry dikes of a more or less dacitic composition. They contain plagioclase and quartz phenocrysts up to 8 mm. in diameter in a fine grained light grey groundmass. Sometimes hornblende and biotite phenocrysts also occur. The dikes are from 5 to 15 feet wide. Only a few attitudes were obtained. Their average trend is N 45° E and their dip vertical. Some dikes contain inclusions of schist and microdiorite. No chilled margins were observed on the dikes.

These dike rocks contain 10 to 35% large, euhedral plagioclase phenocrysts. The plagioclase has normal and superposed oscillatory zoning. Its composition ranges from An 55 to An 32. In a few rocks some of the plagioclase phenocrysts display a prominent calcic zone in an intermediate position between core and rim. The most notable example measured has a composition of An 45 in the core, An 78 in the intermediate zone, and An 23 in the rim. The inner part of the calcic zone is mottled. This may have been caused by diffusion within the crystal tending to decrease the difference between the highly calcic zone and the adjacent areas. In a few specimens the plagioclase crystals have somewhat rounded edges. Some grains are crystal fragments. The plagioclase phenocrysts include earlier hornblende, which is often euhedral. Plagioclase and garnet inclusions also occur.

Large, euhedral to anhedral quartz phenocrysts make up 0 to 25% of the dacitic porphyry dikes. They tend to be somewhat rounded. Quartz includes some early hornblende. Hornblende constitutes 0 to 25% of these rocks and occurs as small to large, subhedral to euhedral phenocrysts. It is brown to green in color, and it sometimes includes smaller quartz and plagioclase grains. Biotite (0 to 15%) occurs in subhedral to euhedral phenocrysts and sometimes grades down to groundmass size. A few biotite pseudomorphs after hornblende occur. Chlorite, usually green penninite, forms pseudomorphs after hornblende and biotite, and carbonate and sphene are often included in the chlorite. In one rock the chlorite pseudomorphs after hornblende contain prehnite.

A fine grained groundmass composed mainly of quartz and feldspar and containing smaller quantities of hornblende and biotite constitutes 40 to 70% of these dacitic porphyries. It varies from fine grained to extremely fine grained. In one rock it consists of a cryptocrystalline aggregate with considerable glass.

Accessories are epidote minerals, sphene, apatite, zircon, and opaques.

Specimen B-9-2-b from the northern Suiattle River road contains a microdiorite inclusion. The inclusion has a sharp border as far as its mafic minerals are concerned. The inclusion contains a considerable amount, namely 25%, of brown hornblende, whereas hornblende constitutes only 5% of the dacitic dike rock. The hornblende of the inclusion occurs in small to medium sized, subhedral to euhedral grains. Very fine grained, dacitic matrix invades the microdiorite so that a considerable portion of the inclusion seen in the thin section has a matrix resembling that of the dacitic dike rock. The amount of this fine grained matrix becomes less towards the center of the inclusion.

One dike at Green Mountain Lookout contains somewhat more calcic plagioclase phenocrysts and rather dark brown hornblende (specimens A-16-1-a&b). The average composition of the plagioclase phenocrysts is that of calcic andesine, but some of them are calcic labradorite. No quartz was found in specimen A-16-1-a, but in specimen A-16-1-b from the same locality the groundmass appears to contain a significant amount of quartz. One plagioclase phenocryst in specimen A-16-1-b includes a garnet partially altered to chlorite.

Specimen B-12-2 from the ridge east of the summit of Green Mountain contains medium sized to large plagioclase phenocrysts (25%) with oscillatory and reverse zoning. Often two principal zones occur, within each of which minor oscillations are present. One crystal measured has a core of An 34 and a rim of An 43. The plagioclase crystals include garnet, hornblende, and groundmass grains. A few phenocrysts have incorporated some groundmass at their margins and have irregular borders and numerous inclusions. Quartz occurs in the groundmass and as a few large, anhedral grains. Green penninite (10%) forms pseudomorphs after hornblende, which occurred in medium sized,anhedral to euhedral phenocrysts. The chlorite of these pseudomorphs is associated with epidote and carbonate. A very small amount of biotite occurs with the chlorite. Small to large, subhedral grains of light orange garnet are included in some plagioclase phenocrysts and in former hornblende phenocrysts. In one plagioclase phenocryst a large garnet aggregate includes quartz. A fine grained groundmass of quartz, plagioclase, and chlorite makes up about 65% of the rock.

All these rocks have an igneous aspect. However, many of them at the same time display features one would not expect in a typical orthomagmatic rock. This is especially true of the last rock described (specimen B-12-2). This rock contains a metamorphic type of garnet. Moreover the garnet is earlier than the plagioclase and hornblende phenocrysts. The rock also contains phenocrysts that include groundmass grains, usually in small aggregates. Some of the phenocrysts have irregular margins that tend to incorporate the adjacent groundmass. These features suggest that the phenocrysts are, in fact, porphyroblasts. These facts are difficult to reconcile with orthomagmatic fractional crystallization. Rather, an

PLATE XXXVIII

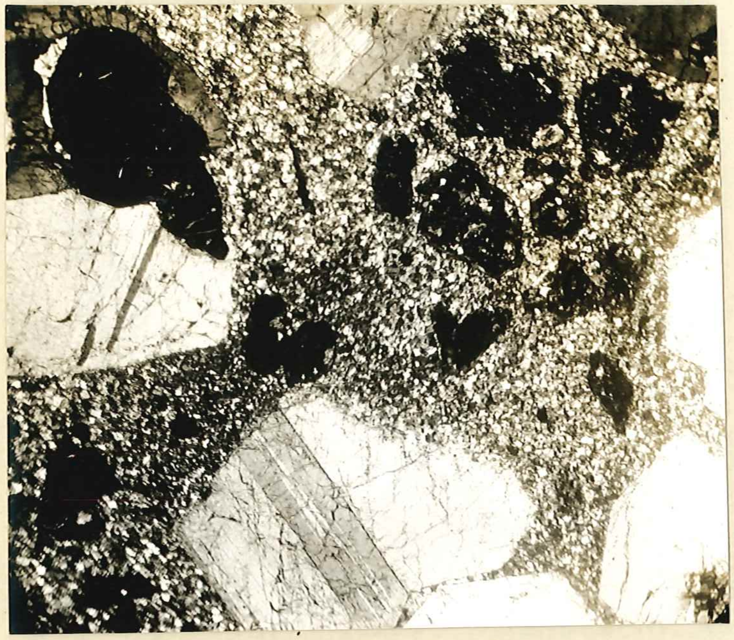


Fig. 1 Chloritized hornblende daciet porphyry from intrusive dike on Green Mountain. Irregular margins on plagioclase phenocrysts tend to incorporate fine grained matrix. Garnet (Upper left) included in plagioclase phenocryst. (specimen B-12-2) 20x, crossed nicols.

Fig. 2 Resorbed plagioclase phenocrysts in dacite porphyry dike. Groundmass contains glass in part. (specimen A-7-2-c) 13x, crossed nicols.

early metamorphic chapter in the evolution of this rock seems to be indicated. This rock is markedly similar in texture and mineral composition to some of the "porphyries" of the Snowking massif. Probably it has been formed by incomplete liquefaction of earlier migmatitic material.

The other dacitic dike rocks are similar in composition but show less evidence for an early metamorphic chapter in their evolution. Certain features, though, are still present which recall the rock discussed in the preceding paragraph. They are rare inclusions of earlier, anhedral minerals in the phenocrysts and occasional sutured margins on the phenocrysts. Probably these rocks have had the same history as specimen B-12-2, but liquefaction has been more complete so that their texture has become more typically igneous.

Thus in the Snowking area we see all gradations from "porphyries" of definite metamorphic derivation, which occur in the granitic massif very close to their place of origin, to intrusive, essentially igneous, dikes which occur in the schists over a mile, and probably several miles, from their birthplace.

Other Late Intrusive Dikes

General Statement

Intrusive basalt, andesite, and microdiorite dikes occur in the Green Mountain unit and the Snowking massif. They are most numerous in the Green Mountain unit and are best exposed on Green Mountain and the 6622 foot peak to the north. At two localities in the Whitechuck unit diabase occurs. Since these diabase bodies were not recognized in the field, their shape is not known.

Field Description

The basalt, andesite, and microdiorite dikes vary from 8 inches to

15 feet in width. Some, but not all, have chilled margins. Occasionally they include fragments of country rock. Contact metamorphic effects are small, even next to dikes which have chilled borders. On the northern Suiattle river road a 10 foot wide dike with chilled margins is exposed, which has slightly hornfelsized the adjacent rock over a distance of about 1/2 inch. On the northeast side of the cirque on the south side of Snowking a pale greenish tan weathering dike of andesite is cut by a later grey weathering dike of microdiorite. One dike exposed on Chaval Mountain has a rather sinuous pattern, and the presence of chilled borders indicates that, unlike most of the dikes in this vicinity, this is not a relict dike.

On Downey Mountain a melanocratic dike is cut by the Downey Mountain trondhjemite. On the main ridge between the east and west peaks of Snowking a melanocratic dike in the Snowking Mountain unit is cut by the marginal, mobilized portion of the West Snowking unit.

Petrographic Description

Basalt, andesite, and microdiorite dikes. These rocks are rather variable in composition and texture, but they do not seem to fall into distinctly separate categories, since intergradations in texture and composition are common.

They contain 35 to 75% plagioclase varying from An 70 to An 30 in composition, except in hydrothermally (?) altered rocks where the plagioclase is more sodic. Normal zoning often occurs, whereas reverse zoning is rarely present. Relatively few of the rocks contain a plagioclase as calcic as labradorite. The plagioclase ranges in size from microlites in the groundmass of some of the porphyritic rocks to fairly large anhedral crystals in the microdiorites. In a few plagioclase-rich microdiorites the plagioclase crystallized before the hornblende, and is euhedral.

The dikes contain 5 to 50% hornblende which varies from brown to green in color. Zoning is quite common. Specimen A-24-1-c from a basalt dike on the knob southeast of Boulder Lake has mostly brown hornblende with a rim which shows a weaker brown color, slightly higher birefringence, and a slightly greater extinction angle than the core. A few hornblende crystals in the same rock have a rim with stronger absorption. Some hornblende crystals in that rock have a rim with green absorption and a higher birefringence than the core. In this case the extinction angles in both zones are the same. Sometimes hornblende grades to a light green or a colorless amphibole without a change in extinction. In specimen B-10-1-a, an andesite from near the summit of Green Mountain, the hornblende is generally brown, but in some cases it has greenish cores. One hornblende grain in this rock has a greenish brown zone intermediate between the core and the rim, both of which are brown. The hornblende in the dike rocks is generally euhedral and varies in size from large to small. In a few rocks it is anhedral and fills the interstices between the plagioclase laths.

Augite occurs principally as small phenocrysts in the chilled margins of the dikes. In the interior portions of the andesite and basalt dikes a few relict grains occur, and usually they are partially altered to hornblende. In one specimen (A-33-2-b from the east end of Chaval) some uralitized hypersthene occurs.

Chlorite, usually penninite, constitutes a trace to 15% of the rocks. It often forms pseudomorphs after hornblende, sometimes in association with carbonate and a light green to colorless (tremolitic ?) amphibole.

Biotite makes up 0 to 20% of the rocks and is usually found in small anhedral crystals derived from hornblende. Sometimes it forms pseudomorphs after hornblende. However, in one specimen (B-16-1), a plagioclase-rich microdiorite from the south side of Green Mountain, part of the biotite occurs as an interstitial filling between the plagioclase crystals. The rest of the biotite of this rock was derived from hornblende.

Secondary epidote and occasionally prehnite are associated with hornblende and its alteration products.

Opaque minerals, mostly magnetite and ilmenite (?), constitute up to 5% of the rocks. Apatite and sphene are common accessories. Some small micropegmatitic intergrowths of quartz and feldspar occur. In a few dikes serpentine occurs in small knots that may represent former phenocrysts of olivine or pyroxene.

Quartz (0 to 5%) occurs mainly as anhedral, rounded xenocrysts, which are sometimes surrounded by reaction rims. In specimen A-24-1-c the reaction rim consists of plagioclase and sphene. In specimen A-27-1-a, a basalt dike from the knob northeast of Boulder Lake, the reaction rim is made up of hornblende and augite. One dike contains quartz xenocrysts surrounded by chlorite, which is probably retrogressive after hornblende.

Just south of the east peak of Snowking Mountain a cataclastically and epizonally metamorphosed, mineralized dike occurs (specimen C-33-3). It contains 60% fine grained, anhedral actinolite which locally also forms in segregation pods and veinlets of coarser grains. Plagioclase and quartz make up 35% of the rock. Sphene constitutes 5% of the rock. Light yellow green clinochlore occurs in veinlets and as radial growths in small cavities. Tiny, anhedral grains of relict brown hornblende are found. Epidote, malachite, and an opaque mineral complete the rock.

Another altered dike (specimen C-33-2-a) from south of the east peak of Snowking contains about 35% of the zeolite thomsonite (?), which appears to have been derived from the alteration of plagioclase. A light green amphibole with an extinction angle of 19° occurs in small, anhedral to euhedral grains. Medium sized, anhedral biotite (20%) sometimes forms pseudomorphs after the amphibole. Plagioclase, epidote, and opaque minerals each constitute 5% of the rock. One grain of relict augite was observed. Sphene is an accessory.

The textures of the dikes vary from porphyritic with a glassy or microcrystalline groundmass to a medium grained, rather distinctive texture in which euhedral hornblende crystals are included in plagioclase grains. The dikes which have this latter texture are referred to as microdiorites. In one dike exposed on the northern Suiattle River road, specimens from both the chilled margin and the interior were examined. The margin has a porphyritic texture and the interior a microdioritic texture, so probably all gradations between the two occur. The textures in the various specimens studied at least partially depend on the thickness of the dike and the position of the sample within the dike.

Diabase. Two specimens of basic igneous rock collected within the outcrop area of the Whitechuck unit have well-developed diabasic texture. Specimen D-36-2 is from about 1300 feet elevation on the south side of the Suiattle River, just west of the junction between the roads to Darrington and Concrete. It contains plagioclase (40%) with a composition of An 55 and some normal zoning. The plagioclase occurs as small to medium sized, euhedral laths. Small to fairly large, anhedral augite crystals (40%) include the plagioclase. Deuteric oxyhornblende makes up 20% of the rock. It has an extinction angle of 8° and a pleochroism: Z=brownish olive, Y=yellowish green, and X=tannish yellow. It occurs in small, anhedral grains. Opaque minerals are the accessories. The texture is ophitic.

The other dike examined is more altered and contains only relict augite. The augite is altered to greenish brown hornblende with an extinction angle of about 18^{o}, and to light yellowish green serpentine.

Conclusions

The age and origin of the late igneous dikes is not certain. Possibly dikes of more than one age may be present. Those dikes which have chilled borders must have been emplaced at some time after the metamorphism. More detailed examination of each individual dike with special attention to its borders might help to ascertain how many of them were definitely intruded in post-metamorphic time. In a fine grained rock the presence of chilled borders might be overlooked in the field.

The fact that the mobilized rock of the West Snowking unit cuts one of the dikes indicates that this dike was emplaced before or during metamorphism; for the observed facts show that the mobilization of the West Snowking unit was a result of the metamorphic and tectonic processes active during the main metamorphism. The microdiorites have the same texture and composition as the relict dikes in the Chaval unit of the Snowking massif, (see Chapter IIIC3biv). This suggests that many of the dikes described in this chapter may be related to the relict dikes. Perhaps the intrusion of these dikes took place during a late stage of or immediately after the metamorphism.

However, the existence of considerable Tertiary volcanism of similar composition in the Cascades, especially to the south, suggests that some of the dikes may be of Tertiary age.

STRUCTURE

Structures of the Epizonal Rocks of the Whitechuck Unit and the Cascade Valley Schist Zone

The epizonal rocks have a foliation which is well developed in some places and poorly developed in others, depending on the amount of platy minerals in the rock. The phyllites always have excellent foliation, whereas the greenstones have none. During folding the phyllites acted very incompetently, and in many outcrops of the contorted phyllites it is impossible to see any consistent trends. Some greenschists are also contorted, but much less so. In several localities where bedding was observed, it is parallel to the foliation. The general trend of the foliation is northwest, but many variations occur. Direction and steepness of dip vary considerably. Not enough closely spaced attitudes were taken to map the complex structural details. The variations might be considered local contortions superposed on the regional structure. Occasionally greenstone contains variously oriented shear planes.

Lineation is common, and it is most often formed by small crinkles in the foliation planes. In outcrop A-46-1 on the ridge west of Jordan Creek two intersecting foliations form the lineation. In the logged area west of Boulder Creek the rock in outcrop A-56-1 contains two lineations. One consists of coarse pencils formed by isoclinal drag folds. The other is caused by small crinkles in the foliation planes. The foliation strikes N 70° W and dips vertically, and the drag folds plunge 28° SE and the crinkles 73° NW. The lineation in the epizonal rocks trends northwest, except in rare outcrops. The direction and steepness of its plunge is not at all uniform. The lineation is b lineation because it parallels the

PLATE XXXIX

Fig. 1 Typical contorted structure in the phyllites of the Whitechuck unit. On the north end of the ridge west of Illabot Creek.

Fig. 2 Close up of the outcrop in Fig. 1.

northwesterly regional structural trend and it is partially formed by the axes of minor folds.

Later shears occur in scattered places throughout the area. They have in general a northeast trend and dip fairly steeply to the northwest.

The attitudes of minor folds were measured at outcrops where they seemed to be systematic. Their axial planes strike northwest, but their plunge varies.

Structures of the Mesozonal Rocks of the Green Mountain Unit,

the Cascade Valley Schist Zone, and the Illabot Creek Schist Zone

Foliation in the mesozonal rocks is well developed and more regularly aligned than in the epizonal rocks. Where foliation and bedding were observed they are parallel. Small isoclinal folds occur at numerous localities scattered throughout the area.

The foliation generally strikes northwest and dips to the southwest. However, large and small folds cause deviations from the regional trend. Because of the wide spacing of traverses even the larger structures cannot exactly be delineated. A rather sharp crested, northwesterly plunging anticline crosses the Horse Creek-Downey Creek ridge just south of the col south of Buckindy. Along the ridge of Huckleberry Mountain and the ridge from there north to Mt. Chaval the schists, migmatites, and gneisses are concordant with and dip steeply under the quartz diorite of the Chaval unit of the Snowking massif. Thus the Chaval unit in that area seems to occupy the trough of a broad syncline which plunges steeply to the northwest. Sparse outcrops along the Suiattle River roads indicate that here the syncline narrows. The trough of the syncline crosses the road where the Huckleberry Mountain trail begins.

PLATE XL

Fig. 1 Fold in banded garnet-biotite-hornblende schist overturned to the west in the Green Mountain unit on the south ridge of Buckindy Mountain.

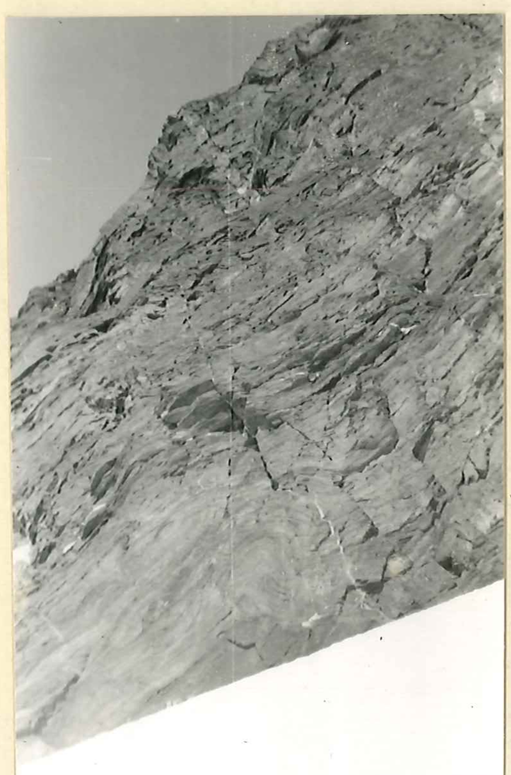


Fig. 2 Fold in amphibolite of the Green Mountain unit on the southern part of Buckindy Mountain.

Along the ridge from the mouth of Downey Creek to the summit of Downey Mountain an anticline and a syncline were observed to trend across the ridge. Their axes strike about N 20° W and plunge about 25° to the northwest.

In the northern part of the area the foliation is generally concordant with the border of the Snowking massif. In the thin band of mesozonal rocks adjacent to the massif the foliation dips steeply under the massif west of Boulder Creek and steeply to moderately away from it east of Boulder Creek.

In the mesozonally metamorphosed portion of the Marblemount quartz diorite and the quartzitic schist at the head of Irene Creek two foliations occur. One strikes northwest and parallels the general trend of the northern margin of the Snowking massif. The other strikes north or slightly east of north, and it parallels the border of the Snowking massif where that body bulges out to north and northeast on the west side of upper Irene Creek.

On the south slope of the Cascade River valley west of Kindy Creek all the dips observed are to the northeast, but they vary from almost horizontal to almost vertical. Perhaps in that area the structure is a northeasterly dipping homocline with superposed, rather open minor folds.

In the Illabot Creek schist zone the few attitudes observed strike to the northwest and parallel the trend of the Illabot Creek valley. They dip steeply to the northeast.

Lineation is common in the mesozonal rocks, and it is due either to small folds or the alignment of amphibole needles in the foliation planes. In detail its attitude is variable, but the overall tendency is for a northwesterly strike and plunge. The plunge is gentle to moderate except in the Illabot Creek schist zone where it is steep in the two localities in which it was measured. Since the lineation is parallel to the northwesterly regional structural trend and it is partially formed by the axes of minor folds, it is b lineation.

Some jointing occurs in the mesozonal rocks, but the few attitudes measured do not fall into any definite pattern. At two localities joint sets occur that strike perpendicular to each other. Although these two localities are adjacent, no correspondence between the joint sets exists.

Structures of the Migmatite Zones and in the Gneissose and Directionless

Granitic Rocks of the Snowking Massif

The gneissose granitic rocks have foliation formed by biotite flakes or clusters and lineation determined by the alignment of hornblende crystals. Foliation in the granitic rocks occurs in the migmatite zones, in the Snowking Mountain unit on the Found Creek-Mutchler Creek ridge, in places in the unit of the ridge east of Kindy Creek, at the contact of the Northern unit with the Snowking Mountain unit, and in the Chaval unit. The gneissose structure is generally concordant with the northwesterly regional structural trend. At the contact of the Snowking massif on the Found Creek-Kindy Creek ridge and at the head of Sonny Boy Creek the foliation in the gneiss turns sharply and takes on a northeasterly trend, which is perpendicular to the strike of the contact. This bend might be due to some lateral movement along the site of the contact before or during an early stage of the emplacement of the Snowking massif.

Late shear zones were observed in the directionless granitic rock. Some northeasterly trending late shears occur in the Buckindy unit. They are believed to follow zones in which paracrystalline and late paracrystalline shearing and some metallization took place. Reconnaissance observations indicate that this shearing is not a local feature. These zones or a parallel series of zones appear to extend to north of Cascade Pass, a distance of over 15 miles from Buckindy Mountain. In the Northern unit one similar zone occurs on the ridge south of the second Jordan Lake, and it strikes N 24° E.

On the southeast side of the 6000 foot peak south of Razor Back a fault striking N 6° W and dipping 41° NE forms the plane along which a large quantity of rock has slid into the valley of Irene Creek.

Joints are common in the granitic rock, and locally they seem to form a pattern. However, after measuring a joint set at one locality, the author often observed that their orientation gradually changes over a short distance. In one place on the northeast ridge of Snowking aplite dikes are joint controlled.

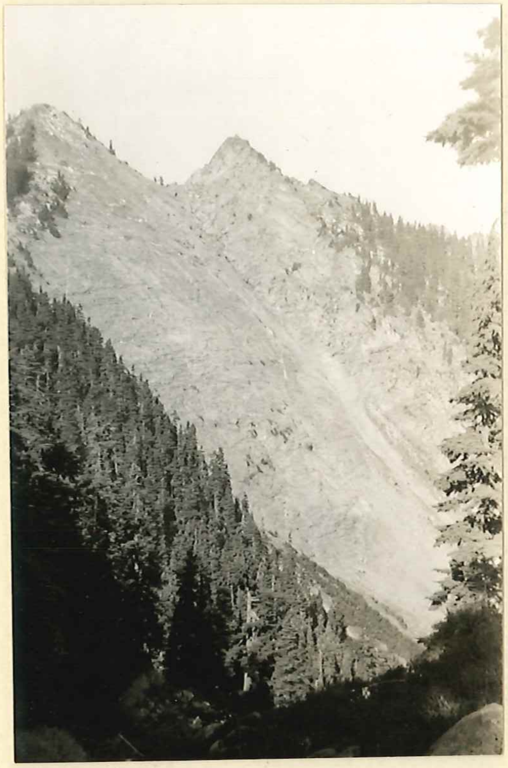
Structure of the Illabot Creek Schist Zone

The Illabot Creek schist zone occurs between the Northern unit of the Snowking massif on the north and the Chaval unit on the south and extends from Bluebell Creek at least to Illabot Lake. It may continue to the ridge between Snowking and Buckindy at the head of Illabot Creek valley, where katazonally metamorphosed rocks occur in a zone only a few hundred yards wide.

The rocks in the zone strike parallel to the northwesterly regional trend, and they dip steeply away from the Chaval unit and under the Northern unit of the Snowking massif. Thus they are probably not a part of the lower plate of a thrust of which the upper plate is composed of the granitic rock of the Snowking massif. No contacts between the Illabot Creek schist zone and the Snowking massif were observed. However, float on the ridge east of

PLATE XLI

Fig. 1 Recent slide controlled by fault plane in the granitic rock of the Northern unit of the Snowking massif on the 6000 foot peak south of Razor Back



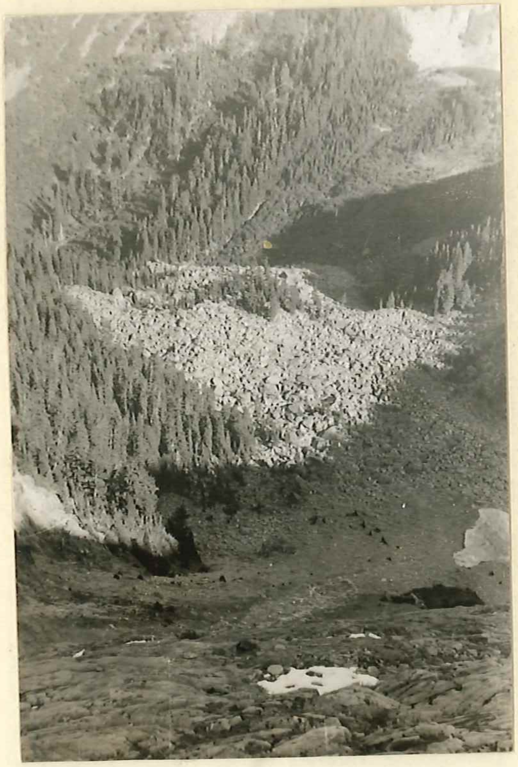


Fig. 2 Talus in valley of Irene Creek from slide on the 6000 foot peak south of Razor Back. Slabs in foreground are essentially the fault plane.

Arrow Creek suggests that there the ortho-amphibolites may grade into quartz diorite of the Chaval unit. No such indication of a gradational relationship between the schist and the granitic rock was seen on the ridge east of Bluebell Creek.

On the basis of the very few facts known about this zone any explanation for it must be purely hypothetical. Perhaps it is a small-scale counterpart of the Cascade valley schist zone or the Green Mountain unit. If its contacts with the granitic rocks were exposed, we might be able to make an analogy, if any is possible.

Contacts of the Snowking Massif

Northern Contact

The exact nature of the northern contact of the Snowking massif is not obvious in the field. Both field and petrographic data have to be considered to arrive at an interpretation.

Description of the Contact

The northern contact of the Snowking massif trends about N 70° W from the head of Sonny Boy Creek to the head of Irene Creek. At the head of Irene Creek it turns to N 30° W for about a mile and then to N 20° E for about 1/2 mile. Then it rather abruptly changes to N 60° W and after that forms a gradual arc from Razor Back to west of Jordan Creek. On the Jordan Creek-Illabot Creek divide field observations indicate that locally the contact trends N 10° to 20° W, yet the contact zone as a whole has an overall northerly trend on the west side of the divide and a northeasterly trend on the crest of the divide. Thus it has a zigzag pattern.

West of Boulder Creek the contact dips steeply southward. South of the

Illabot Creek-Jordan Creek ridge it is not accessible and probably not exposed in the dense forest of the Illabot Creek Valley. East of the Boulder Creek valley it probably dips steeply to the north and northeast.

Adjacent to the contact intrusive and replacement dikes occur. It is difficult to locate exactly the main contact. In most places it is impossible, due to incomplete exposures.

On the ridge south of Razor Back and on the Illabot Creek-Jordan Creek ridge, inclusions of quartzitic schist occur in the marginal portion of the granitic rock. South of Razor Back some inclusions disappear into granitic rock along their strike. Their orientation is parallel to that of the adjacent schists.

On the northeastern margin of the Snowking massif the nature of the contact is more certain. On the Found Creek-Kindy Creek ridge a narrow zone of synkinematic migmatitic schist and gneiss occurs at the contact. At the contact on the Kindy Creek-Sonny Boy Creek ridge a former migmatite zone has undergone shearing and subsequent recrystallization under static conditions in the mesozone.

Nature of the Granitic Rock Adjacent to the Contact

Adjacent to the contact of the Snowking massif the rock is generally granoblastic east of Boulder Creek, whereas west of Boulder Creek to and including the Illabot Creek-Jordan Creek divide it generally has an igneous type of texture. The quartzitic schist inclusions occur in granoblastic granitic rock south of Razor Back, where they are best exposed, but one was observed in a somewhat sheared igneous-appearing rock on the Illabot Creek-Jordan Creek divide.

Nature and Structure of the Adjacent Schist

A band of mesozonally metamorphosed rocks about 1/4 mile wide adjoins the Snowking massif from the west side of the Illabot Creek-Jordan Creek divide to the head of Irene Creek. At the head of Irene Creek it starts to widen until at Kindy Creek it merges with the mesozonally metamorphosed rocks of the northern side of the Cascade River valley. At the head of Irene Creek part of this band consists of metamorphosed Marblemount quartz diorite, and between that body and the Snowking massif a zone of quartzitic schist occurs. On the Boulder Creek-Jordan Creek ridge float indicates that the Jordan ridge serpentine adjoins the Snowking massif, but because of lack of exposure this relationship is not certain.

Generally the rocks of this band of mesozonal metamorphics, which are quartzitic schists, quartzites, and para-amphibolites, have undergone more shearing during a late stage in their history than the schists and amphibolites of the Green Mountain unit south of the Snowking massif. These rocks are frequently blastomylonites. On the Illabot Creek-Jordan Creek divide the amphibolite adjacent to the granitic rock displays some late shearing, but this shearing is by no means intensive throughout the rocks.

The foliation of the schists is concordant with the contact of the Snowking massif except on the Illabot Creek-Jordan Creek divide where the schists strike N 10-20° W and are parallel to segments of the contact, but where the general trend of the contact as a whole is north and northeast. At the head of Irene Creek in the quartzitic schists and the adjacent portion of the Marblemount quartz diorite two foliations occur. The earlier foliation (s_1) trends about N 60° W and is parallel to the general strike of the contact of the Snowking massif to the south and east. A secondary foliation (s_2) parallels the north and northeast trending portion of the contact, which occurs on the west side of the head of Irene Creek.

On the east side of Irene Creek the second foliation (s_2) occurs only in restricted zones. These zones contain a mineral assemblage which is slightly retrogressive in relation to that in the adjacent rock. Thus s_2 is probably somewhat later than s_1. Adjacent to the contact west of the head of Irene Creek, s_2, which parallels the contact at that locality, becomes more important. On the 6000 foot knob between the lower Granite Lake and the head of Irene Creek adjacent to where the contact was observed, s_2 trends N 15° W. It is difficult to say which foliation is dominant, for many rocks in that vicinity display s_1. The rocks with s_1 strike into the granitic rock. No evidence for a time difference between the two foliations was seen here.

Discussion and Conclusions

Possible hypotheses for the mode of emplacement of the northern portion of the Snowking massif are: intrusion of igneous or mobilized metasomatically derived material, high angle faulting, in situ granitization of the country rock, or a combination of two or more of these processes.

In situ granitization of the country rock took place at the contact on the Kindy Creek-Found Creek ridge. East of Kindy Creek it probably also occurred, but its effects have been modified by later processes. In the vicinity of the contact on the Kindy Creek-Found Creek ridge the granitic rock contains relict structures inherited from the country rock. Outside the contact is a band of mesozonal schist over two miles wide. However, west of Found Creek this band narrows drastically. The author believes that here the rocks of the Snowking massif have definitely moved from their place of origin.

The general absence of intense late shearing along the contact rules out simple post-granitic faulting as a major process in the emplacement of the northern portion of the Snowking massif. However, the blastomylonitic character of some of the quartzitic schists adjoining the contact indicates that they underwent intense shearing during a late stage of their crystallization. On the knob between the lower Granite Lake and the head of Irene Creek and on the Illabot Creek-Jordan Creek ridge some late shearing occurs in the marginal portions of the granitic rock.

From west of Boulder Creek to west of the Illabot Creek-Jordan Creek divide the character of the contact and its adjacent rocks suggests that intrusion may have played an important part in the emplacement of the granitic rock. Along this part of the contact and for a distance of 1 to 2 miles to the south the rock of the Snowking massif has igneous appearing textures, which, after a study of the entire northern unit, are interpreted as having formed during a late stage in the evolution of the rock. This igneous appearing rock was potentially the most mobile portion of the northern part of the Snowking massif. No contacts along this part of the massif are really well exposed.

On the Found Creek-Boulder Creek ridge evidence for intrusion occurs. The granitic rock contains a few rotated schist inclusions, and some intrusive dikes penetrate the adjacent schists. The granitic rock is granoblastic, and considerable evidence for replacement is also found at the contact.

From the head of Irene Creek to the western side of Boulder Creek the Snowking massif is in contact with quartzitic schists which probably all belong to the same stratigraphic unit. Whether or not the quartzitic schists on the Illabot Creek-Jordan Creek divide belong to this unit is uncertain.

In summary, we conclude that west of Found Creek the northern portion of the Snowking massif is a roughly concordant intrusion. Where the granitic rock became liquefied to a considerable extent, intrusion probably started somewhat before liquefaction. From Boulder Creek to Found Creek the granitic rock hardly became liquefied at all, yet it intruded the schists. This movement of rather solid material, which probably took place during a late stage in the regional metamorphism, may account for the blastomylonitic character of many of the adjacent rocks. This movement also caused the second foliation (s_2) at the head of Irene Creek. Some secondary granitization of the quartzitic schists occurred at the margin of the intrusion.

Originally the granitic rock of the Snowking massif was formed by metasomatism of the country rocks, but at its northern edge the granitic rock has moved from its place of origin. Since the intrusion is concordant, the remarkable narrowing of the band of mesozonally metamorphosed rocks west of Found Creek suggests considerable upward movement. The map pattern indicates that the horizontal component of this movement was northward.

Other Contacts

On the ridge between Mt. Chaval and the divide east of Boulder Lake and on the Tenas Creek-Big Creek ridge, the southern contact of the Snowking massif has a band of migmatites adjacent to it. In these localities the migmatite bands are over a mile wide across their strike. South of Bench Lake migmatitic gneiss occurs, but the contact of the Snowking massif was not seen in that vicinity. On the southern part of Buckindy Mountain the contact is tectonic, but whether intrusion or faulting was the process active there is uncertain. On the southwestern side of the massif, float indicates the presence of a migmatite zone between the granitic rock and the Straight Creek fault. On the western side the Straight Creek fault may form part of the contact, but no exposures were found to ascertain this relationship.

Straight Creek Fault

The Straight Creek fault has been named by Joseph A. Vance after a southern tributary of the Suiattle River which follows its trace. In the area he is studying it separates epizonally metamorphosed rocks on the west from warmer-mesozonal schists and gneisses on the east. The fault trends slightly west of north. On Mt. Pugh, 10 miles south of the Snowking area, it is well exposed. At that locality it is a reverse fault which dips steeply to the east. It has a minimum displacement of 4000 feet. (J. A. Vance, personal communication).

The Straight Creek fault extends into the Snowking area. It controls the courses of Grade and Bluebell Creeks and the position of Bluebell Pass. The pass is located at the heads of Bluebell and Grade Creeks and has an elevation of only 3400 feet. It separates the Illabot peaks on the west, which are 5900 feet in elevation, from a mountain to the east which is 6108 feet in elevation. The fault divides the epizonal rocks of the Whitechuck unit on the west from the mesozonal schists of the Green Mountain unit and the quartz diorites of the Chaval unit on the east.

In the Snowking area only one exposure of the fault zone was found. An outcrop of retrogressive cataclastic gneiss occurs 1.2 miles up the Big Creek road from the Suiattle River road. It is inferred that the Straight Creek fault extends at least as far north as Illabot Creek because the courses of Grade and Bluebell Creeks trace a straight line that is a

PLATE XLII

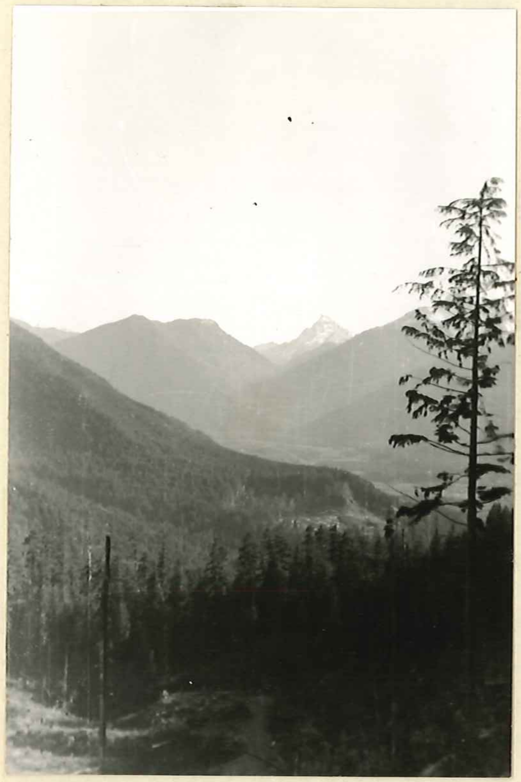


Fig. 1 Looking south along the trace of the Straight Creek fault from the Grade Creek valley up the Straight Creek valley.

Fig. 2 Looking north from Straight Creek up Grade Creek to Bluebell Pass. These features are along the Straight Creek fault.

projection of the known fault line. Another reason for this inference is that Bluebell Creek separates the outcrop area of the mesozonal rocks from that of the epizonal rocks. No evidence for the extension of the fault along its projected strike was found on the ridge three miles north of Illabot Creek. The northwestern border of the Snowking massif appears to trend towards Bluebell Creek from the Illabot Creek-Jordan Creek ridge. A slight change in the strike of the Straight Creek fault would make it trend in the same direction as this contact. However, if the Straight Creek fault forms this border of the Snowking massif, it must have been active at a very different time than to the south. In the Sauk River area the fault cuts some post-metamorphic thrusts (J. A. Vance, personal communication). In the southern part of the Snowking area it is definitely post-metamorphic in age. At the contact of the Snowking massif on the ridge west of the 5200 foot knob west of the upper Falls Lake there is little evidence of post-metamorphic faulting in the granitic rock or the adjacent amphibolite. Perhaps the fault occurs between the mesozonal and epizonal rocks west of that locality. Perhaps it dies out rather suddenly north of Illabot Creek. One hypothesis held during an early stage of this study was that the fault curved around and formed the northern border of the Snowking massif. However, this hypothesis has been discarded because the movements along that contact for which we have evidence took place essentially during metamorphism.

Position of the Snowking Area in the Regional Structural Pattern

The regional structural pattern in the northern Cascades consists of northwesterly trending rocks which contain a core of gneissose and directionless granitic rock. The trend of the granitic core is north-south. However, its western margin forms a zigzag pattern, sometimes paralleling the regional trend of the adjacent metamorphic rocks, and sometimes cutting sharply across that trend. Thus in some places the granitic core projects out into the schists, and in other places schists project into the granitic core.

The Snowking massif is one of these northwesterly projections of the granitic core. The Cascade valley schist zone is one of the southwesterly projections of schist. The Green Mountain unit in the Suiattle valley and to the north is another schist zone that projects into the granitic core.

The Cascade valley schist zone separates the Skagit gneiss and the Chilliwack granodiorite on the north (Misch, 1952a, pp. 12-16) from the Snowking massif on the south. This zone is 3 to 6 miles wide, and it extends at least to the east side of the Cascade crest. It contains two bands of mesozonal schist which enclose on three sides a tongue of epizonal rock. The pointed end of this tongue is at Kindy Creek, and the tongue widens westward. East of Marble Creek epizonal rocks crop out only south of the Cascade River. The northern portion of the Snowking massif has intruded the Cascade valley schist zone and has almost entirely cut out the band of mesozonal rock on the south side of the zone. Also, this intrusion has brought rock of the Snowking massif within 3 1/2 miles of granitic gneiss at Marble Creek north of the zone. This intrusive portion of the Snowking massif is analogous to the western, intrusive contact of the Chilliwack granodiorite that Peter Misch has mapped to the north of the Snowking area (1952a, p. 15).

The southern contact of the Snowking massif cuts across the schists of the Green Mountain unit, the full extent of which is unknown. This unit occurs mainly in the Snowking area, for south of the Suiattle River migmatitic schist and gneiss predominate (Joseph A. Vance, personal communication). This schist zone extends an unknown distance to the southeast.

The Straight Creek fault is somewhat similar to the Deception Pass fault described by Richard M. Pratt from south of the Skykomish River (1954).

GEOLOGIC HISTORY

Age of the Pre-metamorphic Rocks

No fossils occur in the Snowking area because the rocks have been too strongly metamorphosed. No certain inferences as to the age of these rocks can be drawn from lithologic similarity with fossil bearing rocks occurring outside the area because the stratigraphic section of this portion of the Cordilleran eugeosyncline is, as yet, poorly known, and rocks of similar lithologies may have different ages.

Fossils have been found at only widely scattered localities in the northern Cascades. Ordovician fossils have been reported from near Skykomish, which is 40 miles to the south of the Snowking area (Smith, W. S., 1916, pp 562-3). R. A. Daly has found "Upper Carboniferous" fossils in the Chilliwack valley just across the border in Canada (1912, p. 515). Peter Misch has found probable Carboniferous (Pennsylvanian ?) fossils at Twin Lakes north of the Nooksack River about 30 miles northwest of the present area and near Concrete about 10 miles west of the present area (1952a, p. 8). At the latter locality he has found Upper Jurassic-Upper Cretaceous rocks immediately underlying the Carboniferous (personal communication). Ted Danner has found Permian fossils near Arlington about 30 miles to the southwest (1950). R. A. Daly has found "Triassic" fossils at Cultus Lake in British Columbia about 50 miles northwest of our area (1912, p. 517). However, Frebold has re-evaluated the sparse fauna from that locality and has decided on a probably Lower Jurassic age (1953, p. 1232). Peter Misch has found a thick Upper Jurassic and Lower Cretaceous sequence in the area of the Nooksack River North Fork underlain by probable Middle Jurassic volcanics (1952a, pp 9-10; personal communication). Younger rocks occur, but they are definitely later than the main orogeny and metamorphism in this portion of the Cordilleran eugeosyncline. Thus probably pre-orogenic rocks ranging from Ordovician to Lower Cretaceous have been dated in the northern Cascades.

The rocks of the Snowking area are nearest and most nearly on strike with the fossiliferous rocks near Concrete. Yet the stratigraphic relationships are poorly known, and moreover, in that area structural relations between rocks of differing ages appear to be rather complex (P. Misch, personal communication). In the Snowking area the possible occurrence of Upper Jurassic and Lower Cretaceous rocks can probably be ruled out on lithologic grounds. No limestone beds like those containing the Carboniferous fossils at Concrete were found in the Snowking area. No definite correlation can at present be attempted. It is probable that the rocks of the Snowking area are of various ages.

Age of the Main Orogeny and the Regional Metamorphism

No rocks of certain post-orogenic age occur in the Snowking area. The arkoses may be post-metamorphic, but their relationships with the other rocks and, hence, their age is uncertain. Thus it is impossible to date the main orogeny in the Snowking area.

Observations by P. Misch (1952a) elsewhere in the northern Cascades show that an orogeny in which folding, thrusting, and at least some low grade metamorphism took place, definitely occurred in the Middle Cretaceous. An early Mesozoic orogeny may have taken place, but as yet Upper Jurassic-Lower Cretaceous rocks have been found only in tectonic contact with older rocks (P. Misch, personal communication).

Age of the Granitization

The age of the granitization in the Snowking area is essentially the same as that of the main orogeny and the regional metamorphism. However, there is a slight time difference between the maximum intensity of the main orogeny and that of the granitization. The regional metamorphism was mostly synkinematic, whereas the granitization was late-kinematic and post-kinematic. In some of the component units of the Snowking massif it is not possible to determine the time relationships between any possible granitization and the regional metamorphism and orogeny because later processes have erased evidence for granitization.

GLACIATION

General Statement

Glacial observations made in the Snowking area were incidental to mapping the bedrock geology, but in such a region where the dominant process shaping the topography has been glaciation and where a few small glaciers occur even today, the features observed should not be passed over.

Old Till

In a cut on a logging road on the north end of the ridge between Boulder and Jordan Creeks deeply decomposed till crops out. It is at an elevation of 1200 feet above the valley floor in a logged area on a part of the slope that is relatively gentle. The till contains granitic pebbles and boulders up to a foot in diameter. The granitic rocks are weathered to a grus, except for some of the larger ones, which have less weathered cores. It is overlain by a gravel deposit made up of fresh granitic boulders, probably stream deposited during the Wisconsin stage. No other outcrops were found. The degree of weathering most nearly approximates that of the pre-Admiralty till in the Puget Sound region.

Fresh Till

Practically unweathered till crops out in many places on ridge slopes along logging roads. It was noted only in those localities where the cut had remained fresh, and there seemed no danger of confusion with the creeping soil mantle. These deposits had no observable lateral surface expression.

PLATE XVIII

Fig. 1 Weathered granitic boulder in pre-Admiralty (?) glacial till on the Cascade River valley side between Illabot and Jordan Creeks.

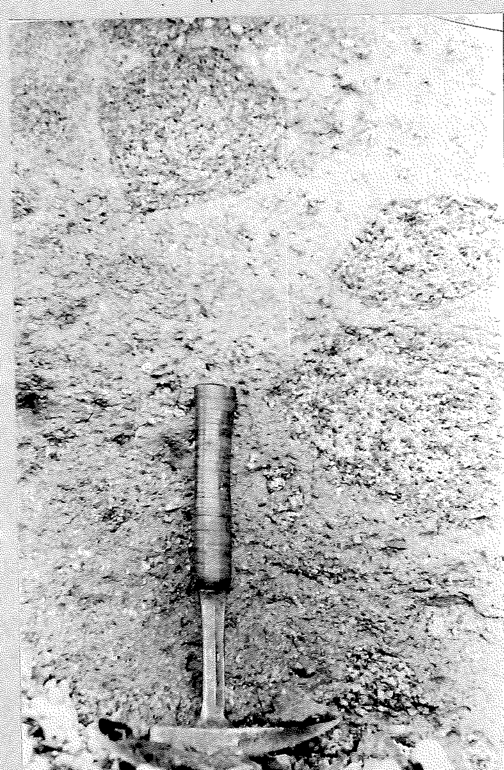


Fig. 2 Glacial till with weathered granitic boulders on Cascade River valley side between Jordan and Boulder Creeks.

TABLE I

OCCURRENCES OF FRESH TILL

LOCALITY	UNDERLYING ROCK	ROCK IN DEPOSIT	DIRECTION OF MOVEMENT
N. side of Suiattle valley about 1 mi. N. of Big Creek, 1400 feet above valley floor	greenstone and phyllite	angular epizonal rounded mesozonal	probably from east
W. part of S. side Suiattle Mt., 2400 feet above valley floor	greenschist	large granitic erratics up to 8 ft. in diameter	from east or north
4800 feet elevation on north slope and on top of 5000 foot knob on ridge W. of Kindy Creek 1/4 mile from contact of Snowking massif	mesozonal schist	granitic gneiss	NE from Snowking
S. side Skagit valley W. of Illabot Creek 2000 feet above valley floor	greenschist phyllite	till and erratic epizonal meta-quartz diorite (Marblemount)	probably from north (down Skagit valley)
Low hills near junction of Sauk River and Skagit River, 1000 to 1500 feet above valley floor	greenschist glaucophane schist phyllite	granitic erratics	from north

Fresh Outwash

On the south side of Suiattle Mountain over 2000 feet above the Suiattle River occurs more than 10 feet of pebbly sand and a few beds of pure sand probably deposited by an ice marginal stream.

The Grade Creek Kettled Terraces

At about 2000 feet in a partially logged area on either side of Grade Creek are kettled terraces composed of sand and gravel. The one on the east side is more uniform in aspect than the one on the west, which is small and highly irregular. In cuts above the terraces torrentially bedded sand and gravel was observed dipping down the Grade Creek at an elevation of 3400 feet between Illabot Peak at 5900 feet on the west and a 6108 foot peak on the east suggests that perhaps the pass was a channel draining meltwater from ice to the north. However, if Bluebell Pass were a channel for glacial drainage, it may have been during an earlier glacial stage, for no rock types definitely derived from the area north of the pass were observed in the deposits. Most of the rocks are greenschists from the Illabot Peaks area, indicating the deposits were probably derived from outwash from local ice on the Illabot Peaks. Even the mesozonal rocks forming the east side of the Grade Creek valley are absent. Cirques of any size are not found on the east side of the Grade Creek valley. Yet the volume of the terraces seems considerable to have been derived from such a small drainage area. The terraces appear to have been built marginal to wasting ice in the lower Big Creek valley.

Deposits Along the North Side of the Suiattle River

Along the north side of the Suiattle River bedded sands and gravels are visible in road cuts.

At the mouth of the Sulphur Creek valley is a sloping surface above the present creek bed. That this is a fan is shown by an exposure in a road cut of coarsely bedded sands and gravels derived from the Sulphur Creek watershed. Topographically below that exposure is another road cut .1 mile away displaying sand and gravel carrying volcanic rocks from Glacier Peak.

At Downey Creek occurs another fan with a gently sloping surface about 100 feet above the road. Some large road cuts expose gently dipping coarse sands and gravels from the Downey Creek drainage area. Below the Downey Creek fan, cropping out between the road and the river, are 20 feet of intercalated coarse and fine sand, the coarse sand containing pebbles and boulders. The fine beds display both torrential and graded bedding, and the coarser material is mainly derived from Glacier Peak.

Along the road west of Downey Creek are interbedded sands and gravels with Downey Creek material predominating and very minor Glacier Peak contributions present.

Existing Glaciers and Present Moraines

Small glaciers exist on the high peaks of the area. Snowking itself probably has more ice on it than any other mountain of similar altitude in the Cascades with the possible exception of Bacon Peak. It has a glacier on the northeast side extending along the ridge for a mile and for 1/4 mile downslope. On the north side the extent of the ice is greater than indicated on the topographic map, and a glacier fairly well mantles the mountain between 6000 and 7000 feet. A small, flat, dead-appearing glacier fills the bottom of a cirque on the south side. The

PLATE XLIV

Fig. 1 Deglaciated slabs and recent moraine on the northeast side of the ridge southeast of the southeast peak of Snowking. Note that the fresh moraine is adjacent to mature alpine zone trees

Fig. 2 Recent moraine on the north side of the east part of the Chaval ridge.

relatively large amount of ice on this mountain can be accounted for by its position unprotected from storms by any ridges of comparable height to the west and the fact that it consists of a northwest trending zigzag ridge continuing over a distance of four miles without falling below 6500 feet in altitude. A large amount of rock flour suspended in the Found Lakes below the northern glacier and in a pond uncovered by retreat of the northeastern glacier indicates that at least the northern and northeastern glaciers are active.

The cirque glacier on the south side has just retreated from a very fresh moraine at the outer edge of the cirque floor leaving a segment of ice adjacent to the moraine sheltered by it from the sun.

The northeast glacier has retreated about 1/4 mile from a fresh moraine which stands next to alpine fir of the size characteristic of those trees on slopes of that elevation and orientation showing no signs of recent glaciation. The moraine is at approximately 5000 feet; the ice now terminates at 6000 feet. However, the upper edge of the glacier is much higher than indicated on the topographic map and is from 6500 feet to 6800 feet. The recent moraines extended east along the spur from the southeast peak of Snowking to where it starts declining sharply, far beyond the area of the glacier as mapped in 1897-99. In September 1953 the upper part of the northern and northeastern glaciers had a thick covering of snow.

A small patch of residual ice is present on the north side of the 6735 foot peak at the head of Boulder Creek.

On the north side of the 6700 foot peak between Buckindy and Snowking is found a small remnant of a former glacier whose previous extent is indicated by a recent moraine at nearly 5000 feet. The fact that in September 1953 this small glacier was quite free of neve suggests that ablation is

PLATE XLV

Fig. 1 Moraine dammed lakes; the first and second Jordan Lakes.

Fig. 2 Glacier on the northeast side of the 6700 foot peak on the Buckindy-Snowking ridge photographed from its lateral moraine.

exceeding accumulation.

On Mt. Buckindy are two hanging glaciers, in one of which the ice in the lower portion has become detached from the upper part of the glacier by melting. At the head of Goat Creek on the southeast side of Buckindy is a glacier which from a distance appeared quite vigorous, large, and well broken up to a degree unexpected from its small area as represented on the topographic map.

On the north side of the ridge east of Buckindy is a small unmapped glacier with a very marked moraine visible even through a heavy early July snow cover.

On the north side of the east part of the Chaval ridge are recent moraines, but the glacier that formed them has melted away. There are a few small patches of ice on the north face of Chaval.

There may be other localities in the area where recent moraines are present, but they were not visited late enough in the season to be observed. The fact that the development of vegetation immediately outside the recent moraines is similar to that in localities lacking glaciers and young moraines indicates that these are not recessional moraines but were formed by ice that reached its maximum extent in the recent past. W. H. Mathews (1951) in the Garibaldi area in northwestern British Columbia has shown an ice advance in the early 18th century and for most glaciers a greater advance culminating in the middle of the 19th century. Matthes (1939) in the Sierras has shown that the small glaciers there originated since the climatic optimum, and they are no more than 4000 years old. This post climatic optimum glaciation he calls the little ice age. In the southern Wind River Mountains Moss (1951) has observed very young cirque moraines from which the ice has retreated in the last 100 years 50 to 300 feet in front of small dwindling

PLATE XLVI

Fig. 1 The northeast glacier on Snowking from the west peak. This is the largest glacier in the Snowking area.

Fig. 2 Glacier on the east side of Buckindy at the head of Goat Creek. Photo from the 7000 foot peak at the head of Milt Creek.

glaciers. Ray (1940) in the southern Rocky Mountains has a Wisconsin V substage indicated by the formation of protalus ramparts and small fresh moraines that might be correlated with the recent advance. Fryxell (1935) has a photograph of the Teton Glacier in the Grand Tetons of western Wyoming retreating from a recent moraine. Gibson and Dyson (1939) cite moraines up to 200 feet high from which the Glacier National Park have retreated. They estimate that the glaciers were at their maximum extent in 1890. The formation of recent moraines in the Cascades and retreat from them correlate roughly with these similar events elsewhere in the Cordillera.

The several substages of the Wisconsin that have been described in the Rocky Mountains (Moss 1951, Ray 1940) have not been distinguished in the Northwest. That they may exist is indicated by the presence of lower, forest-covered, yet little weathered, moraines in some of the mountain valleys. In the Snowking area they were observed damming the first Jordan Lake at 4150 feet, the second Jordan Lake at 4550 feet, and Illabot Lake at 2550 feet. Higher up southwest of Hurricane Mountain is a dammed cirque lake, Lake Toketie. These are clearly older than the very fresh moraines described above and may correlate with substages III or IV or the southern Rocky Mountains.

Glacial Erosion

The landforms of the area are mostly the result of glacial erosion. The principal drainage is by streams that now lie in rather straight, deep glacial troughs which head in large two storied cirques with floors from 2500 feet to 4000 feet elevation. Often several higher cirques with floors from 4500 feet to 6000 feet are present above the upper end of the trough. Kindy and Downey Creeks are good examples. Some of the cirque lakes are tarns, although many are modified by moraines. Cyclone Lake on the northeast spur of Snowking at 5300 feet is a tarn about 1/3 mile across.

In general the ridges tend to be asymmetrical, especially when they trend east-west or northwest-southeast. In places they are aretes with great cliffs dropping off several hundred feet or more on the northeast and steeply sloping, perhaps crowned by a small cliff, on the southwest. The sharpness of the ridges such as those on Chaval, Snowking, and Buckindy Mountains may be due mainly to mountain glaciation after the Wisconsin maximum of which the recent advance and retreat is the latest episode. Where recent glaciation has not been active the northeast sides tend to have open meadows, while on the southwest at the same elevation there is forest.

CONCLUSIONS

The greenschists and phyllites of the Snowking area underwent typical synkinematic regional metamorphism of the epizone (greenschist facies).

The schists and amphibolites in the Green Mountain unit were metamorphosed at temperatures of the warmer mesozone and, very locally, of the cooler katazone. Metamorphism was predominantly synkinematic, but crystallization lasted somewhat longer than the penetrative rock deformation.

In the mesozonal schists of the Cascade valley schist zone the amphibolites and quartzitic schists adjacent to the Snowking massif were metamorphosed under temperatures of the warmer part of the mesozone. To the west where the mesozonally metamorphosed schists form only a thin band north of the Snowking massif, a rapid gradation to epizonally metamorphosed rocks occurs, whereas to the east where the band is two miles wide the transition is gradual.

North of the Green Mountain unit and south of the Snowking massif is a discontinuous band of migmatitic schist and gneiss, which to the north grade into the granitic rocks of the Snowking massif and to the south into the isochemically metamorphosed schists and amphibolites. Outside this irregular band, the migmatites occur in patches in the schists. The schists contain many replacement dikes and mobilized dikes composed of material of metasomatic derivation; these dikes are genetically related to the migmatites. The migmatites and associated dikes were formed by metasomatism in late-kinematic and post-kinematic time simultaneously with the emplacement of the Snowking massif.

The Snowking massif is a complex plutonic body. Many of its rocks bear evidence of having been produced by late-kinematic and post-kinematic allochemical metamorphism of the country rocks at warmer mesozonal and katazonal temperatures. The country rocks, principally mica schists, amphibolites, and hypersthene diorite have been converted to granitic textured rocks which vary in composition from dioritic to granitic. Quartz dioritic, trondhjemitic, and granodioritic compositions are most common. Metasomatism was predominantly sodic, except locally where late introduction of potash, accompanied sometimes by considerable silica, has been pronounced. In many places silica has been introduced without being accompanied by potash.

In many portions of the massif the rocks have developed igneous-appearing textures during a late stage in their evolution. In certain zones this process appears to have been aided by cataclasis during crystallization, giving rise to porphyry-like rocks of metamorphic aspect and, in a further stage of evolution, to porphyries of igneous aspect. In some places these rocks may have been partially liquefied. These varied porphyritic rocks do not often display intrusive relations with their wall-rock. Movement, if any, has been incipient. In the schists south of the Snowking massif occur intrusive dacitic porphyry dikes, which are interpreted as having been derived by further liquefaction and mobilization of the varied porphyritic rocks.

In the Buckindy unit of the Snowing massif breccias of rheomorphic aspect have formed by cataclasis and recrystallization. These processes probably were accompanied by partial liquefaction. The Buckindy area was a focus of tectonic activity during metamorphism and metasomatism, and none of the rocks have a simple enough history to show the nature of the original material.

The northwestern portion of the Snowking massif has intruded the

Cascade valley schist zone and has cut out most of the mesozonally metamorphosed rocks formerly lying between the granitic rock and the epizonally metamorphosed rocks. A zone 1 to 2 miles wide along the margin of the massif was considerably liquefied, producing a neomagmatic rock. This rock grades into granoblastic rock to the south. The neomagmatic rock appears to be the product of a more advanced stage in the evolution of an originally metamorphic rock.

The Snowking massif is a northwesterly projection of the granitic core of the northern Cascades into the lower grade metamorphic rocks along the regional structural trend. In the Cascade River valley a schist tongue extends far to the southeast into the granitic core. South of the Snowking massif the Green Mountain unit is another southeasterly projection of schist into the granitic core.

In the western part of the area, a post-metamorphic fault (the Straight Creek fault) separates the mesozonal rocks from the epizonal rocks. This fault disappears in the Snowking area north of Illabot Creek.

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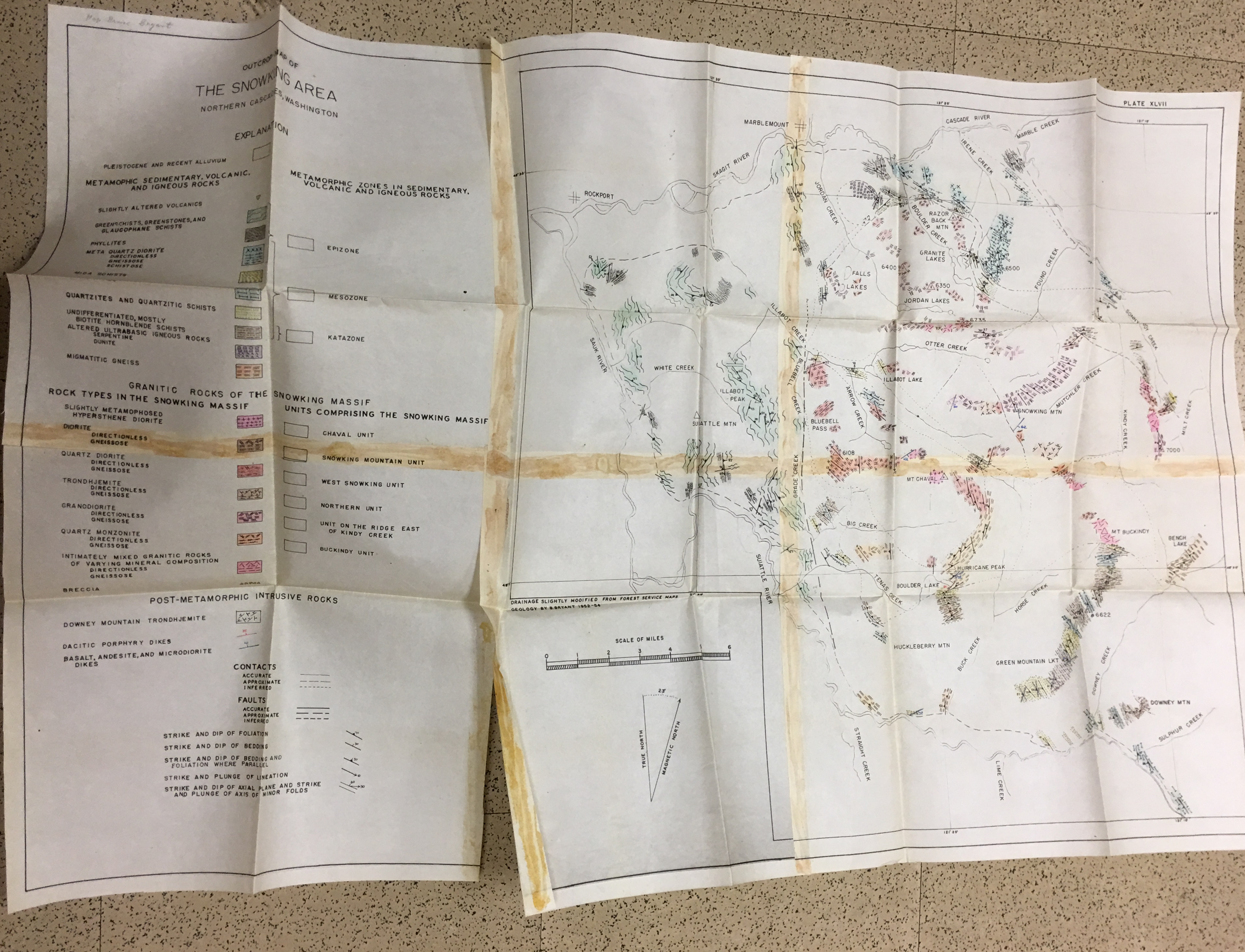

OUTCROP MAP OF
THE SNOWKING AREA
NORTHERN CASCADES, WASHINGTON
EXPLANATION
PLEISTOCENE AND RECENT ALLUVIUM
METAMOPHIC SEDIMENTARY, VOLCANIC, AND IGNEOUS ROCKS
SLIGHTLY ALTERED VOLCANICS
GREENSCHISTS, GREENSTONES, AND GLAUCOPHANE SCHISTS
PHYLLITES
META QUARTZ DIORITE
DIRECTIONLESS
GNEISSOSE
SCHISTOSE
QUARTZITES AND QUARTZITIC SCHISTS
UNDIFFERENTIATED, MOSTLY BIOTITE HORNBLENDE SCHISTS
ALTERED ULTRABASIC IGNEOUS ROCKS
SERPENTINE
DUNITE
MIGMATITIC GNEISS
METAMORPHIC ZONES IN SEDIMENTARY, VOLCANIC AND IGNEOUS ROCKS
EPIZONE
MESOZONE
KATAZONE
GRANITIC ROCKS OF THE SNOWKING MASSIF
ROCK TYPES IN THE SNOWKING MASSIF
SLIGHTLY METAMOPHOSED HYPERSTHENE DIORITE
DIORITE
DIRECTIONLESS
GNEISSOSE
QUARTZ DIORITE
DIRECTIONLESS
GNEISSOSE
TRONDHJEMITE
DIRECTIONLESS
GNEISSOSE
GRANODIORITE
DIRECTIONLESS
GNEISSOSE
QUARTZ MONZONITE
DIRECTIONLESS
GNEISSOSE
INTIMATELY MIXED GRANITIC ROCKS OF VARYING MINERAL COMPOSITION
DIRECTIONLESS
GNEISSOSE
BRECCIA
UNITS COMPRISING THE SNOWKING MASSIF
CHAVAL UNIT
SNOWKING MOUNTAIN UNIT
WEST SNOWKING UNIT
NORTHERN UNIT
UNIT ON THE RIDGE EAST OF KINDY CREEK
BUCKINDY UNIT
POST-METAMORPHIC INTRUSIVE ROCKS
DOWNEY MOUNTAIN TRONDHJEMITE
DACITIC PORPHYRY DIKES
BASALT, ANDESITE, AND MICRODIORITE DIKES
CONTACTS
ACCURATE
APPROXIMATE
INFERRED
FAULTS
ACCURATE
APPROXIMATE
INFERRED
STRIKE AND DIP OF FOLIATION
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF BEDDING AND FOLIATION WHERE PARALLEL
STRIKE AND PLUNGE OF LINEATION
STRIKE AND DIP OF AXIAL PLANE AND STRIKE AND PLUNGE OF AXIS OF MINOR FOLDS
PLATE XLVII
MARBLEMOUNT
CASCADE RIVER
MARBLE CREEK
IRENE CREEK
SKAGIT RIVER
ROCKPORT
JORDAN CREEK
BOULDER CREEK
RAZOR BACK MTN
GRANITE LAKES
6400
6500
FALLS LAKES
6350
JORDAN LAKES
FOUND CREEK
6735
ILLABOT CREEK
OTTER CREEK
SAUK RIVER
WHITE CREEK
BLUEBELL CREEK
ILLABOT LAKE
ILLABOT PEAK
ARROW CREEK
MUTCHLER CREEK
SNOWKING MTN
SUIATTLE MTN
BLUEBELL PASS
KINDY CREEK
MILT CREEK
6108
7000
GRADE CREEK
MT CHAVAL
BIG CREEK
MT BUCKINDY
BENCH LAKE
HURRICANE PEAK
SUIATTLE RIVER
TENAS CREEK
BOULDER LAKE
HORSE CREEK
6622
DRAINAGE SLIGHTLY MODIFIED FROM FOREST SERVICE MAPS
GEOLOGY BY B.BRYANT 1952-54
SCALE OF MILES
0 1 2 3 4 5 6
HUCKLEBERRY MTN
BUCK CREEK
GREEN MOUNTAIN LKT
DOWNEY CREEK
DOWNEY MTN
SULPHUR CREEK
TRUE NORTH
MAGNETIC NORTH
23°
STRAIGHT CREEK
LIME CREEK

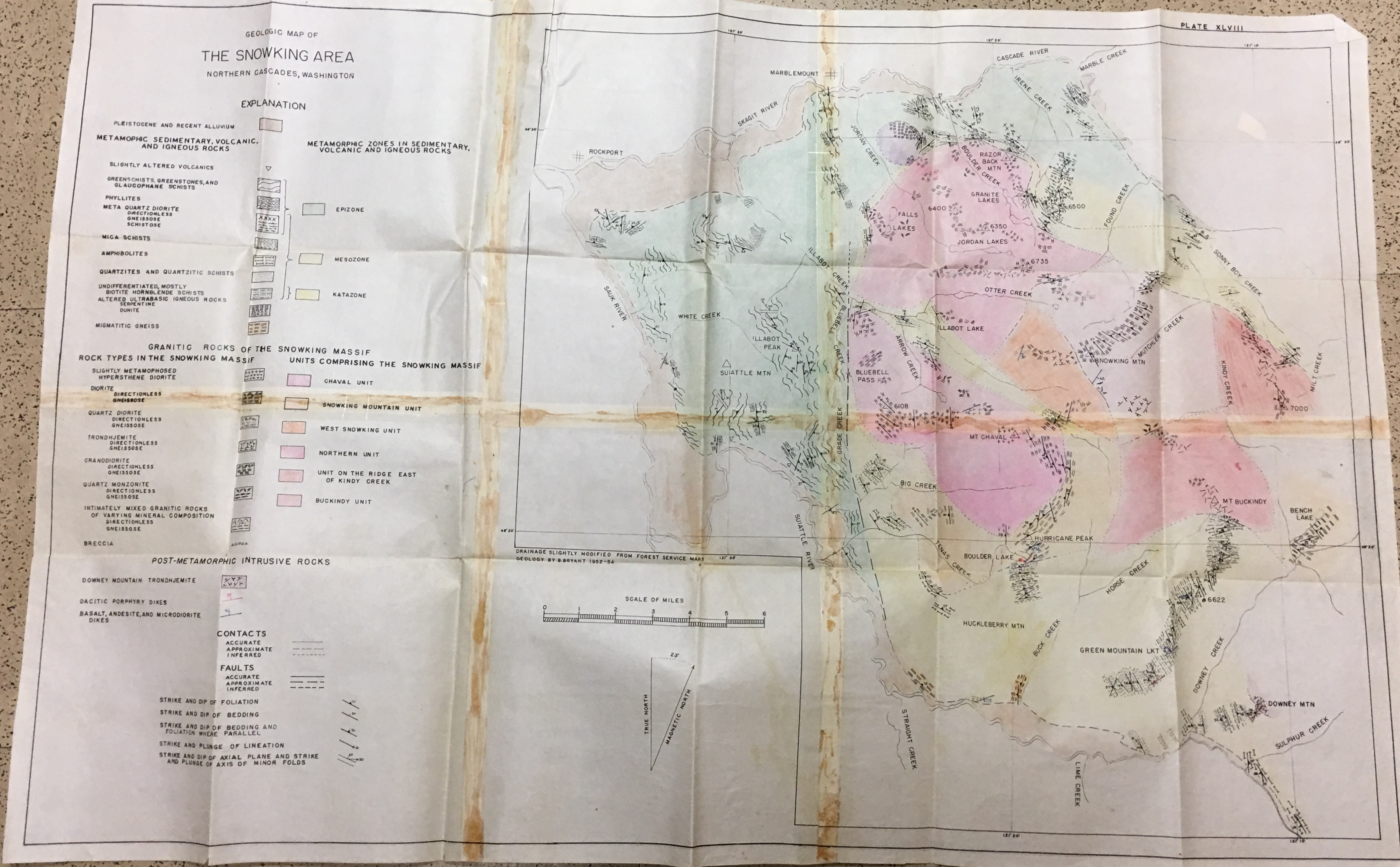
PLATE XLVIII
GEOLOGIC MAP OF
THE SNOWKING AREA
NORTHERN CASCADES, WASHINGTON
EXPLANATION
PLEISTOCENE AND RECENT ALLUVIUM
METAMOPHIC SEDIMENTARY, VOLCANIC, AND IGNEOUS ROCKS
SLIGHTLY ALTERED VOLCANICS
GREENSCHISTS, GREENSTONES, AND GLAUCOPHANE SCHISTS
PHYLLITES
META QUARTZ DIORITE
DIRECTIONLESS
GNEISSOSE
SCHISTOSE
MICA SCHISTS
AMPHIBOLITES
QUARTZITES AND QUARTZITIC SCHISTS
UNDIFFERENTIATED, MOSTLY BIOTITE HORNBLENDE SCHISTS
ALTERED ULTRABASIC IGNEOUS ROCKS
SERPENTINE
DUNITE
MIGMATITIC GNEISS
METAMORPHIC ZONES IN SEDIMENTARY, VOLCANIC AND IGNEOUS ROCKS
EPIZONE
MESOZONE
KATAZONE
GRANITIC ROCKS OF THE SNOWKING MASSIF
ROCK TYPES IN THE SNOWKING MASSIF
SLIGHTLY METAMOPHOSED HYPERSTHENE DIORITE
DIORITE
DIRECTIONLESS
GNEISSOSE
QUARTZ DIORITE
DIRECTIONLESS
GNEISSOSE
TRONDHJEMITE
DIRECTIONLESS
GNEISSOSE
GRANODIORITE
DIRECTIONLESS
GNEISSOSE
QUARTZ MONZONITE
DIRECTIONLESS
GNEISSOSE
INTIMATELY MIXED GRANITIC ROCKS OF VARYING MINERAL COMPOSITION
DIRECTIONLESS
GNEISSOSE
BRECCIA
UNITS COMPRISING THE SNOWKING MASSIF
CHAVAL UNIT
SNOWKING MOUNTAIN UNIT
WEST SNOWKING UNIT
NORTHERN UNIT
UNIT ON THE RIDGE EAST OF KINDY CREEK
BUCKINDY UNIT
POST-METAMORPHIC INTRUSIVE ROCKS
DOWNEY MOUNTAIN TRONDHJEMITE
DACITIC PORPHYRY DIKES
BASALT, ANDESITE, AND MICRODIORITE DIKES
CONTACTS
ACCURATE
APPROXIMATE
INFERRED
FAULTS
ACCURATE
APPROXIMATE
INFERRED
STRIKE AND DIP OF FOLIATION
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF BEDDING AND FOLIATION WHERE PARALLEL
STRIKE AND PLUNGE OF LINEATION
STRIKE AND DIP OF AXIAL PLANE AND STRIKE AND PLUNGE OF AXIS OF MINOR FOLDS
MARBLEMOUNT
CASCADE RIVER
MARBLE CREEK
IRENE CREEK
SKAGIT RIVER
ROCKPORT
JORDAN CREEK
RAZOR BACK MTN
BOULDER CREEK
GRANITE LAKES
FALLS LAKES
6400
6500
6350
JORDAN LAKES
6735
FOUND CREEK
SONNY BOY CREEK
ILLABOT CREEK
OTTER CREEK
SAUK RIVER
WHITE CREEK
BLUEBELL CREEK
ILLABOT LAKE
ARROW CREEK
MUTCHLER CREEK
SNOWKING MTN
KINDY CREEK
MILT CREEK
ILLABOT PEAK
SUIATTLE MTN
BLUEBELL PASS
6108
GRADE CREEK
7000
MT CHAVAL
BIG CREEK
MT BUCKINDY
BENCH LAKE
SUIATTLE RIVER
HURRICANE PEAK
TENAS CREEK
BOULDER LAKE
HORSE CREEK
6622
HUCKLEBERRY MTN
BUCK CREEK
GREEN MOUNTAIN LKT
DOWNEY CREEK
DOWNEY MTN
SULPHUR CREEK
STRAIGHT CREEK
LIME CREEK
DRAINAGE SLIGHTLY MODIFIED FROM FOREST SERVICE MAPS
GEOLOGY BY B. BRYANT 1952-54
SCALE OF MILES
0 1 2 3 4 5 6
23°
TRUE NORTH
MAGNETIC NORTH