GEOLOGY OF THE OLDS MOUNTAIN-CLARK PEAK AREA

JUNEAU VICINITY, ALASKA

by

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

ALASKAN GEOLOGY BRANCH
TECHNICAL DATA FILE

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ABSTRACT

The area under study lies about ten miles east of Juneau, Alaska, and includes the bedded rocks adjacent to the Coast Range batholith, and intrusive rocks related to the batholith.

Deep glaciated valleys and glacially scoured peaks are the major topographic features. The relief is about 3500 feet, and the highest mountain reaches an altitude of 4,453 feet. Remnants of larger glaciers and perennial snow fields cover many of the higher summits, and glacial erratics at elevations above 3100 feet attest to a former thick ice cover.

The bedded rocks are crystalline schists that locally reach katazonal metamorphic rank as indicated by biotite-garnet-kyanite-sillimanite mineral assemblages. The schists are believed to be dominantly a product of regional metamorphism predating the intrusion of rocks related to the Coast Range batholith. It appears, however, that stresses continued to be active during igneous and granitizing activity accompanying the Coast Range orogeny.

The major intrusive bodies are a composite quartz-dioritic batholith and quartz-diorite sills that locally reach a thickness of more than two thousand feet. The sills usually are notably gneissic, and appear to have formed by intrusion rather than replacement. The batholith is a composite body formed by migmatization, replacement, and local fusion. A stressed environment during formation is suggested by a primary gneissic structure. A high quartz content and a paucity

of potash feldspars is diagnostic of the intrusive bodies. In addition to the bodies of quartz-diorite, small sills and dikes of gabbro, quartz-pegmatite, and unmetamorphosed diabase intrude the schists.

Overturned folds in the schists are nearly isoclinal, and some of the folds are large enough to cause repetition of beds in the Clark Peak schists.

Two persistent northwest-trending strike faults of small displacement cut the schists. Two east-trending faults of larger displacement are marked by thick gouge zones locally containing graphite. The rocks near the faults are hydrothermally altered and pyritized, and at least two of the diabase dikes are crushed and hydrothermally altered near one of the northwest-trending faults. Faulting and hydrothermal activity probably continued at least into the early Tertiary.

INTRODUCTION

The Mt. Olds - Clark Peak area lies due east of Juneau, Alaska, in the northeastern portion of the area shown in the Juneau and Vicinity topographic map issued by the U. S. Geological Survey in 1950 (see index map, Plate I). The area is bounded on the north by the divide between Salmon Creek and Lemon Creek. The western boundary of the geologic map is at the approximate eastern edge of the area mapped geologically by W. S. Twenhofel of the Geological Survey in conjunction with his Juneau Gold Belt report (in preparation).

Scope of the Problem

The problem was undertaken to accomplish the following objectives:

(1) to help complete the geologic mapping of the area covered by the Juneau and Vicinity topographic map.

(2) to investigate the intrusive rocks of the area to determine their geologic history and their relation to the Coast Range batholith that forms the basement to the northeast.

(3) to determine the metamorphic rank of the Clark Peak schists, and, if possible, their structure.

Methods of Investigation and Acknowledgements

Field mapping was done directly upon the topographic map; stations were located by reference to the topography as shown on the map and the altitude as determined by an aneroid barometer. Aerial photos of the area were used to supplement the topographic map.

More than 75 hand specimens of rocks were collected from which 65 thin sections were cut. In addition to the specimens collected by the writer, specimens and sections of rocks collected in the Juneau area by W. S. Twenhofel were studied in order to deduce regional relationships and correlations.

Special thanks are tendered W. S. Twenhofel for his support and assistance during the initial phases of the study, and to Dr. V. C. Clauson of the University of Washington for his assistance during the final period of field work.

The work was done while the writer was employed as a geologist by the U. S. Geological Survey, and my indebtedness to the Survey and many of its geologists with whom problems bearing on the geology were discussed is gratefully acknowledged. This paper is submitted as a thesis by permission of the Director of the Geological Survey.

Previous Work in the Area

A. C. Spencer (1906) mapped the western portion of the area on a reconnaissance scale in conjunction with an early report on the Juneau Gold Belt. Charles Palache (1904) examined a thin section of a specimen from the westernmost sill in Granite Basin. Beyond this, no work was done in the area until the years 1946 - 1948 when W. S. Twenhofel extended his Juneau Gold Belt map to cover the area near Granite Basin. The writer has modified Twenhofel's map somewhat, and is responsible for noting and mapping all the faults shown on the geologic map except the Silverbow fault.

Definition of Terms Used

Intrusive. Intrusive is defined as any body of rock emplaced as a fluid at elevated temperature. The quartz-dioritic rocks discussed under the term "intrusive rocks" probably were formed by both magnetic intrusions and neo-magmatic injections, but whether the ultimate sources of these intrusives, as defined above, was a true silicate melt, or a mobilized sediment, is not known. No genetic connection, therefore, is attached to the term "intrusive", and the field relations are the primary consideration in assigning the rocks an intrusive origin. It should be noted, however, that these intrusive rocks singularly are lacking in true relict bedding structures and without doubt were mobile.

Migmatite. Migmatite is defined as a rock containing intimately admixed bedded rock and intrusive rock as defined above. The proportions of the two types differ over wide ranges.

Batholith. Batholith is defined as a body of rock larger than forty square miles in area consisting dominantly of intrusive rock and migmatite as defined above.

TOPOGRAPHY AND GLACIATION

Rugged glaciated topography prevails throughout the region (see Plate 2), and remnants of larger glaciers and perennial snowfields cover parts of the higher ridges (see Figures 1). Steep slopes, and a rigorous climate at higher altitudes, inhibits growth of vegetation, thus giving many bedrock exposures.

An ice sheet covered the highest peaks during the Pleistocene, and produced a rounded topography. Glacial erratics are found on interstream divides above altitudes of 3,000 feet. Prolonged valley glaciation followed and large cirques were cut into the higher mountains. A clue to the length of time that glaciers occupied valleys after the recession of the ice sheet is given by the depth of weathering of the erratics of quartz-diorite. Two of these erratics were examined carefully, and the quartz-diorite was found to be weathered to a depth of more than 1 inch. Boulders of the same rock deposited by valley glaciers are completely unaltered. The bedrock of the interstream areas above the level of valley glaciation also is deeply weathered and considerable residual soil has formed. Solution cavities and sinkholes are developed in the thicker limestones above the level of valley glaciation. Owing to the steepness of the slopes, and the heavy rainfall, the morainal material of both stages of glaciation is largely removed, although the present stream channels commonly flow on reworked glacial material. The headwaters of many of the creeks flow in valleys transverse to the regional strike of the rocks, which seems to indicate that the ice over-rode a previously established antecedent drainage system.

Topographic expression of faults and soft beds was accentuated by the glaciation, and most of the faults are marked by steep, talus-filled cuts (see Fig. 2).

GEOLOGY

The bedded rocks are metamorphosed and originally consisted of clastic sediments and limestones of marine (?) origin. Numerous alternating thin beds differing in grain size and lithology indicate a shallow depositional environment. The clastic beds include a few lava flows now metamorphosed to hornblende-talc schists with a knotty texture strongly suggestive of relict amygdules; the amphibolite-talc schists also contain a few relict augite crystals.

The texture and composition of the schists changes rapidly in the section, and it was beyond the scope of the study to map individual beds. However, an attempt was made to map the thicker marble beds in order to decipher the structure of the schists. Schists derived from clastic beds such as quartzites and graywackes are much more common than schists derived from limestone and limy shales. Individual beds tend to be fairly persistent along the strike, and one limestone bed just west of the mapped area can be traced for at least 4 miles. All of the schists are grouped under the term Clark Peak schist, which is the accepted name for crystalline schists bordering the Coast Range batholith in the Juneau area.

General Petrolography of the Schists

On the basis of thin section study, the writer recognizes five metamorphic rock types derived from different sedimentary rocks:

Group I. The rocks of this group are characterised by varying amounts of primary carbonates, and range from pure schistose marbles to carbonate-bearing hornblende schists and hornblende-mica schists.

Figure 1. View southeasterly from headwall of cirque in Granite Basin showing perennial snowfields, cirque with Cyclopean stairs, and massive weathering of sill 2. Steep cuts in lower left corner mark strike faults.

Figure 2. View northeasterly from upper cirque in Granite Basin showing topographic expression of Olds Mountain fault, and related minor splits. Headwall of lower cirque at right is cut into a massive graywacke, and ridge in upper left corner is quartz-diorite of the batholith.

These rocks are strongly foliated and dragged out magnetite clusters (see Fig. 5), and "snowball" garnets with quartz and biotite crystallized on their "lee" sides indicate that the schists were dynamically metamorphosed. The purer marbles are distinctly foliated, with carbonaceous material forming fine laminae. The absence of cordierite in schists derived from very impure calcareous beds is puzzling, but perhaps stress conditions precluded the formation of cordierite.

Group II. Rocks of this group are classed generally as quartzites, although many impure varieties grade into quartz-mica schists. In thin section the quartz grains are seen to commonly have sutured boundaries. Biotite, muscovite and hornblende in impure quartzites commonly are interstitial to larger quartz grains. Some of the quartzites contain subordinate feldspar, abundant zircon and sphene, and grade into metagraywackes. The quartz and feldspar show pronounced undulatory extinction, and some of the micaceous quartzites show incipient development of a second plane of schistosity across the major schistosity.

Group III. The rocks of this group represent the metamorphic equivalents of graywackes and are coarser in grain than the quartzites. A massive bed of graywacke several hundred feet thick adjacent to the batholith at Olds Mountain locally contains a large amount of migmatite. In this section this rock is seen to consist of approximately 30 per cent each of quartz, plagioclase feldspars, and hornblende, with notable amounts of rutile, sphene, zircon, apatite and magnetite. Schistosity is poorly developed, probably owing to its coarser grain and the possibility that there has been metamorphic segregation of quartz and feldspar.

Another distinctive member of this group is a biotite schist in which the biotite porphyroblasts attain a length of 2 centimeters. In thin section the biotite schist is seen to consist of about 40 per cent each of quartz and feldspar and 15 per cent of biotite. Rutile is conspicuous and in some sections forms up to 2 per cent of the rock. Many rutile needles are clustered in the biotite (see Fig. 4); some of the biotite is pleochroic in reddish browns and is probably a titaniferous variety. The quartz is segregated into bands, and contains rutile inclusions in linear patterns. The intergrain boundaries commonly are outlined in rutile dust. Garnet occurs as small euhedral crystals. The garnet, rutile and quartz are especially abundant in a specimen collected near the Olds Mountain fault at the head of Granite Basin. The rocks near this fault have been hydrothermally altered, and pyrite was introduced.

Group IV. Rocks in this group represent beds with an initial alumina content high enough to form kyanite schists during metamorphism. The kyanite schists have been found at only four localities. Individual layers are only a few feet thick, but contain as much as 50 to 60 per cent of kyanite. In thin section the kyanite shows a poeciloblastic texture with inclusions of quartz, feldspar and biotite. Minute amounts of fine sillimanite locally have formed along crystal boundaries of kyanite. The rock essentially is a kyanite-garnet-andesine-quartz-biotite schist, and is the highest rank of the schists in the area. It is notable that the kyanite schists bear no proven relation to intrusive contacts, although two of the kyanite schists occur close to intrusive bodies. A restricted chemical composition is indicated for the kyanite-bearing beds. Also notable is the apparent tendency for sillimanite to form at the expense of biotite in rocks with appreciable sillimanite.

Group V. The rocks of this group are small in volume but diverse

Figure 3. Hornblende schist. Minerals shown are magnetite (opaque), Quarts (Q) and green-blue pleochroic hornblende (h). Elsewhere in the slide are a few calcite crystals. Section cut perpendicular to the schistosity. 20 X

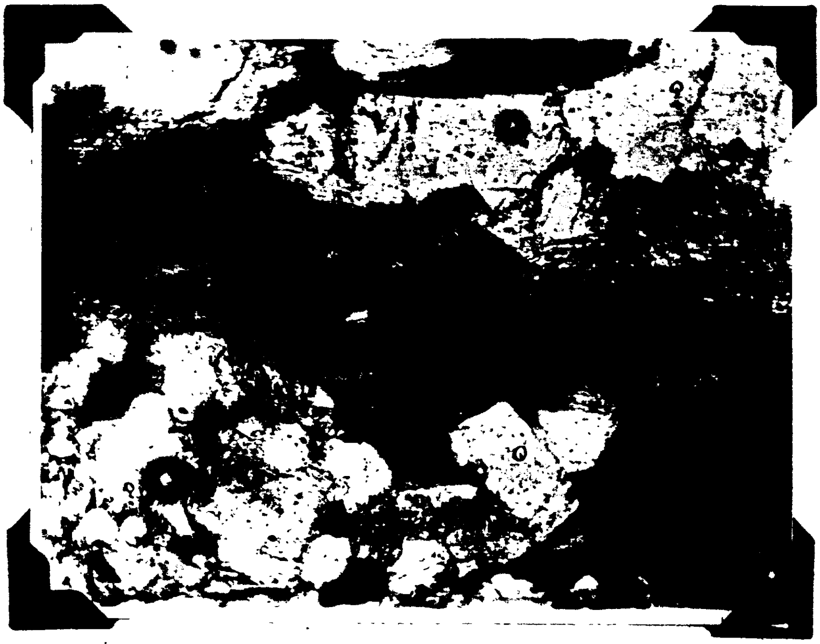

Figure 4. Rutile needles in biotite. Specimen from massive graywacke bed at base of Olds Mountain. Minerals shown are biotite (B), quartz (Q), rutile (opaque needles), and chlorite (C) as an alteration product of biotite. Elsewhere in the slide are large rutile crystals, and much quartz containing abundant rutile dust. About 65 X

in mineral composition; they are the metamorphic equivalents of basic igneous rocks and consist largely of antigorite-talc-hornblende schists. In a small fault block near the mineralized fault on the east side of Olds Mountain, a hornblende schist of this group contains abundant grains of anhedral pleonaste. Most of the rocks of group five contain relict augite crystals (see Fig. 5) and knotty structures suggestive of relict amygdules.

Rank of the Schists

Lower mesozonal or upper katazonal conditions of formation for the highest rank schist are indicated on the basis of the following criteria:

(1) Chlorite is almost completely lacking, except for a few beds near the extreme western margin of the mapped area.

(2) Primary quartz and calcite co-exist with no apparent formation of wollastonite.

(3) Calcite co-exists in contact with oligoclase.

(4) Metamorphic pyroxenes have not been formed.

(5) Kyanite in large amounts has formed in rocks of favorable chemical composition, but sillimanite formation is incipient only.

The writer believes these mineralogic assemblages offer convincing evidence for establishing the highest grade of metamorphism as lower mesozonal to upper katazonal. Although no attempt was made to draw metamorphic zones on the geologic map, an increase in rank in the Clark Peak schists is noted from west to east as one approaches the batholith. The fact that marbles containing primary quartz are not chemically reconstituted in mesozonal conditions suggests that metamorphism occurred under deep-seated conditions where carbon dioxide could not escape. However, in one limy bed between two sills of quartz-diorite

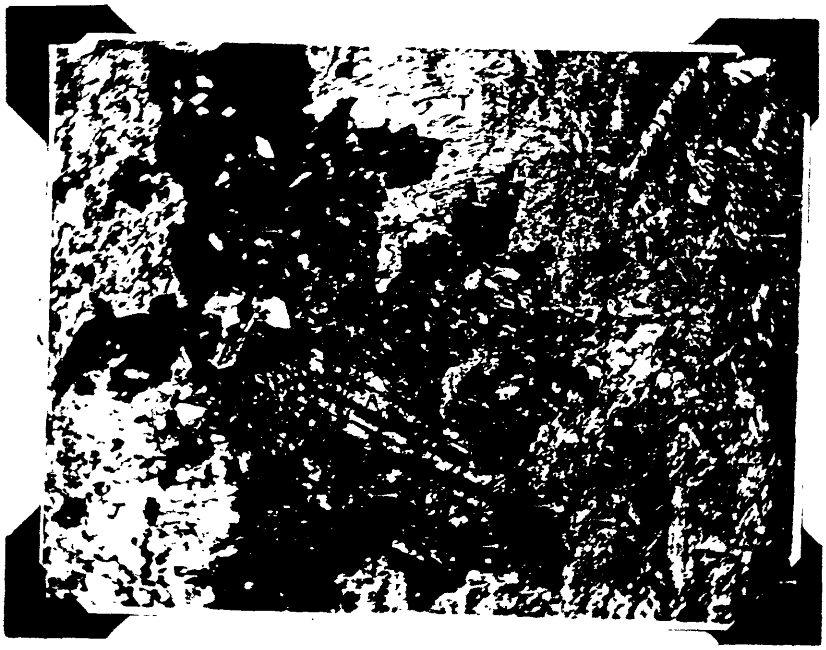

Figure 5. Altered lava (?). Minerals shown are augite (A) altering to uralitic hornblende and magnetite, hornblende (h) pleochroic in green and blue, and talc (T) that also contains some antigorite. This altered basic rock contains the only pyroxenes noted in any rock that predates the diabase and basalt dikes. About 18 X

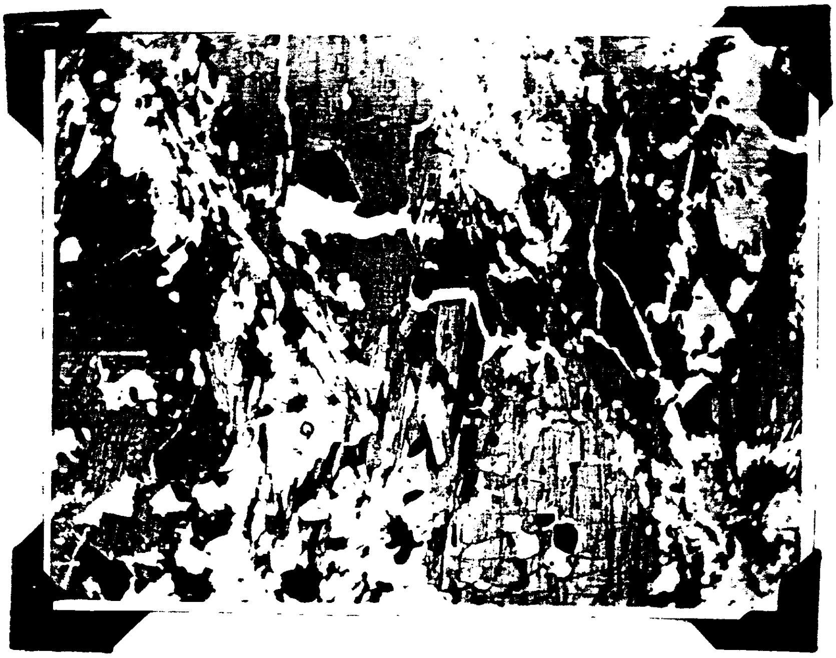

Figure 6. Quartz-diorite from the batholith near Olds Mountain fault showing microscopic shears and incipient cataclastic structure. Minerals shown are hornblende (h), biotite (B), quartz (Q), zircon (Z), and pyrite or pyrrhotite (opaque). Note best cleavages in hornblende and the formation of biotite along the shear planes. About 14 X

abundant diopside is present.

Special Notes on the Schists

Certain notable facts arise from a microscopic study of the schists:

(1) In rocks containing large amounts of biotite and hornblende, increasing grade of metamorphism causes biotite to predominate over hornblende.

(2) Cordierite and andalusite, two common metamorphic minerals, do not occur. Perhaps the stress environment prevented their formation, as both minerals have been thought by some metamorphic petrologists as incapable of resisting shearing stress (Turner, 1950, P. 81).

(3) Strong undulatory extinction in the quartz and feldspar in the schists indicates stress probably continued until after the rocks had cooled from the higher temperatures reached during metamorphism.

(4) Marked lack of chlorite as an alteration product of hornblende and biotite, and the freshness of the feldspars, indicates that metamorphism accompanied a rising temperature. Effects attributable to diaphthoresis are minor.

(5) Metamorphic red garnet is found in rocks throughout the schists, and acted as a stable mineral into upper katazonal conditions.

(6) The schists were subjected to a permeating alteration consisting of albitization, silicification and pyritization locally. Late clear albite and quartz ~~is~~ are ubiquitous. Late fractures contain veinlets of calcite and ankerite, and many beds of schist are pyritized. Locally, pyrite selectively replaced garnet, and marble beds were extensively pyritized, particularly near the faults. This phase of alteration was mainly post-metamorphic.

Structure of the Clark Peak Schists

Folding

In a recent report on the geology of the Alaska-Juneau lode system Twenhofel (1952) disagrees with the structural interpretations for the bedded rocks of the Juneau area that were expressed by Eakin (unpublished report 1922), Buddington and Chapin (1929, pps. 298-299), and Spencer (personal notes, 1926). The present writer is inclined to accept the structural interpretation of the Clark Peak schists of the earlier investigators, and cannot support Twenhofel's conclusions.

In general, the Clark Peak schists strike northwest and dip northeast, although the strike ranges from N. 35° W. to N. 85° W., and the dip from 35° NE. to 80° NE. This constancy of strike and dip at first suggests that the structure essentially is an east-dipping homocline. However, the writer believes that actually the schists form very closely compressed, almost isoclinal anticlines overturned to the west. The axial planes of the folds dip steeply east, and, locally, minor thrust faulting has occurred along the axial planes. Because of the similarity of many beds in the Clark Peak schists this folding and repetition of beds cannot be detected readily except by detailed mapping. Fortunately, vertical exposures approximately perpendicular to the axial planes of the folds exist in at least one place within the mapped area, and at two other localities very close to the mapped area.

On the northeast flank of Clark Peak, a section of schists is exposed over a vertical distance of 800 feet and for a horizontal distance of at least 1,000 feet in the steep headwall of a cirque (see Plate I). In the cirque headwall are exposed almost isoclinal folds involving beds up to 100 feet thick overturned to the west. The distance between the crests and troughs of adjacent folds is at least 500 feet. The folds are asymmetrical with the west limbs dipping approximately eighty degrees east, and the east limbs dipping apprizimately seventy degrees east. In two of these folds, the axial planes are marked by thrust faults with several tens of feet of displacement. The bed nearest the axial plane is stained a very deep red by limonite, and the overlying bed is a massive graywacke that is infolded in such a manner that it crops out over a wide area on the flank of Clark Peak above the cirque. In this area the bedding is obscure and the graywacke superficially resembles a massive intrusive rock. The outcrop width is several times the thickness of the bed, anddefinitely is caused by infolding. Southeast of this exposure the schists contain many small dragfolds whose axis plunge southeasterly.

In unpublished notes Spencer said the structure of the Clark Peak schists could be solved by tracing the "limestone" beds southeasterly. To the southeast, however, the structure is greatly complicated by faults and crosscutting sills (see Plate II). Northwest of Salmon Lake the field relations are much less complex, and the marbles can be traced out with little difficulty. The persistent limestone bed that crosses Salmon Reservoir was found to lie on the east limb of a major fold.

The attitudes of drag folds in the schists is not constant over the area, and indicates a complex structure. In the southeast portion of the area many fold axis plunge southeasterly. On the ridge west from Olds Mountain dragfolds larger than average were seen whose axis plunged eighty degrees N. 30° E., or approximately down the dip of the beds. Elsewhere many dragfold axis were seen to plunge northwest.

Faults

Four persistent faults cut the schists; two are strike faults, and two trend obliquely across the strike of the schists (see Plate II). The strike faults are the more persistent, and each has a known length of more than ten miles, but the oblique faults have the larger displacement. The strike faults are marked by steep talus-filled cuts in which the fault plane is covered. The net displacement along the strike faults is unknown, but probably it is small, although fault displacement may be obscured because the faults parallel, or sub-parallel, the bedding. Whether the strike faults are normal or reverse is not known, but the fact that thrust faulting along axial planes of folds has been noted in the Clark Peak schist seems to favor a thrust origin for the strike faults. The writer believes the strike faults belong to a system of northwest-trending faults that is widespread in southeastern Alaska (Sainsbury and Twenhofel, 1952, unpublished).

The oblique faults trend northeasterly and terminate near the westernmost strike fault. The Silverbow fault swings into the strike fault apparently, but the Olds Mountain fault appears to die out across the strike fault. In the area studied the apparent horizontal displacement along the Silverbow fault is about 3,500 feet as contrasted with 1,400 feet displacement noted by Twenhofel a few miles to the west. Near its junction with the strike faults, the Silverbow fault strikes N. 77° W. and dips 60° N. Striations on the slickensided footwall pitch 45° N. 70° E. in the fault plane. If the striations record the true direction of the net slip, an abnormal amount of movement is indicated, as this direction is trace-slip approximately. It is believed, therefore, that these striations record only the latest direction of movement along

Silverbow fault. This direction of movement, however, is directly opposite to that noted by Twenhofel, who states the north block went west and down (Twenhofel, page 126).

The Olds Mountain fault cuts the strike faults and is not a split from them. The fault only slightly displaces the schist-diorite contact at Olds Mountain, an observation that indicates that the movement was trace-slip or oscillatory. The diorite within one hundred yards of the Olds Mountain fault is granulated to a degree greatly exceeding the regional granulation of the rocks (see Figures 6 and 7).

Locally, the rocks along the faults are pyritized, and near Olds Mountain the diorite was altered and bleached, and pyrite, apatite and rutile were introduced hydrothermally.

Intrusive Rocks

The intrusive rocks comprise dikes and sills ranging in thickness from a fraction of an inch to almost a mile, and ranging in composition from quartz-pegmatite to diabase. Except for the diabases and basalts, the intrusive rocks are metamorphosed so that they are gneissic or schistose. The amount of chemical reconstitution depends upon the time of injection relative to the Coast Range orogeny. The following types, and their metamorphic equivalents, listed with youngest at the top, are recognized:

Intrusive type	Metamorphic equivalent
basalt and diabase	unmetamorphosed
aplite and pegmatite	slightly schistose semi-granulite
quartz-diorite and related types	semi-granulated orthogneiss
albite-monzonite	albite-mica schist
gabbro	hornblendite (metagabbro)

Albite Monzonite. The albite-monzonite is represented by one small area of quartz-mica schist in the southwest corner of the mapped area. The rock is very schistose owing primarily to a high muscovite content, but slight crosscutting relations to the enclosing schists prove its igneous origin.

In thin section the rock is seen to be in an advanced stage of recrystallization with a definite tendency for segregation of the quartz and albite into bands. Muscovite, probably derived in large part from potash feldspars, is interstitial to the quartz and albite, and zircon, sphene and garnet are common accessory minerals. Evidence of a second period of stream is noticeable in the fractured and strained quartz grains and a second generation of fine muscovite oriented across the primary schistosity. A few bits of chlorite are developed, and orthoclase feldspar in rounded grains forms approximately 20 per cent of the rock.

The quartz-mica schist is considered to be derived from an intrusive that predates the quartz-dioritic intrusives entirely on the basis of its greater degree of schistosity.

Gabbro. One sill of metagabbro crops out near the western end of Salmon Creek reservoir. The metagabbro is a massive, slightly schistose rock that consists of large, oriented hornblende crystals in a groundmass of plagioclase feldspar near andesine in composition. The rock apparently is completely recrystallized.

In thin section the metagabbro is seen to consist of green hornblende that poikilitically encloses some feldspar, and interstitial andesine. The accessory minerals are zircon, apatite, sphene and garnet. Garnet grains are small, and are not nearly so well developed as in the schists adjacent to the metagabbro.

Quartz-Diorite and Related Types. The quartz-dioritic intrusives occur mainly as sills locally crosscutting that range in thickness from less than 1,000 feet up to 3,000 feet, and in the intrusive phases of the batholith. For purposes of reference the sills are numbered consecutively 1, 2, and 3 going from southwest to northeast up Granite Basin.

Sill 1 is a fine-grained gneissic rock with a fairly-well defined foliation shown by oriented biotite. The feldspars are crushed, and pyrite is a conspicuous constituent. In thin section the rock is seen to be composed essentially of plagioclase near andesine in composition, biotite, strained quartz, and a small amount of orthoclase. Magnetite, pyrite, zircon, sphene and garnet are minor accessories. Clinozoisite is a common alteration product of the plagioclase.

Sill 2 is much coarser-grained than sill 1, and has feldspar augen up to more than two centimeters in length (see Figures 8 and 9). A foliation is shown by both feldspar augen and biotite. The rock contains much less pyrite and garnet than sill 1, and no magnetite. In thin section the rock is seen to consist dominately of andesine blastocrysts containing abundant inclusions of clinozoisite; quartz in rude veinlets and as aggregates with sutured boundaries containing inclusions in linear or curved arrangement; blue-green pleochroic hornblende and brown biotite with pronounced "birds-eye" structure. Accessory minerals are garnet, sphene, apatite, kyanite (?), and pyrite. Alteration products are slight, but a little chlorite has developed in the biotite, hornblende and feldspar. A few round grains of late, clear albite also are present. Some of the andesine is clear, and contains

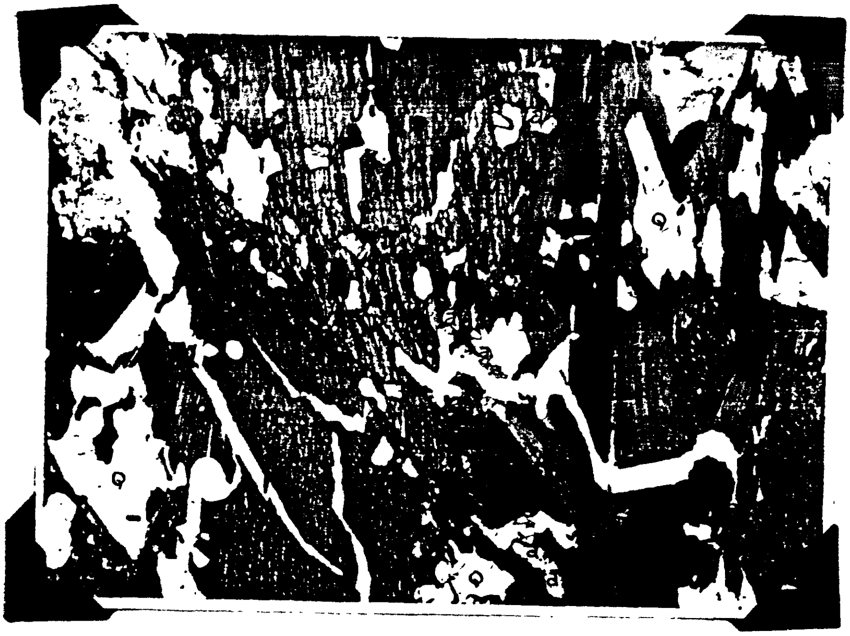

Figure 7. A section of figure 6 enlarged to show details of shearing. Minerals identified are hornblende (h), quartz (Q), biotite (B), apatite (a), and zircon (Z). The opaque mineral is pyrite or pyrrhotite. Apatite is particularly abundant. About 28 X

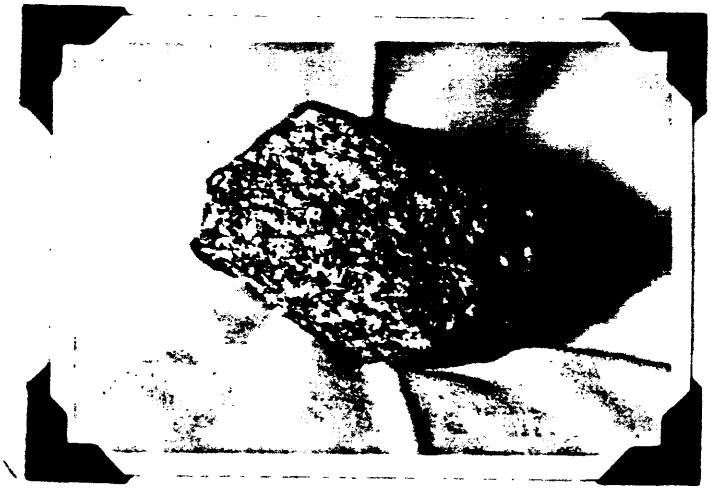

Figure 8. Photograph of quartz-diorite from sill 2 showing augen of andesine with interstitial biotite and hornblende. Photo slightly less than one-half actual size.

small patches of a feldspar tentatively identified as albite. A Rosiwal analysis of two thin sections of rock from this sill is shown in Table I. Table II shows the chemical composition computed for these rocks compared to the average chemical composition of seven specimens of quartz-diorite from the Ketchikan area.

A chemical analysis of rocks S-5B and S-6A probably would show slightly less Na_2O or CaO than computed, because a few crystals of andesine contain a little antiperthite. The variation would probably amount to less than .5% of K_2O. The rock of sill 2 quite clearly is a quartz-diorite, and conforms closely in chemical composition to the quartz-dioritic rocks of the western margin of the Coast Range batholith in the Ketchikan area.

Sill 3 is much less gneissic than sills 1 and 2, and generally is intermediate between the two in grain size. Locally, sill 3 is an even-grained rock with only a hint of foliation, and its intrusive origin is manifest. In thin section the textures are seen to be different for rocks of sill 2 and sill 3. Although some crushing is noticed in all the specimens from sill 3, the rock has an igneous texture, never seen in specimens from sill 2. Zoned feldspars are common and few of the feldspars are porphyroblastic. Clinozoisite is not a common mineral in the feldspars, and there is a greater tendency toward euhedral outline in all the constituent minerals. Large, euhedral sphene crystals are common, and a few magnetite grains are associated with the hornblende. Perhaps the most striking difference in the texture is seen in the graphic and myrmekitic intergrowths of quartz and feldspar in sill 3. The writer would not hesitate to call sill 3 a normal igneous rock in most of its exposures. Perhaps it is more than coincidental that a

TABLE I

Mineralogic Composition of Two Rocks from Sill 2

No.	Qtz	Andesine 40% An	Hornblende	Biotite	Clinozoisite	Garnet	Sphene	Other
S-5B 1/	29.4	52.8	5.5	8.44	2	1	some	apatite pyrite chlorite
S-6A 2/	17.55	54.65	6.25	12.25	7.6	traces	1.7	apatite zircon pyrite chlorite

1/ Specimen from base of sill 2. In thin section shows large prophyroblasts of andesine with inclusions of clinozoisite; oriented, brown-pleochroic biotite, and green-blue pleochroic hornblende. Quartz is grouped and fractured, and exhibits extreme undulatory extinction. Accessory minerals are garnet, sphene, apatite, pyrite; minor pale-green chlorite is the only alteration product. No magnetite shows in hand specimens or in this section. The rock is distinctly granulated in thin section.

2/ Specimen collected 35 feet below top of sill 2. In thin section shows minerals and structures similar to S-5B, with a little zircon. The rock is less granulated than specimen S-5B.

Figure 9. Andesine prophyroblast in sill 2 showing poikilitic texture. Minerals shown are andesine (A), included clinozoisite (C), albite (al), and biotite (B). About 40 X

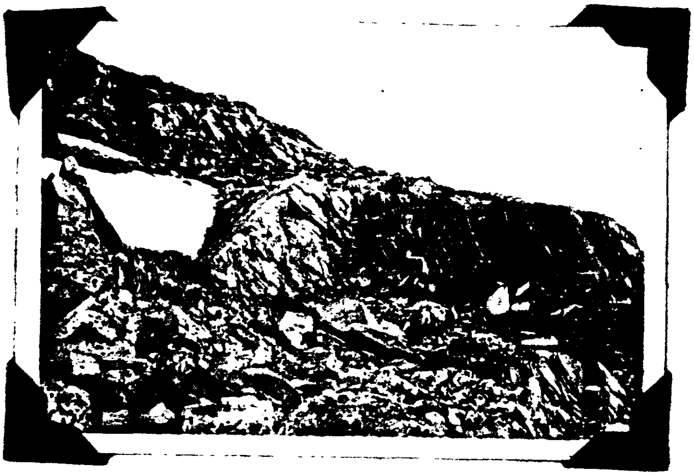

Figure 10. Photograph of an upper contact of sill 2 and overlying hornblende schist. The schist retains its perfect schistosity with no tendency toward a decussate or hornfels texture. The quartz-diorite is very well foliated and contains much quartz and feldspar with subordinate ferromagnesian minerals. Note sharpness of contact.

TABLE II

Chemical Composition of Sill 2 as Compared to Quartz-Diorite of Ketchikan area

Oxide	S-5B 1/	S-6A 2/	Average	X 3/
SiO_2	65.96	56.76	61.36	61.0
Na_2O	3.78	2.75	3.27	3.3
Al_2O_3	16.67	20.65	18.66	17.5
CaO	5.83	10.26	8.05	6.9
MgO	1.59	1.84	1.73	2.4
FeO	1.75	2.32	2.04	2.7
Fe_2O_3	2.30	2.95	2.64	1.6
K_2O	.95	1.30	1.13	2.3
TiO_2	.33	1.23	.78	1.0
MnO	.01	trace	.005	.9
Total	99.17	100.06	99.67	99.6

1/ S-5B is from base of sill 2

2/ S-6A is 35 feet below upper contact of sill 2. The composition of the hornblende, based upon its optical properties, is expressed by the following oxide formulae: $4CaO \cdot Na_2O \cdot 4MgO \cdot 4FeO \cdot Al_2O_3 \cdot Fe_2O_3 \cdot TiO_2 \cdot 12\ SiO_2$.
Biotite composition is expressed by the following oxide composition: $K_2O \cdot 2MgO \cdot Al_2O_3 \cdot Fe_2O_3 \cdot 6\ SiO_2$.

3/ Average chemical composition of seven specimens of quartz-diorite from the Ketchikan area, Alaska, Wright, F. E. and C. W. (1908).

bed of kyanite-sillimanite schist lies beneath sill 3 where it is most massive, and float limestone rich in diopside is particularly common in the same area.

The individual crystals of the greater portion of the dioritic intrusive rocks exhibit metamorphic characteristics. Diagnostic characteristics are as follows:

(1) The feldspars commonly are blastocrystic in outline, and contain myriad inclusions (see Figure 11). The quartz often is grouped into masses too large for primary crystallization, and sutured contacts only are developed among quartz, andesine, biotite, and hornblende. There is no tendency for biotite to rim hornblende as is common in true igneous rocks.

(2) Garnet blastocrysts (see Figures 12 and 13) have acted as "shields" during metamorphism so that biotite and quartz have crystallized preferentially in their "lee" sides (see Figure 14).

(3) Early minerals, such as sphene, garnet and apatite have been broken and dragged out, and then recrystallised into euhedral or subhedral crystals.

(4) Large euhedral clinozoisite crystals are found in the feldspar porphyroblasts, but they are much more common near the centers as if they could not be expelled during the growth of the feldspar. A few large, twinned and zoned clinozoisite crystals occur in all the intrusive rocks (see Figures 15 and 16).

(5) The plagioclases, though twinned, are unzoned (except locally in sill 3), and no order of crystallization could be suggested for the constituent minerals, except for the minor accessories.

An incipient cataclastic structure is prevalent in both schists and intrusive rocks (see Figure 17). The degree of granulation increases near the east-trending faults where microscopic conjugate shears are developed (see Figure 18), but most of the rocks of the problem area and throughout the region to the north are granulated to some degree. Two generations of biotite are seen often with the later generation being oriented at a large angle to the earlier one. The writer believes the gneissic structure was formed during the recrystallization of the intrusive rock under regional stresses prevailing during the Coast Range orogeny, and that the cataclastic structure probably was formed by regional stresses that continued until after the cooling of the rocks from the higher temperatures reached during regional metamorphism. The second generation of biotite is believed to have formed during the development of the cataclastic structure. If this is true, it indicates that there was a re-orientation of forces in the waning stages of the orogeny.

The Coast Range Batholith. Although it is beyond the scope of this paper to describe in detail the various phases of the Coast Range batholith, a few of its features must be described in order to support the conclusion that the batholith is a composite body formed by the replacement of existing rocks, and by large-scale injection of intrusive material. One needs only to stand on Olds Mountain and look back into the batholith to be convinced that it represents, in its major portions, a permeating replacement of the crystalline schists. A rough banding conformable with the regional strike and dip of the schists is distinct, and bands of incompletely replaced schist similar to the one mapped on Olds Mountain can be seen many miles back in the batholith. These schist bands, so far as the writer has seen, never are oriented across

Figure 11. Broken andesine augen in sill 2. Note that all the twinned andesine is part of a single, once-continuous blastocryst. Minerals identified are andesine (A), clinozoisite (C), quartz (Q), and albite? (al?). About 40 X

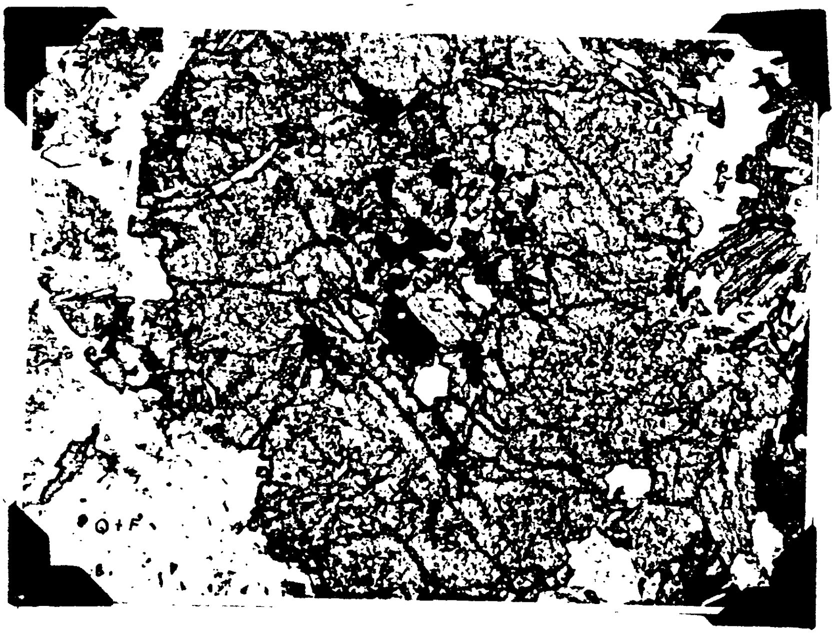

Figure 12. Garnet blastocryst in sill 2. Note concentration of inclusions in center of garnet, circular outline of garnet, and detached garnet fragments. Minerals identified are garnet (G), a chlorite (C) with peculiar blue interference colors, biotite (B), and mixed quartz and andesine (Q & A). Opaque mineral is pyrite. 25 X

Figure 13. Center of garnet blastocryst enlarged to show details of inclusions, or replaced inclusions. The opaque mineral is pyrite, and probably represents a selective replacement of an earlier inclusion. 50 X

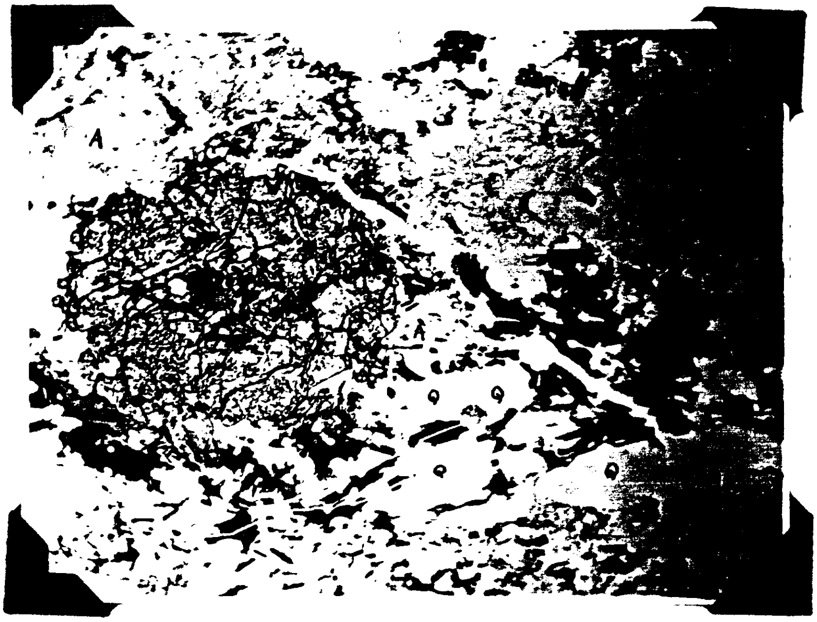

Figure 14, Garnet blastocryst of figures 12 and 13 photographed to show "tail" of biotite crystallized in "lee" side of antecedent garnet. Minerals identified are garnet (G), andesine (A), chlorite (C), hornblende (h), quartz (Q), and biotite (B). 14 X

Figure 15. Zoned, twinned clinozoisite blastocryst in quartz-diorite of sill 1. Note granulation of other minerals. Minerals identified are clinozoisite (C), quartz (Q), andesine (A), and albite (al). 30 X

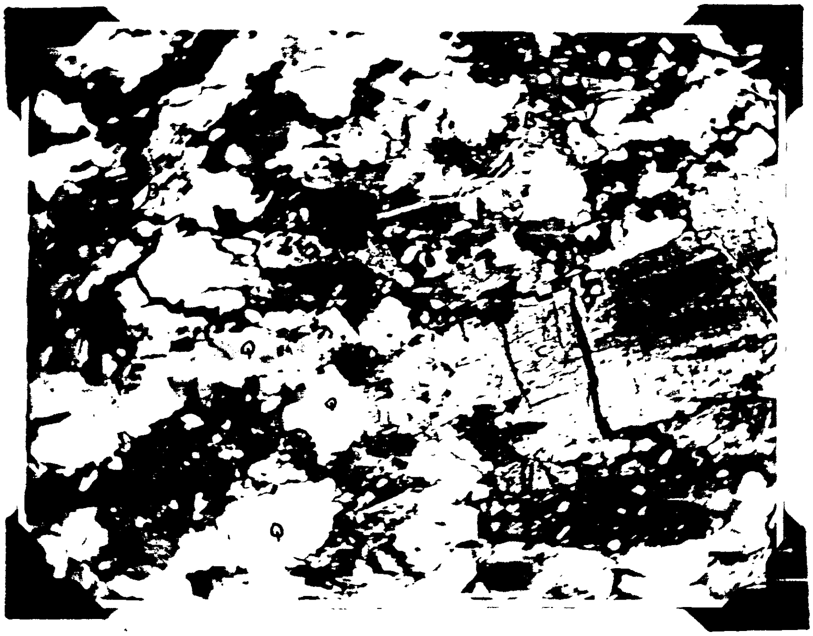

Figure 15. Zoned, twinned clinozoisite in quartz-diorite of sill 2. Note extreme granulation of all minerals except the clinozoisite, which is broken. Specimen bears no relation to a fault. Minerals identified are clinozoisite (C), andesine (A), quartz (Q), and biotite (B).

Figure 17. Conjugate shears in quartz-diorite of batholith near Olds Mountain fault. Minerals identified are hornblende (h), quartz (Q), andesine (A), and albite (al). The albite always occurs as late, clear grains.

the regional structures of the batholith. At many places one can walk into the batholith by crossing crystalline schists that grade into a dioritic rock with relict bedding and dragfolds. This dioritic rock grades into massive hornblende-diorite essentially igneous in texture and with no hint of relict bedding (see Figure 19). In other places are found large schist relicts.

To the casual observer the striking preservation of relict bedding on a regional scale tends to obscure the smaller features that prove that much of the batholith was formed from by intrusion. Locally, as on the ridge trending westerly from Olds Mountain, the writer has traversed intensely dragfolded schists that terminate at a sharp intrusive contact. Immediately beyond the contact there are no relict structures, and the foliation of the batholith is constant. In many of these areas, thin bands of schistose material consisting of hornblende, plagioclase feldspar and garnet crosscut the foliation at small angles. Often the foliation of the batholith bends around these bands where they have been thickened or thinned by flowage. The bands in many places are cut by pegmatitic veins and are displaced by the veins. The writer believes the bands represent relict bedding, or schlieren formed from deformed masses of schist. The orientation of the bands in relation to the regional structure is the major reason for believing that they are a relict feature resulting from incomplete replacement of beds of schist. The writer, accompanied by Dr. V. C. Clauson of the University of Washington, examined several exposures of schist of this type in Taku Inlet, a short distance southeast of the mapped area. That the batholith was a plastic mass capable of flowage was indisputable here, but the constancy of strike and dip of deformed hornblende-plagioclase bands refuted an intrusive igneous origin.

Thin sections of massive portions of the quartz-diorite of the batholith show textures similar to the massive portions of sill 3, already described, and certainly suggest an intrusive origin. Locally, however, a blastocrystic texture prevails similar to that of sills 1 and 2. Foliation in the batholith (except near deformed schlieren) is so constant throughout the area mapped that the writer is convinced that it is the result of regional stress acting on a plastic mass rather than preservation of bedding. The abundant intrusive dikes of pegmatite and quartz-pegmatite prove that much of the sialic phase of the batholith was mobile enough to be injected into the surrounding rocks.

The writer believes an objective consideration of the evidence favors the interpretation that although much of the batholith is a result of replacement of schist, a large portion of it was formed by fusion or mobilization of the schists at temperatures obtained under lower mesozonal to upper katazonal metamorphic conditions, and that the regional foliation was impressed upon this plastic mass by stress.

Aplites and Pegmatites. Aplitic and pegmatitic dikes and sills cut all the intrusive rocks and the schists. Locally they were injected along bedding planes, schistosity or foliation of the enclosing rocks, but at other places they transect all planar structures. All gradations exist from aplitic diorites to pegmatites to quartz-pegmatites, and the mineralogical compositions vary widely. The upper portion of Sill 2, where exposed in Granite Basin, is cut by many dikes injected parallel or sub-parallel to the foliation (see Figure 20). Their abundance suggests a genetic association with sill 2, and petrographic evidence supports this conclusion. In thin section, these dikes are seen to be composed almost entirely of albite-oligoclase and quartz with a little microcline, biotite, garnet, and muscovite. Sill 2 also contains a large amount of garnet in this area. Locally pyrite replaces garnet, and the muscovite is oriented as if the dikes had crystallized under stress.

All the late pegmatitic and aplitic dikes in the batholith are thought to be related to a late stage in the formation of the batholith, when much of the sialic material was mobile. The chemical composition of the mobile material varied considerably from place to place, but mainly in the potassium content. On the immediate western boundary of the batholith intensive injection of pegmatitic material produced some migmatite, and the schist inclusions in the batholith also were intimately injected. Because many of the pegmatitic dikes contain accessory minerals such as zircon, sphene, and apatite commonly found in igneous rocks, the writer favors the interpretation that the dikes were injected at elevated temperatures, and possibly were magmatic.

Diabase and Basalt. The youngest intrusive rocks are basalt and diabase dikes that were intruded across the regional strike, foliation, and schistosity of the enclosing rocks in a general northeasterly trend. This direction in general appears to coincide with the master joint system which has the strongest joint oriented northeasterly. Only three of these dikes were seen in the problem area, and all are too small to show on the geologic map, as the thickest one was about 15 feet.

At the east end of Salmon Reservoir are two basalt dikes that intrude the limestone. The dikes have a chill border, and have caused diopside to crystallize in a band a few inches wide in the limestone. The dikes are crushed and broken, presumably by movement along the northwest-trending fault, although the trace of the fault plane is

Figure 18. Same quartz-diorite as figure 17, but showing sheared-off andesine broken up, and with twin lamellae bent. Minerals identified are andesine (A), quartz (Q), and albite (al).

Figure 19. Photograph showing pegmatitic dikes injected sub-parallel to the foliation at the top of sill 2. Dikes tend to parallel foliation in strike, but to crosscut foliation down the dip. White area at lower left is an icefall.

Figure 20. Photograph of a massive intrusive phase of the batholith showing a strong foliation and lineation created by blue-green pleochroic hornblende. Onethird natural size.

beneath the stream gravels a few feet north. In thin section these dikes are seen to consist essentially of microlites of plagioclase feldspar and basaltic hornblende. A few zoned plagioclase phenocrysts with corroded rims occur, and the average phenocryst is labradorite in composition. The rock exhibits a distinct flow banding in thin section, and contains abundant primary pyrite or pyrrhotite.

On the ridge northeast of the reservoir, a diabase dike intrudes the schists. The dike is traceable for a few hundred feet northeasterly down the headwall of the cirque at the head of Salmon Fork. On the ridge top several offshoots from the dike have pushed up the intruded schists, and outcrop in a circular pattern. In thin section the dikes are seen to be a diabase with labradorite laths surrounded by basaltic hornblende. The dikes contain abundant pyrrhotite, and seem to be a coarse-grained phase of the basalt dikes exposed near Salmon Reservoir. These dikes are characterized by basaltic hornblende, abundant primary sulphides, and labradorite. They contain no magnetite. These dikes are correlated with other basalt and diabase dikes mapped in the Juneau area, and considered to be post-Eocene in age (Spencer 1906, p. 19) because they intrude stratified rocks of Eocene age on Admiralty Island, approximately fifty miles southwesterly. The diabase and basalt dikes are not metamorphosed or crushed except near faults.

INTRUSIVE HISTORY

The intrusive history suggested from the study of the rocks of the area is as follows:

(1) Intrusion of gabbroic magma into regionally metamorphosed rocks, presumably during the early stages of the Coast Range orogeny.

(2) Intrusion of magma of monzonitic composition in lesser quantity.

(3) Continued orogeny with local fusion or mobilization of material which approached a quartz diorite in composition, and injection of large amounts of this material into the Clark Peak schists where it solidified under continued, though perhaps intermittent, stress to form the gneissic sills.

(4) Continued orogeny to bring large areas of bedded rock, exemplified by the batholith, to a plastic state, and local fusion of sialic constituents to give rise to pegmatites and aplites that were injected into the surrounding rocks at an elevated temperature, and into residual schist areas in the batholith. No large scale transfer of molten or mobilized material in the batholith is visualized.

(5) Cooling of the rocks from the temperatures reached during regional metamorphism under continued stress to produce a granulation in all the rocks.

(6) Injection of basaltic and diabasic dikes in the early Tertiary along tension joints in the rocks. The regional stresses were abated by the time of this intrusion, although some movement along the northwest-trending faults probably post-dates the dikes.

(7) Continued vertical uplift and erosion to expose at the surface the dioritic rocks intruded at great depth. Faulting may have continued concomitantly with uplift into Recent time.

Age of the Dioritic Rocks. The Coast Range diorites are considered by Buddington and Chapin (1929, p. 173), by Spencer (1906, p. 11), and by Knopf (1912, p. 27) to be of probable Early Cretaceous age. The writer can offer no original contribution to the dating of the Coast Range diorites in the Juneau area. The present study indicates, however, that the formation of the Coast Range batholith took place over a considerable span of geologic time by intrusion and by replacement of existing rocks. The most important contribution, on the part of the writer, is the determination of the fact that a strong regional stress prevailed throughout the period of formation of the batholith and its outlying sills, and into the period of solidification of all the intrusives.

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