CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

MEMOIR 292

DEWAR CREEK MAP-AREA WITH SPECIAL EMPHASIS ON THE WHITE CREEK BATHOLITH, BRITISH COLUMBIA

By

J. E. Reesor

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View southwest into White Creek batholith from a point near the north contact. Thin-bedded rocks of Lower Aldridge division in the foreground. (July 12, 1950)

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PREFACE

Dewar Creek map-area is immediately northwest of the Sullivan mine at Kimberley, B.C. This report describes the Precambrian sedimentary rocks that form part of the sequence in which the Sullivan orebodies occur, and the structural deformation these rocks have undergone.

Much of the report is, however, concerned with a small, zoned, granitic batholith, most of which is in the map-area. The origin and structure of these zones are discussed in some detail and a well supported hypothesis for the method of emplacement of the batholith by magmatic intrusion is presented.

GEORGE HANSON,
Director, Geological Survey of Canada

OTTAWA, June 5, 1956

Dewar Creek Map-Area with Special Emphasis on the White Creek Batholith British Columbia

CHAPTER I

INTRODUCTION

The work on which this report is based was initiated as a study of stratigraphic and structural problems in the general region of the Sullivan lead-zinc mine at Kimberley, B.C., and as a study of the White Creek granitic rocks and their possible relation to the mineralization in the area. The stratigraphic horizon of the Sullivan lead-zinc orebody has been followed throughout the map-area without finding further significant associated mineralization. On the other hand, excellent exposures above timber and the occurrence of the White Creek batholith within the map-area surrounded by sedimentary formations of a type allowing easy interpretation of structural relations presented an opportunity to study the petrology and structural emplacement of the batholith in some detail. As a result considerable information regarding its formation and emplacement has been gained. The report therefore emphasizes the results obtained from the study of the White Creek batholith and is presented not only as a description of the geology of Dewar Creek map-area, but also as a contribution towards the eventual understanding of the method of emplacement and the origin of minor batholithic bodies of this region of the Cordillera.

Location and Accessibility

Dewar Creek map-area lies between longitudes 116°00′ and 116°30′ and latitudes 49°45′ and 50°00′. It includes 385 square miles of mountainous terrain in the Purcell Mountains of southeastern British Columbia. There are no roads within the map-area, although the boundary of the area is accessible along private logging roads up St. Mary River and Skookumchuck Creek, and a road northwest of Kimberley owned by the Consolidated Mining and Smelting Company. From these three points, trails passable for pack-horses lead up the main river valleys. To examine areas beyond the reach of the main valleys, it is necessary to back-pack camp and provisions up minor tributaries to the high basins at or above timber-line.

Geological Investigations

Systematic reconnaissance work by H. M. A. Rice (1941)[1] in Nelson map-area, east half, covered Dewar Creek map-area and his published results have served as the basis for the present more detailed work. During the seasons of 1948 and 1949, exploration geologists of the Consolidated Mining and Smelting Company of Canada[2] carried out detailed mapping on a scale 1 inch to 2,000 feet along the south edge of Dewar Creek map-area and in the area to the south to St. Mary River. There has been some prospecting in the area surrounding White Creek batholith during the last half century.

The present field work in Dewar Creek area was begun in 1950 and continued in 1951 and 1952. The mapping was carried out on a scale of 1 inch to ½ mile for eventual publication at 1 inch to 1 mile.

In the course of this investigation many persons have given assistance both in the field and in subsequent office and petrographic study, their cooperation is gratefully acknowledged. In particular, for courtesies extended in the field, the writer is indebted to Mr. George Warning, of the Consolidated Mining and Smelting Company. In addition, J. S. Ambler, H. A. B. Jose, and J. G. Souther have given efficient assistance in the field work.

Subsequent petrographic and office study has been done partly at Princeton University, under the guidance and helpful criticism of Professors A. F. Buddington, H. H. Hess, and F. B. van Houten.

Topography and Drainage

Dewar Creek map-area lies on the east flank of the Purcell Mountain range. The area consists of deeply dissected, irregular mountain masses, with few well defined, continuous mountain ridges. In the eastern part of the area peaks rise from 8,000 to 8,500 feet above sea-level, and have rounded, gentle profiles, deeply cut by minor streams and abandoned cirques. In the west, peaks rise to 9,500 feet and are rugged and difficult to climb, especially where underlain by massive quartzite or granodiorite. Everywhere numerous tarn lakes lie amongst the peaks at or just above timberline at 7,500 feet. Main valleys rise from 4,000 feet at their lower ends to about 5,500 feet towards their upper reaches, thus local relief varies from a minimum of 3,000 feet in the eastern part of the map-area to a maximum of 5,000 feet in the northern and western parts.

The area is drained principally by two river systems: in the west the south flowing upper part of St. Mary River system, consisting of Dewar Creek and White Creek; in the east the eastward flowing Skookumchuck

[1] Dates in parentheses are those of references cited in Chapter V.
[2] R. MacEachern and G. Warning.

Creek system consisting of Skookumchuck and Buhl Creeks. The northwest corner of the area is drained by the headwaters of Findlay and Fry Creeks, and the southeast corner by Mark Creek. The main streams flow in rather narrow, steep sided, U-shaped valleys into which most minor tributary streams plunge from hanging valleys over a lip or through a canyon 500 to over 1,000 feet deep. In the upper basins at the head of most tributaries lie small tarn lakes, but in the northwest corner of the map-area a few of the cirques are still occupied by small glaciers.

Climate, Forests, Fauna, and Habitation

No official record of weather within the map-area has been kept. A few miles to the southeast, in the Rocky Mountain Trench near Kimberley and Cranbrook, precipitation averages 15 to 20 inches a year. It is probable, however, that snow and rainfall in the Purcell Mountains is at least double this amount as even in June, at altitudes above 6,500 feet, 4 or 5 feet of snow may be found. Furthermore, during the summer, storms may often be observed that die out before reaching the Trench or the Rocky Mountains beyond. June is often a wet month, but long periods of rain in July and August are rare, though local afternoon thunder showers may be common during midsummer. Geological work, above timber-line, can be started in the early part of July, though patches of perennial snow may prevent examination of outcrops in gulleys and on north-facing slopes. Field work may continue at low altitudes in September, but snow and extremely cold weather may be expected at high altitudes any time after the beginning of September.

The main valleys, where not burned, are thickly forested: below 4,500 feet, with spruce, Douglas fir, and some cedar; above 4,500 feet, with spruce, jack pine, and balsam. Open stands of alpine larch are common just below timber-line at 7,500 feet. Undergrowth and deadfall are thick in the lower parts of the main valleys and make travel in the bush difficult. Much of the area is burned, in particular the headwaters of Mark Creek, the lower parts of Dewar and White Creeks, and most of Skookumchuck Creek. Pack-horse trails cut through the burned areas must be cleared after every wind storm.

Game, such as moose, elk, white-tail and mule deer, black bear, and grizzly bear, are common but not plentiful in the area. Mountain goats are numerous.

There are no permanent residents in Dewar Creek map-area. C. Wenger's temporary logging camp is situated on Skookumchuck Creek on the east boundary of the map-area, and his logging operations take crews up Buhl and Skookumchuck Creeks for a few miles.

CHAPTER II

STRATIGRAPHY

The sedimentary rocks of Dewar Creek area consist entirely of fine-grained clastic rocks of the Purcell series of Late Precambrian age. In this area these rocks comprise a series, not less than 30,000 feet thick, of conformable, very fine-grained, thin-bedded quartzites, argillaceous quartzites, and argillites, with limy and dolomitic equivalents in the upper part of the section. Following deposition, the entire series has been folded, gently in the east but with increasing complexity in the west. The pattern of resultant folds is dependent on the intensity of deformation, the composition of the strata involved, and the superposition of rocks of differing composition within the section. Regional metamorphism is relatively low grade, but has resulted in universal recrystallization, the development of cleavage, and in the alteration of matrix clays to chlorite, sericite, and biotite. Finally the intrusion of batholithic rocks has resulted in further local deformation and thermal metamorphism of the sedimentary rocks.

Table of Formations

Era	Period	Rock Unit (Thickness in feet)	Lithology
Cenozoic	Recent and Pleistocene		Stream and glacier deposits; felsenmeer and talus
Mesozoic and/or Cenozoic	Jurassic or later	Fry Creek Batholith	Leuco-quartz monzonite, pegmatite, aplite.
			Relations not known
		White Creek Batholith	Pegmatite and aplite
			Medium-grained quartz monzonite
			Leuco-quartz monzonite
			Porphyritic (microcline) quartz monzonite
			Hornblende-biotite granodiorite (monzotonalite)
			Biotite granodiorite (monzotonalite)

Table of Formations—Continued

Era	Period	Rock Unit (Thickness in feet)	Lithology
		Intrusive contact	
Palæozoic(?) or Mesozoic(?)		Ultramafic stock	Serpentine; serpentinized clino-pyroxenite
		Relations not known	
Late Proterozoic (?) or later		Moyie intrusions	Meta-diorite and meta-quartz diorite sills; rare dykes
		Intrusive contact	
Proterozoic	Upper Purcell	Dutch Creek formation (1,000+)	Buff and reddish weathering silty dolomite, dolomitic quartzite, and much argillite; some grey weathering, very fine-grained, grey quartzite
		Conformable, gradational contact	
	Lower Purcell	Siyėh formation (2,000)	Purple, green, and grey argillite; light and dark green laminated argillite; some very fine-grained, green weathering, green quartzite
		Kitchener formation (4,200)	Buff weathering, dolomitic and calcareous quartzites, siltstones, and argillites; green argillite and black and grey bedded argillite; minor creamy to buff dolomite and black limestone
		Creston formation (4,100-6,500)	Green and grey weathering, green-grey, and purple argillaceous quartzites, metasiltstones and argillites. Lower member (0-1,500 feet); dark weathering, black to dark grey argillites, arenaceous argillites, recrystallized equivalents of siltstones.

Table of Formations—Concluded

Era	Period	Rock Unit (Thickness in feet)	Lithology
		Aldridge formation (Upper division 11,000+)	Upper Argillite member (1,000-1,500+): very rusty weathering, evenly laminated, black and grey argillites and arenaceous argillites. Remainder, of light grey weathering, light to dark grey quartzite with minor partings of black argillite and thin-bedded argillaceous quartzite, and rusty phyllitic equivalents
		Aldridge formation (Lower division 4,500+)	Very rusty weathering, thin-bedded, laminated, light coloured, very fine-grained quartzites and argillaceous quartzites; minor argillite; equivalent phyllites, phyllitic quartzites and schists.

Description of Formations

ALDRIDGE FORMATION

The Aldridge formation was first defined by Schofield (1915, p. 24), and this usage was later followed by Rice (1937, pp. 6-8, and 1941, pp. 8, 9). During the field seasons of 1948 and 1949, exploration geologists of the Consolidated Mining and Smelting Company of Canada[1], mapping in greater detail in the area north of St. Mary River and south of Dewar Creek map-area, divided the Aldridge formation into three separate units: Lower, Middle, and Upper Aldridge. These divisions were followed in mapping Dewar Creek area. It was found, however, that the upper division could not easily be distinguished from the middle division in the western part of Dewar Creek map-area and later, in Findlay Creek area (Reesor, 1953, p. 1), that the two could not be separated. Furthermore it is apparent from Rice's work in Cranbrook map-area (1937, p. 8) that the Aldridge formation east of the Rocky Mountain Trench is predominantly argillaceous, or similar to the rather minor Upper Aldridge Argillite member west of the Trench. In view of these known variations, both across and along strike, it is proposed to subdivide the Aldridge locally into two divisions rather than formations and to consider the Aldridge, as a whole, a formation rather than a group. In this report then the Aldridge is subdivided into a Lower division, about 4,500 feet or more thick, and an Upper division, about

[1] Personal communication: R. MacEachern and G. Warning.

11,000 feet thick. Furthermore from the Upper division, which comprises the beds previously mapped as the Upper and Middle divisions, the upper argillaceous strata, 1,000 to 1,500 feet thick, are separated and mapped as the Argillite member.

Lower Aldridge Division

The Lower Aldridge division is of limited extent in the map-area; about 15 square miles in the central part, near the northern boundary, and about 3 square miles on the west side of lower White Creek.

The thickness, in the north, is over 4,500 feet, of which about 1,000 feet is composed of Moyie meta-diorite sills. In the south, the Lower Aldridge is much folded and faulted above the Hall Lake fault, but there is approximately 3,000 feet exposed, nearly 1,200 feet of which is meta-diorite sills.

The Lower Aldridge division is characteristically rusty weathering, light coloured, very fine-grained, thin-bedded quartzite, sericitic siltstone and argillaceous (sericitic) quartzite. In the more deformed parts of the division there are phyllitic and, near the batholith, schistose equivalents of the above.

In detail, the most common rock types are thin-bedded purple, grey, and white quartzites, commonly with thin black layers of more argillaceous material. Alternate sections occur, in which very thin beds, 1 inch to 4 inches thick, of purplish to grey, thin laminated quartzite persist for 15 to 20 feet, followed by a similar group of beds of grey or purple quartzite with beds up to 2 feet in thickness. Pure argillite or slate may occur in very thin beds, but forms a relatively small part of the division. Crossbedding is common, and rare scour and fill features may be noted on a minor scale. The rusty weathering, the narrowly spaced bedding planes, and predominance of thin laminations, distinguish the formation from others in the Lower Purcell.

North of the pass to White Creek, west of upper Findlay Creek, the large inclusion as shown on the map (in pocket) contains some bands of coarse pyroxenite and very coarse calcite. On the hillside to the east, across Findlay Creek, there is also some tremolite schist within the schistose and hornfelsic rocks of a large inclusion (pendant?) in the granodiorite. At one locality north of upper Skookumchuck Creek there occurs some coarse marble, garnetite, and coarse pyroxenite in a narrow band a few tens of feet wide. Similarly, there are minor skarn rocks in what appears to be the remnants of a roof pendant along lower Skookumchuck Creek, in patches in the bottom of the Creek and on the adjacent hillsides, just below the junction with Burnt Creek. These rocks consist of garnetite, pyroxenite, coarse calcite and much epidote within the rusty weathering, quartz-mica schists of the inclusions or remnants. The origin of the carbonate-bearing, metamorphic rocks is doubtful. Although they are very minor, and are represented only in remnants and inclusions in the granodiorite, they occur over an area of considerable linear extent. The skarn may be metamorphosed equivalents of bands of limestone at the base of the Lower Aldridge division, or may, indeed, be metamorphosed equivalents of the underlying Fort Steele formation (*see* Rice, 1937, p. 5).

In thin section little variation can be seen. Quartz occurs as a very fine-grained mosaic most of which is completely recrystallized from the original detrital grains. Grain size rarely exceeds 0·1 mm. and is generally much less, 0·05 mm. being about average. Biotite, in small shreds and flakes is in places abundant, and is strongly pleochroic from very light tan to dark or golden brown. In some specimens it is developed in tiny flakes perpendicular to the lamination in the rocks, and, though some is undoubtedly detrital, most is of later origin. Commonly fine-grained, fibrous sericite may form up to 30 per cent of the thin section, and represents recrystallized argillaceous material in the original sediments. More rarely, large grains of porphyroblastic muscovite up to 0·5 mm. in size, and small patches of chloritoid(?) may be seen. Other accessories are magnetite and hematite, scattered throughout most thin sections, zircon, rare apatite, and ubiquitous tourmaline. In most cases, tourmaline has been introduced during thermal metamorphism though rarely a rounded grain of blue tourmaline, apparently of detrital origin, occurs in an envelope of brown, euhedral tourmaline. In all, little now remains of the original texture of the minerals.

As the Lower Aldridge division occurs in the vicinity of the batholith or near the Hall Lake fault, it is in most places much deformed. In the north, near the batholith, the formation is compressed into isoclinal folds, with much drag-folding, faulting, and universal development of cleavage. On the north side of Burnt Creek, however, the formation is little disturbed with an average north to northwest dip of 20 to 30 degrees. West of White Creek, the Lower Aldridge is much sheared, faulted and folded. For this reason any measurement of thickness must be only approximate.

Generalized section of part of Lower Aldridge, measured on ridge north of Burnt Creek, at north boundary of map-area

Upper Aldridge	Feet
Massive, non-laminated, white weathering, grey quartzite in beds 6 to 12 inches thick, some beds up to 10 feet thick or more. Argillaceous partings between beds ½ inch or less, much sheared	900
Gradational, conformable contact	
Lower Aldridge	
Sill	10
Rusty, greyish, thin-bedded quartzite and recrystallized and sericitized siltstones; beds average 6 inches	150
Sill	75
Very massive, fine-grained, grey quartzite in beds up to several feet thick	20

	Feet
Rusty, thin-bedded, grey, quartzites, and metasiltstones	150
Massive, whitish weathering, quartzites, in beds 6 to 10 inches thick, black argillaceous partings up to 2 inches thick	150
Thin, platy, rusty, quartzites; some fine laminations. Some thin interbedded slaty beds	300
Sill	15
Massive, whitish weathering, fine-grained, light to dark grey quartzite in beds up to 2 feet thick, a few inches at top or bottom of a bed may be laminated by darker argillaceous quartzite	80
Thin, platy, rusty quartzites, and metasiltstones; some beds finely laminated and some have slaty partings	300
Sill	15
Massive, whitish weathering, fine-grained quartzite in beds up to 2 feet thick; a few inches at top or bottom of a bed may be laminated	80
Mainly fine-grained, finely laminated, thin bedded, purplish to grey, rusty quartzite and argillaceous quartzite	300
Sill	550
Rusty, laminated and non-laminated quartzites and metasiltstones, in beds 1 inch to 2 inches and 6 to 12 inches thick, which alternate in successions 20 to 30 feet thick; a few beds 2 to 3 feet thick of white weathering quartzite as well as a few sections up to 10 feet thick of sheared slate and phyllite	300
White weathering quartzite in beds 2 to 4 inches thick	10
Fine-grained, fine laminated, grey quartzite and sericitic siltstone, in beds 6 to 12 inches thick	125
Fine-bedded and fine laminated quartzite with almost equal amount of rusty weathering slate	75
Fine-grained, grey to purplish quartzite, beds 6 to 12 inches but, towards the top, become 2 to 6 inches thick; some beds show alternate light and dark lines; some show crossbedding; some very minor $\frac{1}{2}$ inch shaly partings	250
Fine-grained, greyish, rusty weathering, quartzite in beds a few inches to a few feet thick	140
Base not exposed	
Total thickness	2,700

The contact relations of the Lower Aldridge are well exposed where it grades into the Upper Aldridge, but the base is nowhere visible within the map-area. The transition to the Upper Aldridge, west above White Creek, is as shown below:

Upper Aldridge	Meta-diorite sill	50–75 feet
	Grey weathering quartzite with black argillite partings	30 feet
Lower Aldridge	Thin-bedded, laminated, rusty quartzite	300–400 feet
	Upper Aldridge type, non-rusty, white weathering, grey quartzite, black argillite partings	200 feet
	Rusty, laminated quartzite	

A somewhat similar relationship exists in the north, but there are several thinner successions of the Upper Aldridge type of quartzite, below the uppermost rusty quartzites of the Lower Aldridge. Thus the division between Upper and Lower Aldridge is based on the predominance of rusty weathering, laminated quartzites in the Lower division and the predominance of white weathering, grey quartzites in the Upper division. It is apparent that in a poorly exposed area the contact could be placed as much as 600 feet below the division point used here.

Upper Aldridge Division

The Upper Aldridge division underlies an area of about 30 square miles northwest of White Creek batholith, and about one-half that area southwest of the batholith between Dewar and White Creeks. A third small area lies in the southeast corner of the map-area. Of the formations of the Purcell series it is the thickest and most competent and is therefore structurally the most significant. In the south the thickness is about 11,000 feet, including 2,000 feet of Moyie sills; in the north the division exceeds 11,000 feet from the lowest exposure to Findlay Creek fault. A thickness of over 2,000 feet occurs above the fault, but much of the strata may be repeated from the lower part of the section.

Towards the top of the Upper division in Dewar Creek map-area the quartzites grade to argillites, which have been mapped separately as the Argillite member. This member is about 1,000 feet thick in the western part of the map-area, and about 1,500 feet thick in the southeast corner.

The Upper Aldridge division is essentially a uniform sequence of thin-bedded quartzites, with various amounts of interbedded argillite and argillaceous quartzite. The predominant quartzite beds are fine grained. grey to purplish grey, grey to white weathering, and vary in thickness from 2 inches to 2 feet. Parts of the formation with beds predominantly 2 to 10 inches thick alternate with parts with beds varying in thickness from 10 to 24 inches. Individual beds, although generally massive, may show fine laminations near the top or bottom, particularly in the northern part of the map-area. The interbedded argillite is black or grey and individual beds vary in thickness from 1 inch to 6 inches. In some parts of the section the argillite interbeds thicken at the expense of the quartzite, and towards the top of the division, below the Argillite member, successions of thin, laminated, black argillite up to 50 feet thick may occur. In places, tops of beds may be determined from individual beds in which quartzite at the bottom grades to argillite at the top, which is, in turn, sharply divided from the quartzite of the next bed. In addition, the quartzite is interbedded with a black and white, thinly laminated, argillaceous quartzite or chloritic and sericitic siltstone. Alternate laminae vary in width from $\frac{1}{4}$ to $\frac{1}{2}$ inch, commonly thickening and thinning considerably along strike.

At the top of this sequence there is a gradational transition to the Argillite member, which consists principally of very rusty weathering, thin-bedded, platy, black and white laminated argillites. There are also black, arenaceous argillites and very fine-grained, impure siltstones. In the west and northwest this member is not well defined, and consists, about half and half, of crenulated phyllites, equivalent to the above argillites, and non-rusty quartzite similar to those in the underlying succession.

In most thin sections of the quartzite two distinct sizes of material can be seen: the first, angular quartz grains between 0·3 and 0·5 mm., the second, interstitial quartz and sericite in grains less than 0·03 mm. Though there may be some comminution of grain size, due to cataclastic deformation, the two distinct sizes of material noted above are found in thin sections with no foliate structure and so must be primary. Feldspar is rare, as in the Lower Aldridge, though grains of oligoclase and microcline do occur. Interstitial sericite is of minor importance in the quartzite, but may form 50 per cent or more of the argillaceous quartzite. In the phyllites, a very fine-grained quartz mosaic occurs between the sericite foliae. Biotite is common throughout in tiny flakes not over 0·1 mm. and may be parallel with, or perpendicular to, the foliation in the phyllitic quartzites. Accessory minerals consist of chlorite, with anomalous blue interference colours, zircon, grains and clots of magnetite, and rare hematite. Tourmaline is found everywhere, in places in sufficient quantity to form a tourmalinized phyllitic quartzite.

Thin sections of rocks of the Argillite member contain up to 50 per cent of very small quartz grains, some up to 0·5 mm. but most less than 0·1 mm. Most thin sections from this member in the southeast corner of the map-area show a fine mesh of small shreds of sericite. Porphyroblasts of biotite, up to 0·2 mm. with good sieve texture, occur in irregular patches with inclusions of all other minerals. In the western part of the map-area equivalent rocks are crenulated phyllites composed of wave-like masses of sericite, or quartzitic phyllites with alternate layers of quartz grains and oriented shreds of sericite. Scattered magnetite occurs throughout the rock, as well as rare zircon, some apatite, and hematite. Again, tourmaline occurs in various amounts in every thin section.

Though these rocks have been metamorphosed, up to biotite grade, they apparently were originally subgreywackes, containing no rock pebbles, little feldspar, but consisting of two principal sizes of detrital material. The graded bedding and interlaminated black argillites are also considered to be characteristic of the greywacke suite.

In contrast with the Lower Aldridge, the Upper Aldridge is much less intensely deformed. Northwest of Rusty Ridge beds dip gently northwest, but the dip increases westward to 40 or 50 degrees on Findlay Creek. As argillite becomes more abundant towards the top of the division, the beds are more highly folded and sheared. In the immediate vicinity of the batholith, Upper Aldridge quartzites and argillites are metamorphosed to a layered hornfels. These laminations follow the original bedding and are now vertical and mainly conformable with the granitic contact. Folding and deformation is much stronger in the Argillite member, with universal development of cleavage.

Fracture cleavage is common in the quartzite south of White Creek batholith, and in many places has an S-shape, commonly with regular, close spacing at about 1-inch intervals. The S-shaped cleavage is apparently due to varying purity of the quartzite within a single bed, top and bottom being more argillaceous so that cleavage flattens towards the plane of the bedding. In the adjacent argillaceous parting the cleavage is of the 'slaty' type and lies nearly parallel to the bedding. It thus appears that orientation of cleavage is a function of bedding relations and rock composition, particularly in areas where deformation has not been intense.

Primary structures, such as mud-cracks, ripple-marks, and cross-bedding, so common in the other Lower Purcell formations, are rare or absent in the Upper Aldridge division. Graded bedding as noted above is the only common primary feature.

Generalized section of Upper Aldridge Argillite Member measured at headwaters of Mark Creek

Sharp, conformable contact with lower member of Creston formation	
	Feet
Flat-lying, rusty weathering, platy, grey chloritic and sericitic siltstone and black argillite; some very fine-grained, greyish argillaceous quartzite. Black argillite commonly has even, continuous, thin laminae of white to grey arenaceous argillite	1,000+
Lenticular, white weathering, grey quartzite, sharp contact at bottom gradational to laminated quartzitic argillite above	10
Laminated, platy, thin-bedded, quartzitic argillite	40
Deformed, soft, black and grey argillite and phyllite	100?
Black, rusty weathering, argillite and grey, rusty weathering sericitic siltstone; a few quartzite beds 4 to 8 inches thick. Soft argillite beds below quartzite in places contorted into waves with sharp crests penetrating into overlying more competent siltstone	60
Rusty weathering, thin-bedded, grey or black argillite and sericitic siltstone	80
Massive, white weathering, fine-grained quartzite	5
Thin-bedded, rusty weathering, black and white laminated, argillite; some grey chloritic siltstone	20
Thin-bedded, white weathering, fine-grained, grey, argillaceous quartzite	40
Rusty weathering, 1/8 to 1/4 inch alternate laminae of grey and black arenaceous argillite and argillite	45
Total thickness	1,400
Gradational, conformable contact with underlying quartzites of Upper Aldridge	

Generalized Upper Aldridge Section measured at headwaters of Findlay Creek, about 1 mile north of Batholith contact

Gradational, conformable contact with overlying Creston formation	
Upper Aldridge Argillite member	Feet
Grey and green, black, and black and white laminated phyllite; 20- to 50-foot sections of 2- to 16-inch bedded, fine-grained phyllitic quartzite and siltstone; much folded and sheared	1,000?
Arbitrary, conformable, gradational contact with main Upper Aldridge quartzites	
Upper Aldridge quartzite	
Rusty weathering, grey, fine-grained quartzite and siltstone interbedded with rusty weathering, black phyllite, all in beds averaging 2 to 4 inches thick; some sheared sections of black phyllite up to 50 feet thick; some minor drag-folds and shears	1,250?
Competent section of rusty weathering, grey to purplish, very fine-grained quartzites in beds 4 to 30 inches thick; rusty weathering; rare black phyllitic partings 1/4 inch to 2 inches thick	750

Fault zone; grey to greenish weathering, sheared phyllitic quartzite and phyllite; in places schistose	300?
Laminated grey and black phyllite and phyllitic argillaceous quartzite; much deformed and in sharp drag-folds	800?
Whitish weathering, grey to white quartzite and siltstone; laminae of darker argillaceous quartzite common; beds average 4 inches thick, although 12-inch beds common; irregular, black rusty weathering phyllitic partings 1 inch to 5 inches thick	1,000
Whitish weathering, very fine-grained, greyish quartzites in beds 2 to 12 inches thick; sheared rusty weathering phyllitic partings between beds, 2 to 4 inches thick	1,200
Fine-grained, rusty weathering, purplish to grey quartzite with darker laminae near top or bottom of a bed	200
Rusty weathering, black and grey phyllite and slate; some black arenaceous slate and argillite, some with regular, thin, white laminae	200
Grey to white weathering, fine-grained, grey and purplish quartzites and siltstones in beds 6 to 16 inches thick, phyllitic and black slaty partings up to 1 inch; some sections of massive, black, rusty weathering arenaceous argillite and some of thin laminated, alternating grey and black argillaceous quartzite	1,000
Meta-quartz diorite sill	300
White weathering, massive, thin-bedded quartzite and argillaceous quartzite	100
Sill	100
Light weathering, white laminated, dark grey argillaceous quartzite in beds up to 2 feet	100
Light weathering, massive and laminated quartzite and argillaceous quartzite in beds 6 inches to 2 feet thick, black argillite and laminated grey and black argillaceous quartzite partings up to 6 inches thick	400
Sill	150
Light weathering, grey to dark grey quartzites with thin argillaceous partings	100
Sill	100
Succession of light and dark grey and purplish quartzites, grey to white weathering; individual beds 3 inches to 2 feet, with rare, massive beds 8 to 10 feet thick; some beds are massive, some show darker grey, thin, laminae of very fine-grained, argillaceous quartzite, particularly near the top of a bed, some show graded bedding to argillaceous parting between beds; argillite or light and dark grey laminated very fine argillaceous quartzite partings are found varying from ½ inch to 2 inches thick between all beds	1,000
Sill	15
Succession of grey to white weathering, grey to purplish, very fine-grained quartzite, rusty in joints, in beds 6 inches to 24 inches; minor black, in places rusty weathering, argillite interbeds up to 2 inches thick; beds of quartzite commonly massive but some grade to a laminated purple and black or dark grey argillaceous quartzite for 1 inch or 2 inches near the top	600
Sill	10
Continued succession of white to grey weathering, grey quartzite in beds 6 inches to 3 feet, with rare beds to 8 or 10 feet; very minor black argillite and ½ inch laminated light and dark grey argillaceous quartzite partings between beds; some thin quartzite beds 1 inch to 2 inches thick associated with argillite sections up to 10 feet thick	500
Meta-quartz diorite and diorite sill	200
Base of section not exposed	
Total thickness	11,200

In the southeastern part of the map-area the contact between the Argillite member at the top of the Upper division and the overlying Creston, green to black weathering argillites and siltstones, is sharp. This is the sharpest and most reliable marker horizon in the Lower Purcell, and the change from rusty, evenly laminated argillites below, to non-rusty, irregularly laminated argillites and quartzites above may be mapped with an accuracy not possible in dividing the other formations of the Purcell.

Unfortunately this accuracy does not persist far, and the contact between Aldridge and Creston in the western part of the area is gradational, with many rusty beds similar to Aldridge rocks occurring well up in the Creston. The contact in the northwest part of the map-area, in the highly deformed and metamorphosed area between Fry Creek and White Creek batholiths, is taken at the first thick section of green quartzites without appreciable argillite partings that lies above a considerable section of rusty argillites and quartzites of Aldridge type.

CRESTON FORMATION

The Creston formation has been mapped in Dewar Creek area essentially as defined by Schofield (1915, p. 28) and by Rice (1937, p. 8; and 1941, p. 9). In more detailed mapping it has been possible in the eastern part of the map-area to separate a lower member consisting of dark weathering, sericitized and silicified mudstones and siltstones. It reaches a thickness of 1,500 feet in the area from White Creek to the eastern boundary of the map-area, but is missing in the western part, along Dewar Creek.

The Creston formation as a whole is the most extensive in the map-area, covering an area of about 70 square miles in two broad strips along the south and west boundaries. It varies in thickness from 6,000 to 6,500 feet and appears to thin to the west to about 4,100 feet on Irish Queen Mountain, in part as a result of the disappearance of the lower member and possibly in part as a result of strike faulting.

The Lower member at the base of the Creston consists mainly of dark weathering, black and grey argillites with irregular, $\frac{1}{4}$ to $\frac{1}{2}$ inch laminae of lighter argillaceous quartzite or impure siltstone that vary in thickness along strike. This is in marked contrast with the continuous, even, white laminae of the Argillite member of the Upper Aldridge lying immediately below, and the two members may be separated on this basis alone. Also abundant in the Lower member of the Creston are very dark, fine-grained, massive, sericitized and silicified siltstones. Individual beds vary from a fraction of an inch to several inches thick. In the lower part of the member, sections up to 20 feet thick may be more evenly bedded, and weather to a rusty colour, similar to the top of the Aldridge formation below; on the other hand towards the top, green argillaceous quartzite may appear, similar to that in the overlying part of the Creston.

The remainder of the Creston lying above the lower argillaceous member consists essentially of grey, green, purple, and white argillaceous quartzites and argillites, which weather a similar or somewhat lighter shade of the fresh colour. These rocks may, in turn, be divided into three parts all of which grade imperceptibly into one another. These divisions have not been mapped, as rocks found in any one division are commonly found in the others.

The lower part of the Upper member of the Creston consists essentially of light and dark green, fine-grained, argillaceous quartzite in beds 2 to 8 inches thick. Thin partings of sheared green argillite are common, and throughout are interbeds, up to several feet thick, of bluish to purple argillite, commonly with mud-cracks. Some beds in the southeastern part of the area, occurring several hundred feet above the top of the Lower member of the Creston, contain abundant magnetite octahedra up to 2 mm. in size. In the western part of the area, however, magnetite octahedra occur at various levels and are not diagnostic of any particular horizon.

This part of the Creston grades upward into a competent series of purple, grey, and white, fine-grained, argillaceous quartzites in beds from 6 inches to several feet in thickness. Laminae, about $\frac{1}{8}$ inch thick, of a darker grey or purple, more argillaceous quartzite are common in the above quartzites. Such laminae, though commonly even and continuous along the strike of a bed, may be minutely contorted or discontinuous, giving the rock surface a mottled appearance. Contorted laminae may be confined to the top or bottom of a bed, and in this case are interpreted as being due to deformation prior to consolidation.

The upper part of the Creston, east of the headwaters of Buhl Creek, exhibits an alternating succession of green or purplish argillite and medium- to coarse-grained, white, purple, and green quartzite. Grain size in the quartzite may reach 2 mm. and is the coarsest found in the Lower Purcell in the map-area. West of Buhl Creek, however, the coarse green and white quartzites do not occur. The equivalent sedimentary rocks in this part of the area are alternating, very thin beds of light and dark green argillite and dark green, fine-grained quartzite, in beds 6 to 8 inches thick, all beds being more calcareous towards the top of the formation.

Primary sedimentary features indicating shallow water deposition are common throughout the Creston formation. Mud-cracks, distorted by later folding, are the most common feature of the Lower member, but in addition, wave ripple-marks, crossbedding and primary slump structures occur. Primary slumping is well exhibited; thin beds or laminae are intensely folded though the lateral continuations of the same beds as well as over- and under-lying strata are completely undeformed. Similar shallow water structures such as wave ripple-marks, crossbedding, minor intraformational breccias, and gouge and fill features are found throughout the upper part of the Creston formation, in the eastern part of the area.

In thin section, the rocks of the formation are seen to consist essentially of quartz, with various amounts of sericite and chlorite. Quartz rarely occurs in grains or recrystallized patches over 0·1 mm., more commonly it is 0·05 mm. in size. Chloritic material is abundant, and may form about 50 per cent of the rock. It is apparently responsible for the green colour of the Creston formation. Sericite varies in amount from specimen to specimen and is everywhere present as fine irregular flakes. The darker laminae in the quartzites contain more chlorite or sericite than the lighter layers. Porphyroblasts of biotite are common and may be oriented across the foliation with obvious displacement of surrounding minerals. Feldspar is rare, though some small grains of twinned plagioclase have been observed at high magnification. Zircon is rare, but hematite and magnetite may locally be present in considerable quantities. Chloritoid may be noted in places as small irregular patches.

In contrast to the Creston rocks in the eastern part of the map-area which are all gently north dipping and in open folds, the Creston formation along the western boundary of the map-area is vertical, irregularly and tightly folded, and sheared. As a result no divisions may be recognized, no primary features observed, and few details of folding or faulting marked. All rocks are phyllitic and in places schistose.

Creston Section measured on ridge west of Mark Creek Pass

Gradational, conformable contact with overlying Kitchener formation, marked at point where rocks are predominantly calcareous and where medium- to coarse-grained white quartzite is no longer present.	
	Feet
Green weathering, green slate; white, purple, and green, coarse-grained quartzite, in beds 2 to 6 inches thick; some grey and purple argillite; mud-cracks, ripple-marks, crossbedding, and intraformational breccia common throughout	500
Dark green weathering, green quartzite; purple and grey, medium- to fine-grained quartzite with 2-inch beds of white quartzite at intervals; some 3- to 4-foot, thin-bedded sections of green argillite	500
Crossbedded and ripple-marked, grey, purple laminated, and mottled quartzite, in beds up to 10 inches	300
White, green, and purple quartzite in beds up to 5 inches; some purple shale and intraformational conglomerate	250
Light and dark green, thinly laminated green and grey argillite and slate	200
Grey quartzites with thin purple laminae, in beds averaging 2 to 4 inches thick with thin partings of grey argillite; commonly with mud-cracks and gouge and fill features	550
Splotchy brown and green weathering, green and grey argillaceous quartzite, argillite, and chloritic siltstone, in beds 2 inches to 2 feet thick; thin green argillaceous partings between beds ½ inch to 2 inches thick	450
Grey weathering, grey argillaceous quartzite; a few sections up to 10 feet thick of crossbedded medium- to coarse-grained, white, purple, and green quartzite; rare intraformational breccia with fragments of purple argillite in white quartzite matrix	300
Green weathering, light green argillaceous quartzite and chloritic siltstone; some beds marked by ⅛ inch regular purple laminae	200
Greyish green, argillaceous quartzite with thin purple laminae and chloritic siltstone, in beds 4 to 16 inches thick	500
Thin-bedded, 2 inches or less, grey laminated, light grey and green chloritic and sericitic siltstone and argillaceous quartzite, all interbedded with black to purple argillite with mud-cracks, some ripple-marks in argillaceous quartzite; many octahedra of magnetite	500
Purple to dark grey laminated, dark greyish green argillaceous quartzite and fine-grained quartzite in beds 2 to 5 inches thick, with interbedded black to purple argillite, ½ to 1 inch thick. Some laminae in argillaceous quartzite very irregular giving a 'mottled' appearance to surface of beds	100

	Feet
Green, fine-grained quartzite with purple to dark grey laminae, some quartzite beds show 'mottled' surface	30
Green weathering, green, argillaceous quartzite in beds 2 to 6 inches thick; light green argillite partings 1 inch to 2 inches thick; a few layers of pale purple argillite. Octahedra of magnetite common in the argillaceous quartzite	220
Total thickness	4,600

Conformable contact with the Lower member of Creston formation.

The contacts of the Creston formation, with the exception of the Upper Aldridge–lower Creston contact in the southeastern part of the map-area, have been set arbitrarily. The Lower member of the Creston east of White Creek, becomes indistinct and may be in part eliminated by bedding-plane faulting. West of White Creek the Lower member does not occur and the Creston-Aldridge contact is difficult to map with any precision. The elimination of the lower siltstones and argillites may be due in part to bedding-plane faulting, particularly in the southwestern part of the area. Northwest of the White Creek batholith, however, the entire transition is well exposed and no equivalent of the Lower member of the Creston was found. It is possible the Lower member may grade westward into argillaceous quartzites typical of the upper part of the Creston or it may, on the other hand, never have been deposited and therefore indicates a local disconformity. The lesser thickness of the Creston formation in this area supports the latter alternative, though such thinning may in part be explained by increased deformation. It must be noted, however, that no evidence of an angular unconformity has been found.

The contact with the Kitchener formation above is arbitrarily marked at a point where all beds begin to show, by their weathering characteristics, the presence of lime. Although there may be minor successions of calcareous rocks in the upper part of the Creston formation, some up to 100 feet thick, the Kitchener argillaceous beds are dolomitic or limy and weather alternately green and buff, depending on the carbonate content, and basal Kitchener quartzose beds show irregular weathering of pods or patches of limy material. As these characteristics may vary along strike, the Creston-Kitchener contact as mapped may vary stratigraphically as much as several hundred feet from point to point.

KITCHENER FORMATION

The Kitchener formation is mapped in this area as previously defined stratigraphically by Schofield (1915, p. 31) and as later used by Rice (1937, p. 9). Rice, in mapping Nelson area, east half, found it impossible to divide Kitchener from Siyeh in many places, but within the limits of Dewar Creek map-area these difficulties are not encountered, and Kitchener and Siyeh formations are mapped separately.

Within Dewar Creek map-area the Kitchener formation outcrops in a large area to the east and southeast of the batholith, and in isolated infolds in tightly folded Creston rocks along the western boundary. A section measured along the east boundary of the map-area shows the formation to be about 4,700 feet thick.

The Kitchener formation is the lowest of the Purcell series within Dewar Creek area to contain carbonate, but the characteristic rocks are sericitic and chloritic, calcareous and dolomitic argillites and siltstones. The main rocks are: very fine-grained, reddish weathering quartzites and siltstones, characteristically rough on weathered surfaces; fine buff weathering cream coloured sandy dolomite and dolomite, commonly with finely etched laminae on weathered surfaces; black limestone and argillaceous or arenaceous limestone; and alternating beds of black and light grey, thin-bedded argillite, $\frac{1}{4}$ to 1 inch thick, and thin laminated argillite in alternating hues of light and dark green. Bedding is everywhere very thin, varying from a small fraction of an inch to 2 inches. Though most beds contain carbonate, there is little pure limestone or dolomite, and almost all sections contain a large amount of quartz. Though the formation is generally uniform with all sedimentary rocks enumerated above, occurring in various amounts throughout, the predominant colour of the argillites changes from green in the lower part of the formation to black or interlaminated black and white in the upper part.

Characteristic indentations caused by differential weathering of calcite concentrations occur on faces of carbonate beds, especially the more massive ones. Although many of these concentrations are related to deformation within the beds, and may be shown to follow the surfaces of drag-folds and cleavage planes, many are not so obviously related to internal structural deformation. Such structures have been called 'molar-tooth' (Fenton and Fenton, 1937) because of resemblance to the irregular shape of the cutting edge of a molar tooth.

Thin sections of most of the rocks of this formation show very fine quartz and argillaceous material too fine to identify. In the more quartzose beds the quartz grains are not over 0·03 to 0·05 mm. in size. Detrital grains of carbonate are not recognizable in thin section; it occurs rather in irregular crystalline patches, though some well formed dolomite rhombs are found. Accessory tourmaline, pyrite, hematite, and rare zircon are present in most sections.

Primary features indicating shallow water deposition are common throughout this formation also. Mud-cracks are found in the black argillites and wave ripple-marks and crossbedding in the more quartzitic beds. Very thin quartzite lenses, that are markedly discontinuous along strike, give further evidence of local irregularity of deposition.

This formation is little deformed along the eastern boundary, although the effect of the emplacement of White Creek batholith is clearly visible in the development of cleavage and drag-folding in the rocks along both sides of Buhl Creek. In many places well developed cleavage has so deformed the thin-bedded rocks that attitudes may be taken with confidence only on groups of quartzite beds. There has been some strike faulting, and in the deformed area near the mouth of Buhl Creek the contact with the overlying Siyeh formation is difficult to recognize. In the western part of the map-area the Kitchener has been tightly folded along with the Creston formation.

Kitchener Section measured along east boundary of map-area

Gradational, conformable contact with Siyeh formation at point where black, limy argillites and slates disappear and varicoloured slates and non-limy argillites and siltstones become predominant.

	Feet
Buff weathering, thin, irregularly laminated, limy siltstone and argillaceous dolomite; about one-quarter of this succession is irregularly interlaminated black shale and grey arenaceous shale and slate in beds ¼ to 1 inch thick...	200
Smooth, light green, buff weathering, argillaceous dolomite, in beds 2 to 12 inches; green, green weathering, chloritic siltstone; interlaminated black and grey slate. All three of these rock types occur in alternating successions about 20 feet thick..........	140
Alternating sections approximately 15 to 30 feet thick of: black, massive, slightly argillaceous, limestone; interlaminated 1-inch beds of black slate and grey arenaceous slate; and reddish, calcareous siltstone in beds ½ inch to 4 inches thick, interlaminated with ⅛-inch beds of shale showing mud-cracks........	480
Thin-bedded, black, argillaceous limestone and limy argillite, some very thin beds of red limy siltstone, and argillite; some black argillite with mud-cracks......	770
Quartz diorite sill..........	900
Very fine-grained, dense, green and white, contact metamorphic rock...........	250
Quartz diorite sill..........	100
Siltstone, buff coloured, thin bedded..........	10
Quartz diorite sill..........	10
Black argillite with mud-cracks; buff weathering dolomite and limy siltstone; dolomitic arenaceous argillite..........	100
Differentially weathered, very thin interlaminated black dolomitic limestone and sandy dolomite; crossbedded, red siltstone and quartzite, and argillite with mud-cracks in very thin beds less than ½ inch; a few white weathering, white siltstone beds up to 4 inches thick; some massive beds of limestone to 20 feet thick with very irregular 'molar-tooth' weathered patterns on surface.......	200
(The above part of the section appears from a distance as a sequence of alternating buff and grey to black successions 10 to 30 feet thick, the part below is alternating buff and green.)	
Green weathering, limy and non-limy slates and argillite that may change to buff weathering along strike; some green weathering argillaceous quartzite and mudstone with about an equal amount of buff weathering, cream coloured dolomite and sandy dolomite in alternating sections 5 to 20 feet thick; minor, buff weathering, dolomitic limestone..........	450
Reddish buff weathering, light grey or cream coloured, massive sandy dolomite with alternating successions of green slate and green siltstone and quartzite; sections of ½-inch bedded green slate and buff weathering, sandy, dolomitic slate and sandy dolomite that alternate every few feet..................	400
Buff weathering, ⅛ to ½ inch beds of sandy dolomite and limy, reddish siltstone; green slate and siltstone. Some ripple-marks in green siltstone............	200
Total thickness..................	4,200

Conformable, gradational contact with Creston formation on hillside east of headwaters of Cherry Creek, where predominant buff weathering dolomitic and limy siltstones and slates end.

The upper contact of the Kitchener formation with the Siyeh is conformable and gradational and is placed at the point where black and grey argillites of the Kitchener are overlain by greenish slates and argillites of the Siyeh.

SIYEH FORMATION

The Siyeh formation occurs in a narrow belt east of the lower end of Buhl Creek and is up to 2,000 feet thick. It consists of a series of very thin-bedded, green, purple, and grey argillites and slates and argillaceous quartzites. It differs from the underlying Kitchener only in that carbonate is much rarer and occurs only locally. In thin section these rocks are essentially similar to the Kitchener.

The Siyeh formation contains abundant evidence of shallow water deposition, such as mud-cracks, crossbedding, and ripple-marks. Other structures are identical with those found in the Kitchener formation.

Siyeh Section measured along ridge east of Buhl Creek about 1½ miles from eastern boundary of map-area

Gradational, conformable contact with overlying Dutch Creek formation placed arbitrarily at top of sheared igneous tuff and breccia.	
	Feet
Sheared tuff and volcanic breccia with most particles very fine, a few up to ¼ inch, and some to several inches in size	200
Diorite sill (flow?)	10
Green weathering, laminated slate, in alternating green and grey beds ⅛ to ¼ inch thick	60
Buff to rusty weathering, reddish siltstone, and arenaceous argillite and slate	200
Very regularly, thinly laminated, partly calcareous, argillite and slate in alternating light and dark green beds of ¼ inch or less; light greenish argillite, very irregularly laminated; some green and purple laminated slate; rare intraformational breccia with particles of light and dark green laminated argillite up to 3 inches in size embedded in a matrix of light green arenaceous argillite; much crossbedding and abundant surfaces with mud-cracks	1,000
Very thin beds, less than $\frac{1}{32}$ inch thick of purple to black argillite; some buff sandy and green sandy argillites	100
Section of very variable rocks in groups of beds not over 10 feet thick; purple and grey, in part limy, slate; green argillite; green and buff laminated argillite and slate; purple and black slate; green argillaceous quartzite. All are very thin bedded up to 4 inches thick, but average much less than 1 inch; some crossbedding and a few mud-cracks	300
Green, non-calcareous argillite and buff, calcareous argillite; buff siltstone	150
Total thickness	2,020
Conformable, gradational contact with underlying Kitchener formation.	

The top of the Siyeh formation marks the top of the Lower Purcell series. In other regions this division has been marked by the occurrence of the Purcell lava flows (Willis, 1902; Daly, 1912; and Rice, 1937 and 1941). No Purcell lavas occur in the Dewar Creek map-area and the Siyeh beds lie conformably and with gradational contact beneath the Dutch Creek formation of the Upper Purcell. There is, however, a sheared band of igneous breccia and tuff at such a stratigraphic position that it apparently corresponds to the Purcell lavas. Rice (1941, p. 10) has placed the contact between the Lower and Upper Purcell at the top of these tuffs. In this report the contact has been placed in the same position, though the tuff only occurs locally, along a short stretch of the ridge east of Buhl Creek.

DUTCH CREEK FORMATION

The Dutch Creek formation is only exposed over a small part of the map-area, southeast of Skookumchuck Creek. It reaches a thickness of perhaps 1,000 feet. In lithology it is similar to both the underlying Siyeh and Kitchener formations and separation from the Lower Purcell has been based entirely on the tuff marker beds. Fine-grained quartzites and argillites and dolomitic argillites and quartzites, with some pure dolomite beds make up most of the formation. Mud-cracks and crossbedding are common in the argillites and dolomitic quartzites respectively. Towards the batholith in the north the rocks of this formation are much sheared and have developed cleavage to such an extent that bedding and attitudes cannot be determined. Separation from the underlying Siyeh formation then becomes difficult or impossible.

Regional Metamorphism

The rocks of the Lower Purcell series in Dewar Creek map-area have been affected mainly by dynamic and dynamo-thermal metamorphism. It is notable that the grade of metamorphism reached has been universally low.

In the highly deformed and folded region in the western part of the map-area sericitic, crenulated phyllites show development of porphyroblasts of chlorite, biotite, generally perpendicular to foliation, small grains of muscovite, and rare chloritoid, in poorly developed patches seen only in thin sections. In the more quartzitic sections, scattered folia of sericite and chlorite show a rude orientation between quartzitic layers or between individual, recrystallized grains of quartz.

On the other hand, in the less deformed areas of the eastern part of the map-area, little change has taken place beyond the development of flow and fracture cleavage. There has been considerable recrystallization of the finer material in argillaceous quartzites resulting in the formation of sericite and chlorite from original clay minerals and scattered porphyroblasts of biotite. Such mineral assemblages are characteristic of the lowest grade of metamorphism, and belong to the biotite-chlorite or the muscovite-chlorite subfacies of the greenschist facies.

Age of Purcell Series

Equivalents of the Purcell series lying to the south and southeast in British Columbia, northern Idaho, and northwestern Montana have been shown to lie unconformably beneath the Cambrian. Emmons and Calkins state that in Phillipsburg area, Montana (1915), the Cambrian lies on Beltian rocks with an angular unconformity of about 30 degrees. In southeastern British Columbia Schofield (1922, p. 9) found that, though there is no discordance between Cambrian and Lower Purcell, a Cambrian conglomerate in Cranbrook area contains boulders of all older (Lower Purcell) formations in the vicinity. Later, Deiss, working in western Montana, considered that up to 20,000 feet of Beltian (Purcell) sediments had been removed before deposition of the Cambrian (Deiss, 1935, p. 106). He further states, "...The magnitude of the erosion interval and of the unconformity in Western Montana is held to be conclusive proof of the Precambrian age of the Beltian rocks..." (Deiss, 1935, p. 124.)

Correlation of Purcell Series

As pointed out by Clapp and Deiss (1931, p. 689), three methods of correlation may be used for unfossiliferous strata: by comparison of the detailed lithological character of each formation; by comparison of the sequence of formations in different stratigraphic sections; and finally, the best method, by the continuity of the beds. Although the formations have not actually been traced all the way, there is a remarkable similarity of both lithology and position in the stratigraphic column from Dewar Creek map-area to Cœur d'Alène District (Ransome and Calkins, 1908) of northern Idaho. This covers a distance of about 150 miles along the western edge of the known Beltian trough of western North America as pictured by Eardley (1951, p. 287). In addition, similar formations are found in the Phillipsburg area (Emmons and Calkins, 1915), another 150 miles to the southeast.

The series is everywhere composed of fine-grained, clastic sediments with little major variation (other than local irregularities in thickness and grain size) over the entire region. The most notable changes are in the Prichard-Aldridge formation. In southeastern British Columbia, the Aldridge formation west of Rocky Mountain Trench is essentially arenaceous, although east of the trench it is argillaceous (Rice, 1937). In Clark Fork district (Anderson, 1930) the Prichard formation is arenaceous, but in Cœur d'Alène, Libby Quadrangle (Gibson, 1948) and in Phillipsburg area it is predominantly argillaceous. This may represent merely a facies change eastward and southward, though the formations have not been traced. Certainly, formations equivalent to the upper parts of the Purcell series have been found to be fine grained, calcareous and dolomitic eastward in the Belt trough (Clapp and Deiss, 1931).

Origin of Purcell Series

GEOGRAPHIC ORIGIN

As noted briefly in the correlation above, the Belt-Purcell sediments have been deposited over a very wide area. Southward from Dewar Creek area they remain similar, fine-grained to very fine-grained clastics; to the eastward they become increasingly fine grained, calcareous, and dolomitic. In addition, particularly along the western part of the Belt-Purcell terrain, shallow water features are common to abundant in the upper part of the series. In the Aldridge-Prichard formation such features are much rarer. It must be noted, however, that in the Lower Aldridge formation of Dewar Creek area and in the Fort Steele formation underlying the Aldridge in Cranbrook area (Rice, 1937, pp. 4-5), there is found every shallow water feature described for the upper part of the series. Such widespread similarity in lithology and primary structures, in a sequence of clastic and limy deposits of this great thickness, is indicative of origin in a marine trough of wide extent. For similar reasons Deiss (1935, p. 105) concluded a marine origin for the Belt sediments in the eastern part of the basin in western Montana.

The geographic source of the Purcell-Belt sediments is not clearly indicated except that on a broad regional scale they may increase in grain size westward and possibly northward. Within the narrower limits of Dewar Creek area it must be noted, however, that the Upper Aldridge becomes increasingly arenaceous to the west, the Creston formation, on the other hand, is markedly coarser grained in the east, as is the overlying Kitchener formation. Furthermore the Creston thickens somewhat eastward. Therefore, after examination of the Purcell sediments in greater detail within Dewar Creek area it seems unlikely that variations of grain size in such fine-grained sediments are indicative of direction of source area at all, and the writer is inclined to agree with Rice that ". . . he has no idea from which direction the material forming the Purcell rocks was derived, but, in the light of present knowledge, the possibility of a source other than from the west cannot be excluded". (Rice, 1941, p. 13.)

TECTONIC ORIGIN

The tectonic environment, both of the source area and the area of deposition of the sediments, may be considered in large part to control the character and composition of any succession of sedimentary strata. Thus geosynclinal deposits are thick and wedge-shaped and are formed as a result of rapid uplift in source area, combined with rapid downwarp in area of deposition. These sediments are deposited below wave base and retain their original character; they may be poorly bedded, or may show graded bedding. Great thicknesses occur. On the other hand, the Foreland facies or orthoquartzite-limestone suite is deposited under conditions of equilibrium on the stable shelf. Rocks of this facies are essentially shoal water deposits and are chiefly orthoquartzites and limestones. Commonly the orthoquartzite grades upward into arenaceous dolomite or limestone, commonly with interbedded orthoquartzite. Such deposits are thin compared with those of the greywacke suite. (Pettijohn, 1949.)

With the principal characteristics of both the Geosynclinal facies and the Foreland facies in mind it is of interest to review briefly the principal characteristics of the Purcell sedimentary rocks in order to reconstruct, at least in part, the tectonic conditions under which they may well have been deposited.

The Purcell succession begins with the quartzites and argillites and their calcareous and dolomitic equivalents of the Fort Steele formation of Cranbrook area. In the Purcell Mountains to the west, this is followed by Lower Aldridge quartzites and argillaceous quartzites. All of these rocks show primary structures indicating deposition in shallow water. The 10,000 feet of Upper Aldridge on the other hand, show few shallow water features, but do show graded beds, local 'squeeze-ups' of shaly rock in pointed crests into overlying quartzite, both features indicating rapid deposition. Further indication of rapid deposition with incomplete sorting is shown in the bimodal character of the quartzites of the Upper Aldridge in which larger grains of detrital quartz are embedded in a much finer matrix of quartz with some sericitic and chloritic material. Much of the clayey material has been removed into intercalated layers of argillite. Above the Aldridge formation there continues about 15,000 feet of thin-bedded, shallow water deposits consisting of fine-grained quartzites, argillaceous quartzites, siltstones and their calcareous and dolomitic equivalents. The thickness of the entire series including the Fort Steele formation is 38,000 feet or more.

This thickness of sediments alone is more consistent with that expected in the wedge deposits of the greywacke suite, yet the composition and physical features of the series is more consistent with that expected in the orthoquartzite-limestone suite.

The occurrence throughout of shallow water features and the general uniformity of sedimentary rock type in the Purcell series indicate a remarkable tectonic balance between source area and area of deposition. Only rarely, as shown by the Upper Aldridge sediments, has the rate of downwarp of the depositional area exceeded the rate of sedimentation so that shallow water features are not abundant. Yet, even with this exception, the series could only have been deposited in a region of relative tectonic stability over a long period. The absence of pure orthoquartzites may well be explained by the fact that in such fine-grained sediments the final separation of clayey and sandy fractions is impossible and they have survived together in the stable shelf environment.

This delicate balance between source area and area of deposition gives rise to several problems. If subsidence and uplift are entirely tectonic, how can such a balance be maintained with only few exceptions over such a long time, as indicated by the continual occurrence of shallow water features yet without good sorting? On the other hand, to what extent may unconsolidated sediments of low specific gravity displace material below of higher specific gravity? Some such movement seems necessary in order to control directly uplift in the source area so that the resulting sediments could keep pace with the downsinking of the basin of sedimentation.

Structures in Pre-batholithic Rocks

Dewar Creek map-area occurs mainly within the axial area and part of the western limb of the gently north-plunging geanticline of the Purcell Mountains. In general, within this area fold structures trend a little east of north on the western limb and west of north on the eastern limb. On the other hand, within the axial area of the geanticline strata may have various trends, depending on local folding and faulting. Also, two major north-trending northeastward curving faults, the Lenia-Moyie and the St. Mary faults, twice repeat most of the Lower Purcell succession along the axis of the geanticline between the International Boundary and Dewar Creek area. As noted below, Hall Lake fault passing through the region White Creek batholith now occupies, has again caused most of the Lower Purcell to be repeated north of White Creek batholith and northward into Findlay Creek area (Reesor, 1953), (*see* Figure 1, p. 26).

Three local regions, each with characteristic structural features, may be recognized for descriptive purposes in Dewar Creek map-area. First, an area of relatively little deformation extending east of, and including, the competent Upper Aldridge quartzites between White and Dewar Creeks; second, an area of isoclinally folded, sheared, and low-grade, regionally metamorphosed rocks west of the Upper Aldridge; third, an area of intensely deformed and metamorphosed rocks that surrounds and is consequent upon the intrusion of White Creek batholith and has involved parts of the first two areas.

AREA OF MINOR DEFORMATION

The area east of White Creek, south and east of the batholith, is part of the axial area of the Purcell geanticline. This area has been deformed into two or more large open flexures with many minor folds, open in the more competent Creston formation but more compressed and with vertical to slightly overturned eastern limbs, towards the eastern boundary of the map-area, in the more incompetent formations above and below the Creston. Though the Creston and Lower Aldridge rocks immediately west of White Creek, in the vicinity of Hall Lake fault, are intensely deformed as a result of the faulting, the Upper Aldridge rocks farther west are considered to belong to this relatively lesser deformed area.

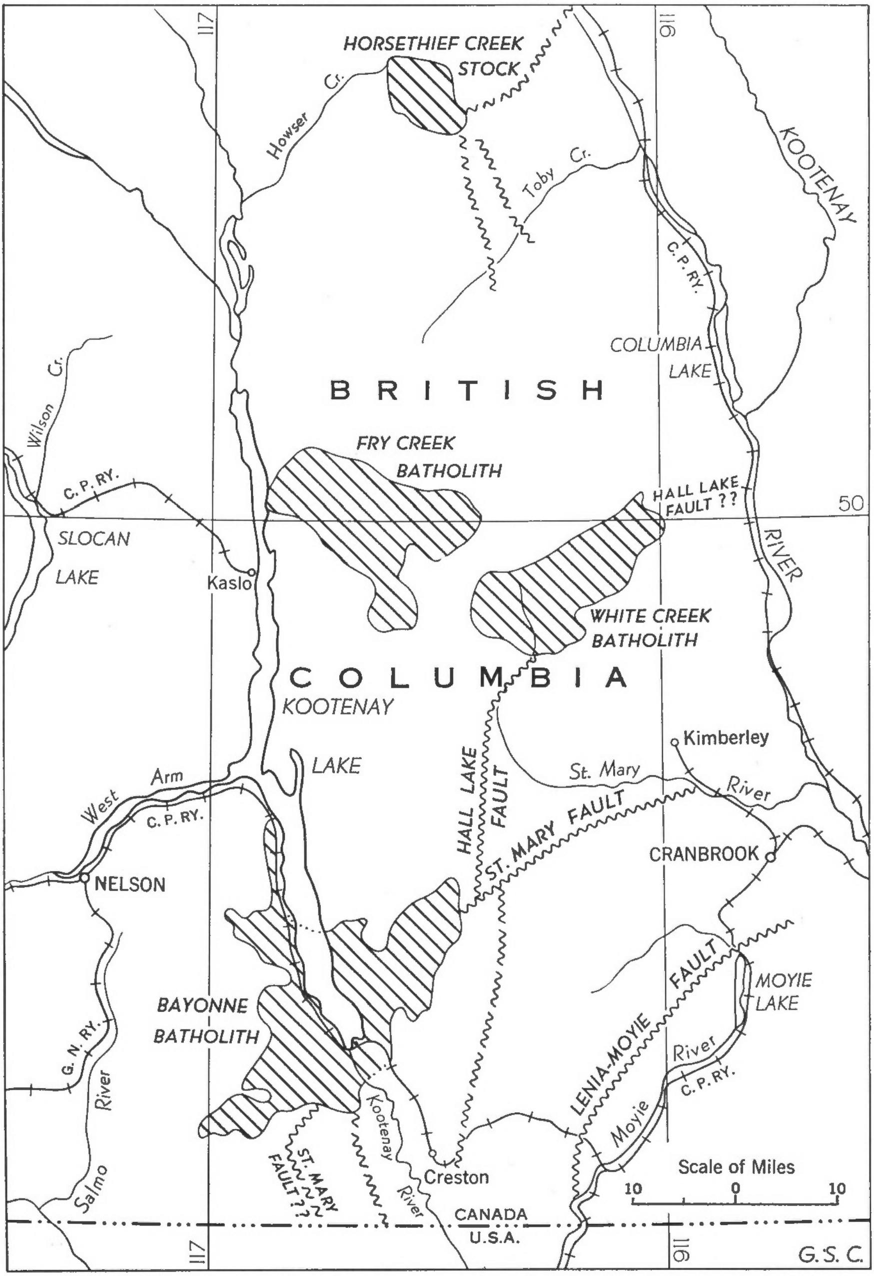


Figure 1. Sketch map showing minor batholiths and major faults. Note three major northeast-curving faults each of which brings older rocks on the northwest side against younger on the southeast. Bayonne and White Creek batholiths bear the same relation to St. Mary and Hall Lake faults, respectively.

With the exception of Hall Lake fault, there are no major faults within this area. There are, however, numerous breaks and shear zones of minor importance striking generally northward. Some are shown on the cross-section, but not on the map as the direction of movement is rarely known nor the extension of the faults traceable for any distance.

East of White Creek, in the Argillite member of the Upper Aldridge, minor folds up to 100 or 200 feet amplitude, with steep west-dipping west limbs and gentle east-dipping east limbs are clearly drag-folds related to major folding. Axial planes of these minor folds dip steeply eastward. In the region of Mark Creek and eastward, however, there is marked overturning in the minor folding. Eastern limbs are vertical to steeply west-dipping and axial planes may dip as little as 45 degrees westward. The overturning is not noted in the more competent overlying Creston formation.

Cleavage is invariably related to the minor folds, except in the vicinity of shear zones. In places, however, within the more resistant quartzitic beds, fracture cleavage may be noted, radiating outward from a point within an overturned fold. Thus, cleavage on the west limb dips steeply towards the centre of the fold, and cleavage on the east limb dips moderately towards the same centre or is horizontal. Fracture cleavage in these competent beds was formed while the fold was still symmetrical and open, and was subparallel to the axial plane of the fold. As deformation of the fold progressed, this cleavage was apparently rotated, particularly on the steep, eastern limbs of the folds, until it appears to radiate from a point within the fold. Cloos (1937, pp. 68, 69) interprets such radiating cleavage as indicating further deformation after cleavage originally formed. This could be interpreted in Dewar Creek area as indicating that minor folds formed at the time of the major deformation that produced the Purcell geanticline, but that later compression from the west further deformed and partly overturned the minor folds in the eastern part of the area.

AREA OF FOLDING AND REGIONAL METAMORPHISM

In contrast to the part of the area described above, the region west of the Upper Aldridge quartzites has been irregularly and more tightly folded and is correspondingly more metamorphosed. The structural pattern is shown diagrammatically in cross-sections A-B and C-D, (*see* Map 1053A).

In general, tight isoclinal folds (*see* Plate II B) may alternate with open folds of much less amplitude, particularly in the more competent parts of the Creston formation. Most folds are, however, so compressed that all beds dip steeply, a few degrees from vertical in either direction. Entire ridge tops may be traversed without folds being noticed and only on open hillsides or on cirque faces may the folding be seen. Furthermore, primary structural features have been destroyed, and tops of beds cannot be established. These structures therefore cannot be worked out in detail.

Cleavage is well developed and is generally nearly parallel with the bedding, although it may crosscut the beds at crests or troughs of folds. The lineation formed by the intersection of the cleavage and bedding, and the axial lines of minor folds and drag-folds is invariably nearly horizontal, but may locally plunge 10 degrees north or south. There is therefore little variation in the attitude of the major structure along the western border of the map-area.

It is apparent from the spatial relations and from the relative competency of the Upper Aldridge and the Creston-Kitchener formations that the Upper Aldridge has acted as a competent buttress against which the rocks to the west have been tightly compressed. It is also apparent that these structures have been formed prior to the intrusion of White Creek batholith, for vertical structures have been modified by the emplacement of the batholith as far west as the westernmost Moyie sill in Creston rocks. It therefore seems that Upper Aldridge quartzite must originally have continued northward in the area now occupied by the batholith and continued the buttress against which the western rocks were folded.

AREA OF DEFORMATION AND METAMORPHISM AROUND WHITE CREEK BATHOLITH

Deformation caused by the emplacement of the White Creek intrusion has been superimposed on the existing structures in both the areas of moderate and strong folding. Although the batholith may locally truncate bordering strata, the pre-existing structures are violently sidethrust and are forced to conform with the direction of contact. These effects are visible up to 2 miles from the batholith. The structural details are described in Chapter III, pages 54-58.

FAULTS

Hall Lake Fault

This fault extends from the southern boundary of St. Mary Lake map-area (G. B. Leech, 1952) northward into Dewar Creek area along the west side of White Creek. From there it curves farther to the east, crosses White Creek, and continues northeast until it terminates against the batholith. The possibility that it may have continued northeastward prior to emplacement of White Creek batholith is considered later (*see* p. 55).

This is a fault of major importance and in Dewar Creek area has brought sheared, rusty weathering, Lower Aldridge quartzites against green, argillaceous Creston quartzites, involving a displacement of at least 15,000 feet, perhaps more. In the fault zone, a short distance below the large sill, intense shearing has developed a marked vertical cleavage parallel with the fault, and locally intense brecciation may be noted. The base of the large sill has been much deformed and sheared with the development of a roughly horizontal lineation, shown by elongate amphibole in the diorite. On the hillside above, in Lower Aldridge strata, are many minor folds, with axial planes dipping steeply west and horizontal to gently south-plunging axial lines. Some of these folds may be breached at the crest by minor faults, mostly with west side moving upward. The resulting complexity of structure and rock relations is shown to some extent by the irregularity of the sills shown on the map (in pocket).

Northward, at the curve in Hall Lake fault, drag-folds with vertical crests are found in the fault plane, with amplitudes of several inches and vertical axial planes striking south 40 to 60 degrees east. This indicates the possibility of some horizontal movement along the fault, apparently with east side southward. In addition, large, isoclinal folds with vertical axes and up to several tens of feet amplitude are found in the Lower Aldridge strata above the curve in Hall Lake fault.

Findlay Creek Fault

This fault lies northwest of White Creek batholith, and west of Mount St. Mary and is marked by a non-rusty zone of drag-folding and shearing, not less than 100 yards wide. Drag-folds in the fault zone appear to indicate that the west side moved upward, but the magnitude of this upward movement is not known. The fault may be traced northward but has not been found in Findlay Creek map-area to the north (Reesor, 1953).

Findlay Creek fault, at its present southern extremity is sharply truncated by White Creek batholith. Foliation in the fault zone is pushed and bent into conformity with the direction of the granodiorite contact, just as are the adjoining sedimentary rocks.

Other Faults

East of Radiant Peak, drag-folds and minor fold axes plunge about 20 degrees south; just north of Nowitka Mountain they steepen to 50 or 60 degrees south. Immediately west of Nowitka Mountain plunges have decreased to 30 or 40 degrees and decrease farther south to 20 or 25 degrees. It appears, therefore, that there is a sharp bow in the strata north of Nowitka Mountain and there may be some faulting there, though it has not been seen.

Other faults, particularly west of Burnt Creek, are clearly shown by displacement of sills. Where no sills are found and faults occur along the strike of thin-bedded, uniform strata they cannot be easily distinguished or followed for any distance. A few have been marked, but many more may occur, particularly in the areas east of Buhl Creek and west of Dewar Creek.

CHAPTER III

INTRUSIVE ROCKS

Moyie Intrusions

The sills and small dykes comprising the intrusions that have been referred to as the Moyie sills (Daly, 1912, pp. 226-255), Purcell sills (Schofield, 1915, pp. 56-75), and Purcell intrusives (Rice, 1941, p. 34) are here called Moyie intrusions in order to avoid using the term 'Purcell' for an individual rock unit within the Purcell series, and to avoid using the term 'Purcell' for rocks that may well be of later age.

The Moyie intrusions occur throughout the Lower Purcell rocks of the map-area, but are most abundant in the Aldridge formation. Although individual sills may break through from horizon to horizon and may disappear along strike, groups of several sills may commonly be traced along a given horizon in the Aldridge formation for many miles. The largest sills are 200 to 400 feet thick, although in a few places they may be 1,000 feet thick or more. Commonly, the large sills include lenses of sedimentary rocks that break their continuity, as for example in the large sill west of White Creek.

The sills are essentially meta-diorite and meta-quartz diorite in which most of the original pyroxene has been replaced by amphibole, and in which the plagioclase is partly to completely albitized. Calcite, and calcite-quartz veins and stringers are common, some with minor chalcopyrite, galena, or sphalerite. The rocks near the margin of some of the larger sills are extremely rich in biotite and albite, and may represent alteration of and reaction with the bordering sedimentary rocks.

The sills are structurally conformable with the enclosing sedimentary rocks, though locally they may sharply cut across the bedding. Furthermore, they may terminate or thin abruptly and such terminations may in many places be mistaken for faulting. The sills have taken part in all the structural deformation, both folding and faulting, that has effected the sedimentary rocks. In addition, near White Creek batholith or near large faults, a marked, regular foliation has developed that, if deformation has been intense, may be found throughout the sill or if deformation has been less severe, occurs only near to, and parallel with, the contacts. The sills have been cut and intruded by the granodiorite of the White Creek batholith. Further descriptions of the sills have been given by Rice (1937, pp. 13-18; and 1941, pp. 24-27).

In a region such as that represented by Dewar Creek map-area, in which the entire sedimentary section is Precambrian and in which the intrusive rocks may belong to one or more of several igneous periods, it is not possible accurately to determine age relations. The writer concurs with Rice (1941, p. 27), that the sills are post-Upper Purcell and possibly of late Proterozoic age.

Ultramafic Rocks

At the southwest corner of White Creek batholith, a small ultramafic stock occurs, that is intrusive into the Creston formation, but is in turn cut by dykes of pegmatite and granodiorite. The body is oval in shape, not over 1 mile long by $\frac{1}{2}$ mile wide.

The characteristic and most abundant rock is a very fine-grained dense, purplish to greenish, brownish weathering serpentine, that in thin section is seen to be composed entirely of antigorite with scattered grains of magnetite. Other rocks within the body are clino-pyroxenite, in places olivinitic, and in places somewhat serpentinized. Near the granitic contact coarse actinolite occurs that in some instances is coated with large plates of biotite.

A semi-quantitative spectrographic analysis of the serpentinized clino-pyroxenite shows that it consists of over 10 per cent each of silica and magnesium, with 8 per cent iron, approximately 0·3 per cent each of calcium and aluminum, 0·05 per cent each of nickel, manganese and titanium as well as 0·06 per cent chromium. This body is therefore considered to be an ultramafic intrusion that has been emplaced after the deposition of the Kitchener but before the emplacement of White Creek batholith. The composition noted above indicates that it is not a highly metamorphosed equivalent of the dolomitic and calcareous quartzites and argillaceous quartzites of the infold of Kitchener rocks which strike directly into it from Irish Queen Mountain.

Fry Creek Batholith

Fry Creek batholith outcrops over 12 square miles in the northwest corner of Dewar Creek map-area, and was previously noted by Rice (1941, p. 34). Wherever examined, the rock of this batholith is a homogeneous, medium-grained leuco-quartz monzonite (*see* modal analysis 44, Table I). There are a few irregular, simple pegmatites and aplites, but no inclusions of sedimentary wall-rocks and no phenocrysts of microcline, so common in White Creek batholith to the southeast. Planar foliation (protoclastic structure) may be noted in both quartz and feldspar near the border of the batholith, but otherwise too little mafic material is present to show a primary foliation, as seen in White Creek batholith.

White Creek Batholith

DISTRIBUTION AND GENERAL DESCRIPTION

The White Creek batholith outcrops over an area of approximately 140 square miles in the central part of the map-area. It is well exposed over elevations from 4,000 feet to 9,500 feet, and above 7,000 feet much of it is cleaned by alpine glacial action, so that thorough examinations of a large area of outcrop is possible. The intrusion occupies a roughly oval-shaped area with the long axis trending northeast, and exhibits a more or less concentric arrangement of its various subdivisions.

Around the margin of the western part of the batholith, is a segment of biotite granodiorite (9)[1]. Adjacent to and within this segment lies a body of hornblende-biotite granodiorite (10). Inward from this again, and forming, in addition, most of the eastern half of the batholith, is a large body of highly porphyritic quartz monzonite (11) that contains microcline phenocrysts in various amounts. The interior of the batholith is composed of leuco-quartz monzonite (12), varying in texture from medium to coarsely granitic. The contacts between each of the above rock types are mainly gradational, although the interior quartz monzonite (12) is intrusive against the highly porphyritic quartz monzonite (11) on the south side of the upper Skookumchuck Creek. Elsewhere this contact is gradational over a considerable distance. West of the upper part of White Creek, a mass of medium-grained, equigranular quartz monzonite (14) intrudes the older granodiorites of the batholith, and later, minor intrusions of aplite (15) and pegmatite (16) occur, not only throughout the marginal area of the batholith, but also, in places, beyond its boundaries.

HORNBLENDE-BIOTITE AND BIOTITE GRANODIORITE

Megascopic Description. Mafic-rich granodiorites (9, 10) form an irregular segment around the western and southwestern borders of White Creek batholith. Though biotite granodiorite grades inward to hornblende-biotite granodiorite over a distance of 200 to 300 yards, they are easily distinguishable, for the hornblende is clearly visible and commonly occurs in idiomorphic crystals up to $\frac{1}{4}$ inch or more in length. In hand specimen, both types of granodiorite are medium-grained, grey rocks. Grey to whitish plagioclase is the most common mineral, and occurs in elongate, visibly twinned crystals up to $\frac{1}{4}$ inch long. Quartz is clearly visible as small irregular grains $\frac{1}{16}$ to $\frac{1}{8}$ inch in size. Mafic minerals, on the other hand, occur in irregular patches and stringers, most even in hand specimen, as tiny 'clots' similar in texture to the inclusions (*see* Plate III A). Such biotite clots and stringers, as well as hornblende porphyroblasts, are oriented in a plane of primary foliation. In some places, distinct lineation may be observed, due to parallel orientation of hornblende crystals.

[1] Numbers in brackets refer to numbers of rock-units on the map.

Table I

MODAL ANALYSES OF GRANITIC ROCKS

Main Rock Types of White Creek Batholith

	White Creek Batholith																
Specimen Number	1	2	3	4	5	6	7	8*	9	10	11	12	13	14	15	16	17*
	Leuco-quartz Monzonite								Porphyritic Quartz Monzonite								
Plagioclase	26	27	26	27	31	31	25	27	33	36	41	35	39	44	41	37	38
Microcline	27	26	28	32	29	24	32	28	29	32	24	21	26	24	16	28	25
Quartz	37	38	36	32	33	38	37	36	28	24	26	34	25	21	31	25	27
Biotite	1	2·5	3	2	3	1	0·5	2	5	6·5	7	8	6	10	11	7	7·5
Hornblende																1	0
Muscovite	6	4·5	4	6	3	5	5	5	3	1		1					0·5
Total Accessories	3	2	3	1	1	1	0·5	2	2	0·5	2	1	4	1	1	2	2
Apatite	x	x	x	x		x	x			x	x	x	x	x	x	x	
Magnetite	x	x	x	x	x				x	x	x	x	x	x	x	x	
Epidote													x	x	x		
Sphene													x		x	x	
Allanite													x			x	
Zircon	x	x	x	x	x	x			x	x			x				
Fluorite						x											
Myrmekite	2·5	x	2	x	x	x	x		x	x	1·8	0·8	2·0	0·6	0·6	x	
Average Percentage An in Plagioclase	20	22	20	21	21	19	23		21	23	25	25	25	28	29	25	
	(126″) Leucoadamellite	(127″) Leucoadamellite	(126″) Leucoadamellite	(126″) Leucoadamellite	(127″) Leucoadamellite	(127″) Leucoadamellite	(126″D) Leucoadamellite		(227″) Adamellite	(227″) Adamellite	(227″) Adamellite	(227″) Adamellite	(227″) Adamellite	(227″) Adamellite	(227′) Monzotonalite	(227″) Adamellite	

	White Creek Batholith											
Specimen Number	18	19	20	21	22	23	24	25	26	27	28	29*
	Hornblende-Biotite Granodiorite											
Plagioclase	49	46	37	44	49	45	45	44	44	38	40	44
Microcline	13	8	21	11	11	10	16	11	14	24	13	14
Quartz	22	26	24	19	18	24	19	24	15	16	18	20·5
Biotite	10	10	10	13	15	10	12	13	13	12	16	12
Hornblende	3	6	4	8	4	9	5	5	12	8	8	6·5
Muscovite												
Total Accessories	3	4	4	4	3	2	3	3	2	2	5	3
Apatite	x	xx	x	xx	x	x	x	x		x	x	
Magnetite	x	x		x	x		x		x	x	x	
Epidote	x		x	x			x	x	x	x	x	
Sphene	x	xx	xx	xx	xx	xx	x	x	x	x	xx	
Allanite							x	x			x	
Zircon		x										
Fluorite							x					
Myrmekite	1	1	2	1·5	x	1	x	x	x	1	3	
Average Percentage An in Plagioclase	27	29	33	33	32	33	33	33	32	30	34	
	(227′) Monzotonalite	(227′) Monzotonalite	(227″) Adamellite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227″) Adamellite	(227′) Monzotonalite	

	White Creek Batholith														Fry Creek Batholith
Specimen Number	30	31	32	33	34	35	36	37	38	39*	40	41	42	43*	44
	Biotite Granodiorite										Quartz Monzonite				
Plagioclase	44	44	38	49	50	47	47	39	42	44	34	37	44	38	33
Microcline	16	19	16	12	16	15	16	25	21	17	20	22	11	19	32
Quartz	16	16	18	12	17	16	18	21	16	17	30	27	31	29	28
Biotite	16	15	20·5	18	12	17	15	13	15	16	12	8	11	10	3
Hornblende	2			x	1	2			x						
Muscovite											1·5	2	x	1	1
Total Accessories	6	6	7·5	9	4	3	4	2	6	6	2·5	4	3	3	3
Apatite	x	x	x	x	x	x	x	x	x		x	x	x		
Magnetite	x	x	x	x		x	x		x		x	x	x		x
Epidote	xx	xx	xx	xx	xx	xx	x	x	x		x	x	x		
Sphene	xx	x	xx	xx	xx	x	xx	x	x			x			
Allanite									x						
Zircon				x											x
Fluorite															
Myrmekite	x	1	1	2	1	x	x	x	x		x	x	x		2
Average Percentage An in Plagioclase	32	34	35	32	35	34	35	32	36		29	35	30		
	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227′) Monzotonalite	(227″) Adamellite	(227′) Monzotonalite		(227″) Adamellite	(227″) Adamellite	(227′) Monzotonalite		(126″) Leucoadamellite

Note: Measurements for modal analyses have been made so that a total length traversed is at least 100 times the length of largest grain of the main constituents in the thin sections. Mineral content reported to nearest per cent.

*Average composition of preceding rock type.

Note: Name and number at bottom of each analysis is according to Johannsen's classification. Names along the top are more common names used in text and on map.

Present also, in both types of mafic-rich granodiorite, are phenocrysts of potash feldspar, up to $\frac{1}{2}$ by 1 inch in size, which, though locally absent, generally form from 1 or 2 per cent to 10 or 15 per cent of the rock by volume. Basic inclusions occur in large numbers throughout the border zones. Their number and size decrease inward and no inclusions were observed beyond a distance of 2 miles from the contact of the intrusion. This is shown diagrammatically in cross-sections E-F, G-H, J-K (*see* map).

Modal analyses given in Table I, facing page 32, show the mineral composition of the hornblende-biotite and biotite granodiorite. The microcline is a variable constituent and the phenocrysts, where they occur, are too large and too scattered for thin sections to serve as a reliable sample. They were therefore ignored and analyses were made of the medium-grained matrix only. If a consistent correction could be made to include the phenocrysts in the mode, the composition of the rocks would probably be closer to that of a quartz monzonite. Analyses 37 and 38, taken within a few feet of the south contact, are of finer-grained, non-porphyritic rocks with much more microcline distributed throughout the groundmass. They may therefore be more representative of the biotite granodiorite map-unit (9) as a whole.

Figure 2 shows the modal analyses plotted according to Johannsen's classification with classes 1 and 2 (less and more than 5 per cent mafic minerals respectively) plotted on the same diagram. Figure 3 shows the locality from which each specimen was taken. It may be noted in summary, that the principal differences between the hornblende-biotite and the biotite granodiorite is in the greater hornblende and quartz content of the former and the greater biotite, epidote, and sphene content of the latter.

Microscopic Description. Under the microscope, the light minerals, mostly plagioclase, are seen to be medium grained and hypidiomorphic, with some interstitial granular quartz, plagioclase, and accessory minerals associated with stringers and clots of mafic minerals. Grain size in the larger minerals averages 1 to 3 mm., rarely double that, but within the groups of mafic minerals it is commonly less than $\frac{1}{2}$ mm. Plate IV A shows the essential minerals and their relationships. Plate IV B shows the relation between light minerals and the patches of mafic minerals.

Plagioclase is the most abundant mineral. It occurs in subhedral to anhedral grains, averaging about 2 mm., though occasionally there are grains up to 6 mm. in size. Twinning after the albite, Carlsbad, and pericline laws is particularly common, but zoning is less common. Several slight reversals of zones within a grain may be present.

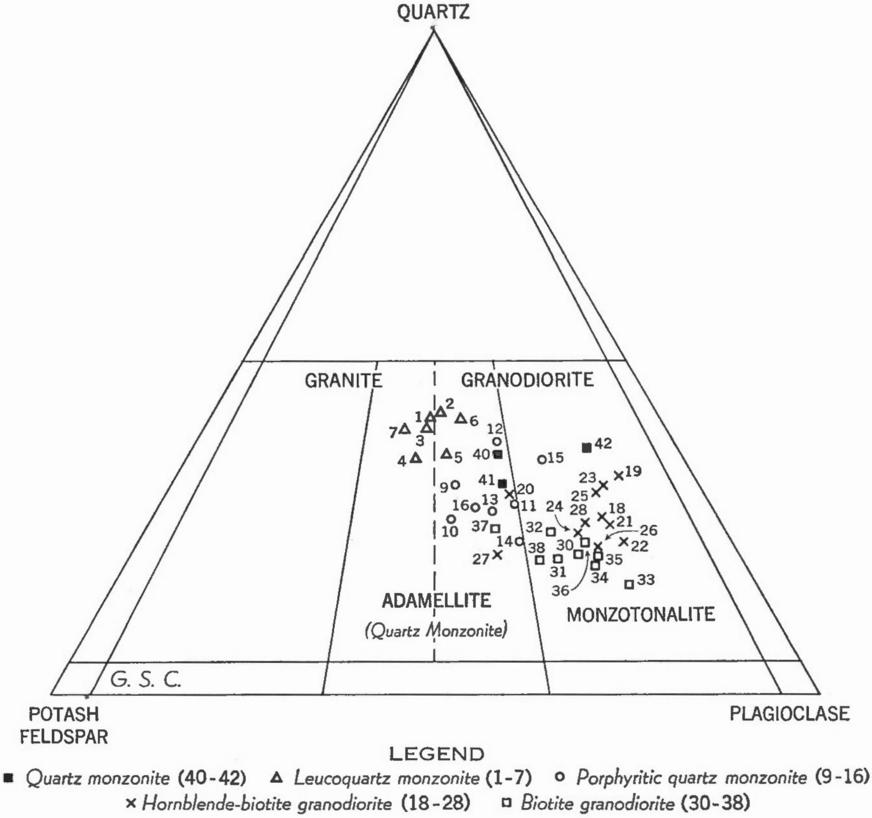


Figure 2. Modes of specimens from White Creek batholith.

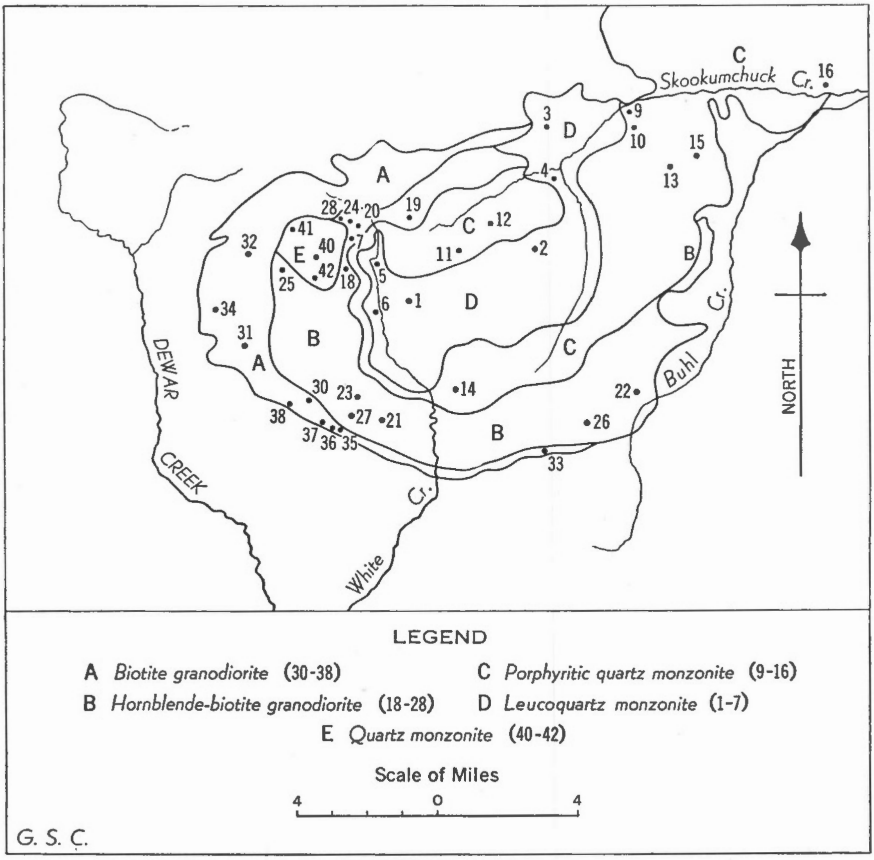


Figure 3. Sketch map showing location of specimens for modal analyses.

Measurements of indices of refraction and extinction angles (Rittmann Method), show that the plagioclase varies in composition from An_{25} to An_{40}. Grains are commonly clouded, some with a fine black dust of iron ore and some with fine shreds of white mica. The centres of grains may be entirely altered to epidote and clinozoisite (saussuritized). Commonly, the white mica is associated with calcite, veinlets of which may even penetrate into clear and unaltered potash feldspar, showing that the alteration has taken place very late in the formation of the batholith as potash feldspar was one of the latest minerals to form. Rarely, the plagioclase may show strained extinction and albite twins may be slightly bent.

Potash feldspar occurs both as phenocrysts and as irregular, interstitial grains and veinlets filling openings between other minerals. The larger phenocrysts are from $\frac{1}{2}$ inch square to $\frac{1}{2}$ inch by 1 inch in size. Many include small grains of all other minerals present in the rock. Most of the potash feldspar shows the grid twinning and cleavage angle in the basal section of microcline but a few indeterminate grains may be orthoclase. A few grains show microperthitic intergrowths with albite. Most of the potash feldspar is clear and unaltered but some shows a brown, dusty alteration along cleavage planes, probably of kaolinite.

Biotite commonly occurs as flakes up to 2 mm. long, or as ragged grains in clusters, mostly as small as 0·1 mm. It is strongly pleochroic from light tan to very light green to dark green or 'cloudy' and has many inclusions of apatite. Commonly the grains and clusters are intergrown with sphene and epidote. It shows, on the whole, little alteration and, though most show even extinction, some cleavage lamellae may be bent and show strained extinction.

Quartz may occur as irregular grains 1 or 2 mm. in size, or as small, recrystallized granular mosaics. It is apparent that large grains of quartz with strained extinction have been recrystallized to form the mosaics of unstrained, granular appearance. That such patches were once larger grains of quartz is shown by the conformity of several adjacent grains with the euhedral shape of a plagioclase grain. Most of the quartz is clear, but contains iron ore as tiny black specks, commonly oriented along definite lines. Quartz is apparently one of the last minerals to crystallize and is found surrounding, or interstitial to other mineral grains, as clearly shown in Plate IV A.

Hornblende may occur as perfect euhedral crystals less than 2 mm. in length or as irregular grains, commonly fresher in appearance than the biotite with which it is associated. It is a common green hornblende: X—yellow-brown, Y—olive-green, Z—dark green, Z C—20 degrees, Nx—1·652± ·002, Ny—1·655± ·002, Nz—1·671± ·002.

In some thin sections it includes tiny flakes of biotite, all with the same orientation. Sphene and epidote are much less plentiful near hornblende than near biotite. Associated biotite is commonly ragged and shows incipient to marked alteration to chlorite. It appears, therefore, that the hornblende is of late development, forming at the expense of biotite, epidote, and sphene. It is much fresher in appearance than these minerals. Furthermore, hornblende may occur pushing aside strings of tiny flakes of biotite, sphene, and epidote, as though some displacement as well as replacement has occurred.

Accessory minerals are abundant. Magnetite, ilmenite, rutile, apatite, sphene, epidote, zoisite and clinozoisite, sericite, calcite, allanite are common, zircon and tourmaline are less common. The iron minerals, apatite, and sphene are commonly associated with, or included in, the mafic minerals, particularly biotite. Sphene is also common as tiny grains along the borders of biotite flakes, or as very large euhedral grains up to 2 mm. long. Myrmekite has commonly two habits: irregular grains at the borders of plagioclase and microcline, and as tiny patches and veinlets between larger grains of the other minerals, not necessarily between potash feldspar and plagioclase.

LEUCO-QUARTZ MONZONITE

Megascopic Description. The leuco-quartz monzonite (12) is a medium- to coarse-grained, light coloured, granitic rock, mostly with less than 5 per cent biotite. In contrast to the rock types nearer the border, it contains no large phenocrysts of microcline, no inclusions, and no pegmatites. In most places the outer contact is gradational over $\frac{1}{4}$ mile, and in this transition zone are a few small phenocrysts of microcline, increasing in number farther from the leuco-quartz monzonite. Biotite also increases slightly, and quartz decreases. Elsewhere however, as on Skookumchuck Creek the contact is sharp. South of Skookumchuck Creek, above the junction with Burnt Creek, successive near-horizontal schlieren of biotite in the leuco-quartz monzonite parallel the contact with the overlying porphyritic quartz monzonite. Pre-existing vertical foliation in the latter is sharply truncated. North of Skookumchuck Creek, a medium-grained leuco-quartz monzonite cuts across all other rock types and extends outward to the outer boundary of the intrusion. Rare inclusions and few structures are found in this rock even in the vicinity of the contact. Both intrusive and gradational contacts are shown diagrammatically in cross-sections G-H and J-K. (*See* map.)

In hand specimens, this rock appears inequigranular hypidiomorphic and consists of patches of granular aggregates of dark grey quartz, up to 10 mm. across, similar patches of white plagioclase, and large euhedral grains of potash feldspar of the same size. In the medium-grained variety, minerals are much more evenly distributed and few are over 2 mm. Modal analyses show a remarkable uniformity in composition between the varieties of differing grain size, even though samples were taken from widely dispersed points (*see* Table I and Figure 3). This is in contrast to the border rocks which show considerable variation in composition, particularly in content of quartz, mafic minerals, and potash feldspar.

Microscopic Description. Under the microscope, as in the hand specimen, the quartz monzonite is markedly different from the mafic granodiorites previously described.

Quartz is the most plentiful mineral in the rock, averaging about 35 to 40 per cent. Though it occurs in irregular aggregates up to 10 mm. across, individual grains average 2 to 3 mm., but may be as much as 6 mm. These grains have irregular boundaries, fill all available spaces between other grains, and may enclose or partly surround all other minerals in the section. In places an irregular quartz grain may be conformable on one or two sides of a euhedral plagioclase grain, elsewhere it may penetrate and replace the earlier plagioclase.

Microcline averages 28 per cent. In the coarse phases of the leucoquartz monzonite it varies in size from very large (5 mm.) grains with rims carrying inclusions of all other minerals, to very small interstitial patches filling irregular openings in the matrix. Most grains show well developed grid, and Carlsbad twinning indicative of microcline, in others the extinction angle on the basal section is that of microcline rather than orthoclase. Similarly oriented, small round blebs of quartz as well as small grains of plagioclase up to 0·5 mm. in length commonly occur within the microcline. Much of this plagioclase is surrounded by a narrow, irregular border of clear albite of very much smaller index of refraction than the euhedral, altered, core of the grain. These albite rims may have been exsolved from the surrounding microcline.

Contacts between microcline and plagioclase are commonly very irregular, with minute, replacing projections of microcline into the plagioclase. At some points along these contacts, myrmekite has formed that is continuous with the plagioclase grain but contains irregular, vermiform quartz and, in some cases, small patches of potash feldspar.

Only a minor amount of exsolved albite occurs within the microcline, as irregular, elongate blebs along cleavage planes. The microcline, though mostly clear and little altered, in places shows a sprinkling of brown spots, perhaps of kaolin.

The plagioclase content of the rock averages 27 per cent. The mineral varies in composition from An_{15} to An_{25}. It occurs, in the coarse-grained quartz monzonite, in euhedral to subhedral crystals from 1 to 3 mm. in size. Some grains are twinned according to the Carlsbad, albite, and pericline laws; others may be continuously zoned, with a broad, euhedral interior, commonly much sericitized, surrounded by a narrow, irregular, unaltered, albitic border, markedly more sodic than the interior.

Biotite occurs in ragged shreds from 0·5 to 2 mm. in size, much of which is altered to green chlorite with patches of associated iron ore. It is commonly pleochroic from light tan to dark red-brown, in contrast to the green biotite of the border granodiorites.

Muscovite, occurs as large subhedral crystals, with a 2V of 35 to 40 degrees and is commonly associated with biotite. Sericite occurs as an alteration product of plagioclase, and may be formed as a result of exsolution or by the replacement of the calcium of plagioclase by potash.

In contrast with the border granodiorites, accessory minerals are relatively rare in the leuco-quartz monzonite. Apatite, magnetite, and zircon are the most common, though fluorite may occur rarely in patches in the plagioclase. Secondary accessories such as chlorite and calcite may also be found.

MEDIUM-GRAINED QUARTZ MONZONITE

Megascopic Description. The light coloured, fine- to medium-grained quartz monzonite (14) intrudes the mafic-rich border granodiorites west of upper White Creek. In detail, the contact is everywhere sharp and irregular, and may, in places, show complex, anastamosing networks of veinlets and irregular dykes penetrating into the granodiorites (*see* Plate VI B). No structural deformation is found in the surrounding older granodiorites, nor is there direct evidence of assimilation except for the irregular contact and occasional inclusions of the older rocks within a few feet of the contact. Yet it appears that the younger magma was sufficiently fluid to assimilate the older rocks, as planar flow structures in the granodiorite are sharply truncated and continue apparently undisturbed on their north-south regional trend on both sides of the medium-grained quartz monzonite (14) body.

In hand specimen it is grey and sub-equigranular, with an even scattering of biotite throughout that becomes more plentiful as the contact is approached. Rarely, small phenocrysts of microcline are visible. Modal analyses show up to 10 per cent less quartz and a correspondingly greater amount of plagioclase than the leuco-quartz monzonite in the interior of the batholith. There is a marked relative decrease in microcline and an equally marked increase in biotite over the leuco-quartz monzonite.

Microscopic Description. The essential minerals of the medium-grained quartz monzonite (14) and their mutual relationships, with the exception of relative quantities and grain size, are similar to those of the interior leuco-quartz monzonite (12). In thin section the rock is of sub-equigranular, granitoid texture, from 0·5 to 2 mm. in grain size. The plagioclase, varying from An_{21} to An_{40}, is strongly zoned, and reversals of zoning are more common than in the leuco-quartz monzonite. The biotite, rather than being the dark red-brown variety, is yellow-green to dark green. Accessory minerals may include, in addition to those found in the leuco-quartz monzonite, rutile, sphene, pyrite, and epidote. Epidote may occur as an alteration product in plagioclase or biotite.

PORPHYRITIC QUARTZ MONZONITE

Megascopic Description. Porphyritic quartz monzonite (11) lies with gradational contact within the crescent of mafic granodiorites in the western part of the batholith, but forms most of the eastern part where no distinct segments rich in mafic minerals occur. In general, this rock is highly porphyritic, light coloured, and medium to coarse grained. It is characterized universally by the presence of a regular, primary foliation shown by folia of biotite, plate-shaped inclusions, and occasionally by aligned phenocrysts of potash feldspar (*see* Plate III B and Plate V A). Various rock types are found. In some localities these rocks are extremely rich in quartz, and contain neither phenocrysts nor inclusions, in still others, particularly near the contact with sedimentary rocks, they have a high content of hornblende and biotite and approach the composition of the granodiorite. Areas occupied by each of these rock types are too small to be shown separately on the map.

In general, the groundmass of the porphyritic quartz monzonite (11) is similar to the interior leuco-quartz monzonite (12), both in grain size and in mineral relations. The non-porphyritic patches in particular within the porphyritic quartz-monzonite could not be distinguished from the interior leuco-quartz monzonite.

Eight modal analyses (*see* Table I, facing p. 32) show the composition of the groundmass, disregarding the microcline phenocrysts, to average about 7·5 per cent biotite, 27 per cent quartz, 38 per cent plagioclase, 25 per cent microcline and 2·5 per cent muscovite and accessories. Megascopic measurements on clean, smooth rock surfaces, north of Skookumchuck Creek give amounts of microcline phenocrysts varying from 14·5 per cent to 29·5 per cent, though, by inspection elsewhere, the variation may be from zero to 30 or 40 per cent. Thus the porphyritic quartz monzonite may closely approach the interior leuco-quartz monzonite in composition, differing a little in biotite and quartz content and in megascopic features. It may also be noted, that the total composition in porphyritic and non-porphyritic areas remains the same, the microcline in non-porphyritic areas being distributed through the groundmass.

Microscopic Description. Thin sections of the porphyritic quartz monzonite show mineral characteristics and inter-relations similar to those of the leuco-quartz monzonite. Quartz occurs in irregular aggregates of small grains, plagioclase in anhedral or subhedral grains with clear irregular borders and sericitized interiors. Large euhedral, twinned grains of plagioclase common in the granodiorites, are rare in the porphyritic quartz monzonite. Grain size may vary from 2 to 5 mm., but the average is somewhat less than that for the leuco-quartz monzonite.

POTASH FELDSPAR PHENOCRYSTS

Phenocrysts of potash feldspar represent a large, if somewhat variable, constituent over the present outcrop area of the White Creek batholith. They are confined to the border rocks and are a particularly characteristic feature of the porphyritic quartz monzonite and the granodiorites forming the western part of the batholith. Phenocrysts form generally from 10 to 30 per cent of the rock by volume, but, where locally concentrated, may form 90 per cent. They may, on the other hand, be absent in small areas within the body of the granodiorite or quartz monzonite. This absence is particularly noticeable along the western and southern contact within 10 to 15 feet of the metamorphic rocks, a condition noted by Rice (1941, p. 34) to be common in the granitic bodies throughout East Kootenay.

In shape and size, the 'phenocrysts' vary from indefinite, rounded 'ovoids' to ½ or 1 inch squares, and, in the porphyritic quartz monzonite of the eastern part of the batholith, often occur as idiomorphic crystals up to 4 inches long by 1½ inches wide. These tabular crystals, where plentiful, are generally oriented parallel with the foliation in the groundmass, whereas the other forms of phenocrysts occur in various orientations, rarely in the plane of foliation (*see* Plates III B and V A). In addition, the phenocrysts may occur in large, vertically oriented open cavities as an interlocking mass of disoriented individuals, or, near swarms of inclusions in the biotite-granodiorite of the western contact, they may be concentrated in large numbers of various shapes and sizes. Phenocrysts may occur as perfect idiomorphic crystals within the basic inclusions, or indeed, may be shared equally by inclusions and surrounding granodiorite. Within the mixed zone outside the granitic contact, they are common, in places transecting the foliation, in places pushing it aside, indicating growth by displacement as well as replacement.

Some phenocrysts contain visible biotite and other minerals of the groundmass, commonly arranged in layers parallel with the crystal faces. Examined closely, on polished specimens, the phenocrysts are seen to grade all the way from sharply idiomorphic crystals to ill-defined patches, penetrating and surrounding the minerals of the groundmass (*see* Plate III B). Narrow stringers of potash feldspar may be followed to a point at which they widen into irregular patches. Elsewhere one side of a crystal may be sharply idiomorphic and the opposite side may irregularly penetrate and include other minerals (*see* Plate III B, lower left). In places, the interior of a large phenocryst is idiomorphic and contains no inclusions whereas the outer third is very irregular, and surrounds earlier minerals in the groundmass. Phenocrysts commonly show well developed Carlsbad twinning, commonly along very irregular twin planes.

In thin section, the phenocrysts are seen to be principally microcline that nearly everywhere show well developed grid twinning. They include all other minerals, generally in grains not more than 0·1 to 0·2 mm. in size.

From the above description of the phenocrysts, some common points bearing on their origin may be noted:

1. The phenocrysts are found only in border quartz monzonite or granodiorite that contains basic inclusions.

2. In parts of the porphyritic quartz monzonite of the eastern part of the batholith that contain no basic inclusions and no phenocrysts, microcline is found distributed through the groundmass, in amounts equivalent to the total microcline found in the porphyritic varieties.

3. Phenocrysts seldom occur at the immediate contact with the metamorphic rocks, but here also microcline occurs distributed through the groundmass (*see* analyses 37 and 38, Table I). The rock at the contact is finer grained than elsewhere, and apparently deformation or more rapid cooling, or both, at the immediate contact has inhibited the formation of the phenocrysts.

4. Inclusions of other minerals are commonly found throughout a microcline crystal, generally parallel to crystal boundaries. Not infrequently, however, inclusions of earlier minerals are found only in an outer irregular border around the euhedral centre of a microcline crystal. In some cases the outer border appears to have pushed small mafic mineral grains aside as it formed.

5. Where phenocrysts are plentiful (up to 30 per cent) in the porphyritic quartz monzonite they may be parallel to the foliation marked by basic inclusions and biotite tabs (*see* Plate V A). On the other hand, if they are few in number or are equidimensional they show little tendency to follow the foliation. In wall-rocks they may be found to bend and push aside pre-existing schistosity.

6. Phenocrysts may be found that are cut by pegmatite or aplite veins. They have therefore formed prior to emplacement of aplites and pegmatites.

In summary, it may be noted that the origin of phenocrysts of this type occurring in granitic rock has presented a problem the world over. The evidence assembled above tentatively suggests that they may form indirectly as a result of contamination and that they do not represent late potash enrichment but rather form by the crystallization under different conditions of potash feldspar already present. It appears that some, at least, form early enough to be involved in a primary foliation, but that the formation and growth of phenocrysts continue after the emplacement of the magma. Thus, the phenocrysts seem to have formed not at one time and under one environment, but over a long period of time covering the whole history of emplacement and solidification of the mass.

PEGMATITE AND APLITE DYKES

Aplite and pegmatite dykes occur in great abundance in parts of the batholith, notably in the porphyritic quartz monzonite. They are absent in the leuco-quartz monzonite and are rare in the medium-grained quartz monzonite and mafic-rich granodiorites of the south and west parts of the batholith. On the other hand, they are particularly plentiful from a point east of the headwaters of White Creek along the contact to the northeast, and down Skookumchuck Creek.

Aplites north of Skookumchuck Creek occur as north-trending vertical dykes from a few inches to a foot wide. Later than these, and commonly displacing them, are both pegmatites and aplites that dip 10 to 30 degrees north and strike east along the creek. Aplites and pegmatites may occur also as irregular masses, either near the contact or outside the body of the batholith. Such an irregular mass of aplite occurs at the contact near the north boundary of the map-area and contains large blocks of unaltered, coarse granodiorite. Another similar mass of aplite occurs on the north side of the lower end of Buhl Creek, where it penetrates layers of altered sedimentary rocks at the contact.

Though the aplites and pegmatites within the granite may rarely be traced for any distance outward into the metamorphic rocks, there are two large bodies of pegmatite lying outside the batholith altogether. One occurs in the 1,000-foot diorite sill west of White Creek, as a series of long curved dykes. The other is on the mountain south of Burnt Creek, north of Skookumchuck Creek. It occurs as a complex of dykes, cutting meta-diorite sills and as an irregular mass in Lower Aldridge schists. Foliation, developed in the schists and sills during emplacement of the granite mass, is cut and bent by the pegmatite, indicating its later intrusion.

Aplite and pegmatite dykes commonly alternate irregularly, but they may be composite, with bands of both rock types, commonly symmetrically arranged, in alternating parallel bands along a single dyke.

In composition aplites and pegmatites are simple, consisting essentially of microcline and quartz, with some albite. Grain size of pegmatites may range to several inches, and graphic intergrowths of quartz and potash feldspar are common. Tabs of greenish mica up to $\frac{1}{4}$ inch in size and a pink garnet, possibly spessartite, are also common. Well crystallized, though shattered, green beryl and black tourmaline are found where pegmatites are plentiful. Rare molybdenite and pyrite cubes are associated with the pegmatite and quartz veins near the northwestern contact of the batholith. One occurrence of crystalline euxenite was found in a pegmatite north of Skookumchuck Creek.

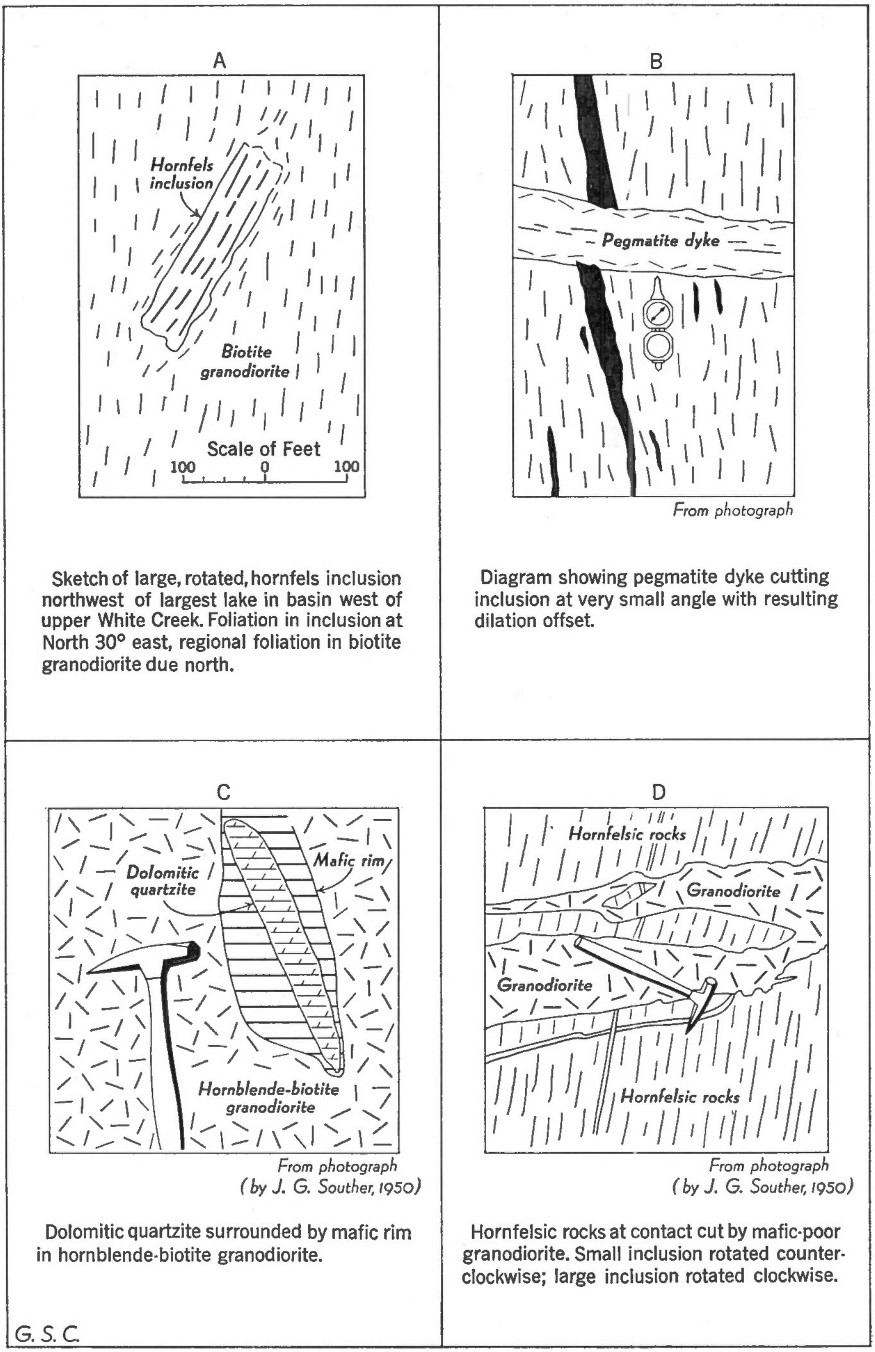
Emplacement of aplite and pegmatite in rocks near the margin of the interior leuco-quartz monzonite, commonly in dykes of considerable lateral extent that dip gently toward the interior rocks, indicates an apparent source in the leuco-quartz monzonite. Furthermore, dilation emplacement of the dykes is commonly shown by offset inclusions (*see* Figure 4 B) within the intrusive mass and by displaced and bent schistosity immediately outside the batholith. Not all dykes, however, show clear evidence of dilation emplacement and the relative importance of replacement is difficult to assess. However, it is notable that wherever a dyke cuts and offsets an inclusion, the offset is equivalent to that required for total dilation emplacement.

INCLUSIONS

Occurrence and Description

Numerous inclusions occur throughout granodiorites in the west, and the porphyritic quartz monzonite in the east half of the batholith. Two distinct types are found: the first, always in the vicinity of the contact or near a roof pendant, are of recognizable metamorphosed sedimentary rocks; the second, and much more common type, are dark, fine-grained, mafic-rich inclusions, varying in composition from quartz diorite to granodiorite (*see* Plate VII A and B).

The recognizable inclusions of hornfels, equivalents of impure wall-rock quartzites, vary in size from a few inches to many hundreds of feet and are very sparsely distributed in the border regions. Generally angular and flat, they lie parallel to the foliation in the granodiorite, and, depending on the local source rock, they show various mineralogical characters. Not uncommonly, the larger inclusions are rotated up to 35 degrees from the regional trend of the foliation in the granodiorite (*see* Figure 4 A). Only very rarely does the granodiorite penetrate such inclusions, in marked contrast with similar rocks at the main contact which are forcefully intruded along and across the foliation. This may indicate that the inclusion was not firmly attached, but was immersed in a liquid. Very large inclusions of this type are found along the western contact up to 1,500 feet below the present top of the batholith and up to 1 mile from the outer contact, though no direct evidence could be found of their having sunk downward through the magma.



A. Sketch of large, rotated, hornfels inclusion northwest of largest lake in basin west of upper White Creek. Foliation in inclusion at North 30° east, regional foliation in biotite granodiorite due north.

B. Diagram showing pegmatite dyke cutting inclusion at very small angle with resulting dilation offset.

C. Dolomitic quartzite surrounded by mafic rim in hornblende-biotite granodiorite.

D. Hornfelsic rocks at contact cut by mafic-poor granodiorite. Small inclusion rotated counter-clockwise; large inclusion rotated clockwise.

Figure 4. Inclusions in granitic rocks.

Along Skookumchuck Creek at, and just below, the junction with Burnt Creek there are numerous patches of schist, hornfels and some skarn rocks in the creek bottom and along the hillside both north and south of Skookumchuck Creek. These may be inclusions, but their distribution and orientation suggest rather that they are remnants of a roof pendant that extended along Skookumchuck Creek from Burnt Creek nearly to the projection of Creston rocks between Skookumchuck and Buhl Creeks.

In both granodiorite and the porphyritic quartz monzonite a much more common type of inclusion is found. These inclusions are fine grained, mafic-rich, and much darker than the surrounding granodiorite and occur in many sizes and shapes (*see* Plate VII A and B). They vary in size from less than an inch, to several feet, and though most are elliptical in cross-section and dish-shaped in the plane of foliation, they may be irregular, diamond-shaped, fish-shaped, cigar-shaped, or more rarely, pinching and swelling as though drawn out when soft. In the western granodiorites these inclusions decrease in number and size inward from the outer boundary, finally disappearing as the inner rim of the hornblende-biotite granodiorite is reached. The disappearance inward of such inclusions in the general region has been noted by Rice (1941, p. 35). In all, in the area within a mile of the outer contact they may form 10 or 15 per cent of the rock volume.

Smaller inclusions and clots are more common in the hornblende-biotite granodiorite than in the other rock types in which they occur, as if larger inclusions had been disintegrated and distributed in the surrounding granodiorite. This is substantiated by the examination of thin sections in which there is shown to be an increase of mafic minerals in the groundmass near the outer boundary of the hornblende-biotite granodiorite (*see* Figure 5).

Although most of these inclusions are uniform throughout, a few may be found with a 2- or 3-inch basic rim enveloping an easily recognizable metamorphic interior. This is shown in Figure 4 C. A series of thin sections from such an inclusion show the sequence of mineral changes from the recrystallized and metamorphosed, impure, dolomitic quartzite of the centre to the outer dioritized rim. The interior of the inclusion consists of a quartz mosaic with irregular interstitial grains of garnet, carbonate, and diopside of about 0·1 mm. grain size. Outward, towards the contact with the dioritized rim, the grain size in the quartz mosaic increases to 2 mm., and crystals are elongate parallel with the contact. Garnet disappears, epidote and clinozoisite appear. About 4 mm. outward from the beginning of the dioritized rim, hornblende begins developing at the expense of the clinozoisite and epidote. A few grains of sericitized 'ghosts' of plagioclase also begin developing at this point, apparently with concurrent decrease of quartz. Outward, there is a very sharp contact with a medium- to fine-grained hornblende-biotite-oligoclase diorite. This zone contains very little quartz, and the feldspar is zoned and twinned. Outward, from this zone hornblende gives way to large ragged grains of biotite and epidote, with much associated sphene and apatite in long crystals. Towards the outer edge, only rare hornblende remains and a small amount of interstitial microcline is visible. It appears from the above examination that there is a definite sequence of changes leading to the dioritization of the sedimentary rock, but it is also clearly apparent that there is a sharp cessation of total alteration within a very short distance from the edge of the inclusion in spite of the great mass of surrounding granodiorite.

Other similar inclusions may be found grading in texture from granoblastic to hypidiomorphic, from diorite as above, to quartz diorite and granodiorite with increasing microcline and quartz. The only difference between the latter and the ordinary granodiorite (9, 10) is the large amount of biotite (rarely, hornblende), apatite, and sphene as well as the diminutive grain size in the inclusions. Commonly the granodiorite in the vicinity of such inclusions is high in sphene, cleárly visible even in a hand specimen. Further, porphyroblasts of plagioclase may be found, that show zoning and reversals of zoning similar to that in the granodiorite. This apparently indicates that such plagioclase grew in an environment fully controlled by a surrounding liquid, so that, if conditions changed in the liquid such as to produce zoning or reversals of zoning these conditions were reflected in the enclosed solid inclusion. It is notable that outside the batholith contact, in the metamorphic zone, no zoning of plagioclase, progressive or reversed, is apparent.

Petrological Discussion and Significance

The majority of dark, fine-grained, ovoid inclusions of the type described above, appear to be reworked sedimentary xenoliths, for they may be found in all gradations from recognizable sedimentary rock to mafic-rich quartz diorite and granodiorite. The question then arises, what is the process by which the inclusions have been so altered, and what bearing, if any, has this on the production of the various rock types found in the enclosing intrusion?

Numerous explanations of the origin of inclusions in granitic rocks have been presented in the literature. They will not all be reviewed here, but it has been suggested that xenoliths may represent, soon after immersion in, and reaction with the magma, a basic residual left after the felsic minerals, higher in the reaction series than those being precipitated in the magma, have been dissolved out. Such a mechanism would follow closely the process indicated by Bowen's experiments (Bowen, 1922) and his discussions of xenoliths immersed in granitic magma. A basification before granitization is further indicated by the experiment in which solid material was added to a liquid of similar composition. From this, Bowen concluded (1922, p. 530) that, ". . . the liquid should be enriched in the constituents toward the low temperature end of a solid solution series and the solid in those toward the high temperature end". Thus the felsic minerals of an inclusion would be dissolved out and mafic minerals, as well as plagioclase more basic than that in the surrounding granodiorite, would be precipitated in the inclusion. This is shown by the 'ringed' inclusion described above. The inclusion would therefore represent not only a basic residual but would be further basified by precipitation of the mafic minerals of the magma within the inclusion. Continued alteration by reaction with the surrounding magma would eventually result in the inclusion reaching the same composition as that of the granodiorite. If further structural deformation took place at a late stage the xenolith might be dispersed into the surrounding medium, but if crystallization intervened ovoid basic residuals would occur as discrete units in the intrusion.

It may be noted that inclusions are mainly confined to a belt in close proximity to the present margin of the intrusion. Further, as may be noted in Figure 5, page 49, the combined biotite-hornblende content of the granodiorite increases to a maximum some distance from the border of the batholith. Moreover, this maximum in the mafic-mineral content coincides with the line in the batholith inward from which inclusions rapidly decrease in both size and number, with a corresponding increase in the granodiorite of clots and stringers of mafic minerals. This may indicate that the magma in the outer border of the intrusion solidified before the inclusions could be effectively dispersed but that the magma nearer the interior remained mobile and moved sufficiently to break up and disperse the individual component minerals of the inclusions.

It is further evident that the variations in composition of the rock-units comprising the intrusion appear to be related to the amount of wall-rocks assimilated, which has resulted in various amounts of basification of an original quartz monzonite magma in a manner similar to that noted for the basification of individual inclusions. As would be expected, more material is assimilated near the boundary of the intrusion and the resulting different rock-units are in bands subparallel with the outer contact. The intensity of alteration is greatest near the contact and decreases inward toward the centre of the body.

SUMMARY AND DISCUSSION OF PETROGRAPHIC DATA

The point of greatest significance apparent from the above descriptions and from the accompanying diagrams (*see* Figures 2, 3, and 5) is the roughly systematic and gradational change in the composition of the rock-units forming the intrusion, from leuco-quartz monzonite in the centre to biotite granodiorite at a part of the margin. Figure 2, page 34, illustrates this phenomenon for all essential components and Figure 5, page 49, for mafic minerals, quartz, and the An content of plagioclase feldspars. This gradation both in physical characteristics and in composition indicates that the

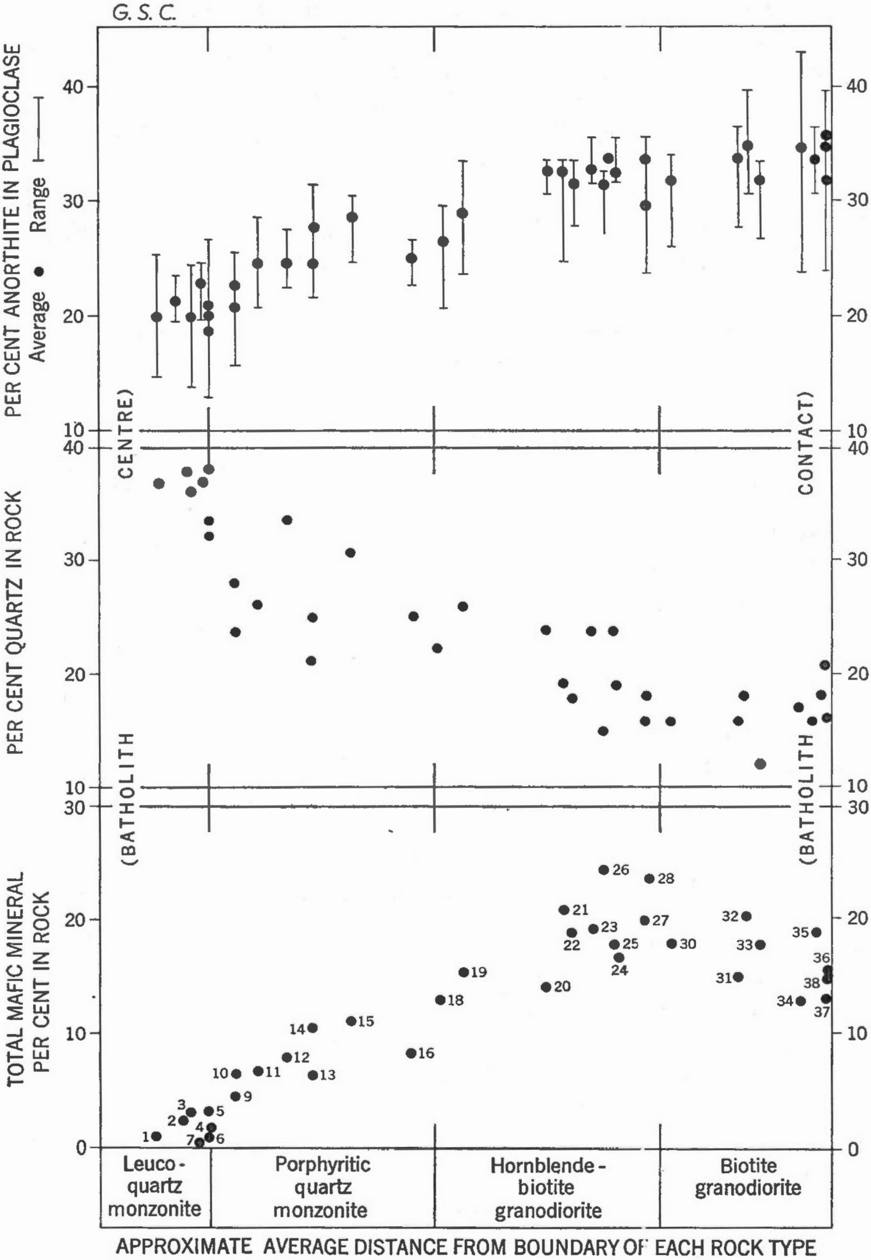


Figure 5. Variation in composition of granitic rocks with respect to distance from the margin of each rock type.

variation in rock types now present has not resulted from multiple intrusion of different magmas at different times and from varying sources, but from contamination of a single magma. This contamination, coupled with progressive cooling and crystallization from the exterior to the interior of the mass, has resulted in the formation of the different rock types and their physical characteristics. Furthermore the magma in the centre remained molten after the outer shell hardened and has in some places intruded the earlier solidified rocks. Further particulars concerning the contamination, physical emplacement and inter-relation of composition boundaries and planar flow structures will be noted below (pp. 60-62).

Structural Features of White Creek Batholith

INTERNAL STRUCTURAL FEATURES

Foliation

In White Creek batholith primary foliation or planar flow structure is shown by plate-shaped inclusions (*see* Plate VII A and B), aligned biotite, microcline phenocrysts, and hornblende. All these structures are not necessarily found in any one outcrop, and are found only imperfectly or not at all in the interior leuco-quartz monzonite. In the border zones, however, one or more of the above elements is always present and foliation can be easily mapped. The results have been recorded on the accompanying geological map.

Planar flow structure has been found everywhere to be vertical with only local variation to 60 or 70 degrees. There is no evidence, even in the highest exposures, for 'doming' or lessening of the steep dips. Further, the foliation is everywhere parallel to the margin of the batholith.

Lineation

Features within the batholith showing lineation, though locally well developed, are nowhere as common as those showing foliation. Lineation may be shown by orientation of the long axis of hornblende, more commonly by cigar or tear-drop shaped inclusions (*see* Plate VII B), or, more roughly, by the long axes of irregularly shaped inclusions. Ratios of the three axes of such inclusions may average 1 : 4 : 7. It is noteworthy that wherever lineation is very well developed, as at the north contact, northeast of Nowitka Mountain, foliation may be absent or locally difficult to determine. As may be seen on the accompanying map, lineation is invariably vertical to near vertical.

Jointing

Marginal Fissures. Jointing is well developed throughout the outer margin of the batholith, but is poorly developed and irregular in much of the interior. One set of joints, common everywhere outside the outer margin of the leuco-quartz monzonite commonly dips at a low angle (*see* Plate VII B). Many of these joints contain coatings of primary minerals such as muscovite, tourmaline, pyrite, hematite, and, in places, epidote. Furthermore, many are filled with aplites or pegmatite dykes, averaging 2 to 4 inches in thickness. All such joints are persistent along strike, well formed, and smooth. All dip from a few degrees to 40 or 50 degrees towards the interior of the body. A low dipping set may, in places, be cut by a more steeply dipping set as illustrated in Plate VII B. Furthermore, pegmatite or aplite dykes filling these joints, as at the contact north of upper Skookumchuck Creek, cut and offset inclusions by amounts proportional to the thickness of the dyke in a manner typical of dilation emplacement. The joints are therefore interpreted as tensional features, and are called inward dipping marginal fissures (Balk, 1937).

A few open joints of this type continue unchanged into surrounding metamorphic rocks; for example in both the granodiorite and the gneiss and hornfels along the western contact on, and south of, Nowitka Mountain.

Rarely, movement along fracture surfaces is indicated by slickensiding. Invariably, in such cases, low-angle thrusting from the interior of the batholith is indicated by the offset of inclusions in the intrusive rock.

Inward dipping marginal fissures of this type are considered to have originated by vertical upward movement within a still mobile core which caused roughly horizontal tensional fractures in the earlier solidified outer shell of the mass. As a wider belt of the outer border solidified, more fractures would form striking parallel to the earlier ones but dipping more steeply into the interior of the intrusive. Both such sets are illustrated in Plate VII B. Inward dipping marginal fissures of this type are therefore considered to be analogous to the up-stream pointing, marginal cracks of an active valley glacier (Balk, 1937, pp. 97-117).

Other Joints. In many parts of the batholith are well developed joints that closely parallel the foliation. Although few carry aplites or pegmatites, many contain primary minerals, and are therefore related to the initial emplacement of the intrusion. In places, however, there are well developed sets of joints that bear no obvious relation to lineation or foliation. Joints of such a set may be found along the west contact of the batholith where they trend northward at an angle to the foliation and do not extend inward into the medium-grained quartz monzonite (14) or outward into the surrounding metamorphic rocks.

SUMMARY AND INTERPRETATION OF INTERNAL STRUCTURES

The internal planar flow structure conforms generally with the shape of the batholith though in detail it follows every irregularity of the contact. This is particularly well illustrated west of the headwaters of White Creek, where foliation in granodiorite follows the boss projecting into Upper

Aldridge rocks. Internal conformity of vertical flow structure is also clearly shown in the southwest corner of the batholith where it follows without break the curve from a southerly to an easterly trend. West of the central part of Buhl Creek metamorphosed sedimentary Kitchener rocks dip steeply eastward in the valley, become vertical on the hillside, and are overturned with steep westerly dips on the mountain top; foliation in the nearby granodiorite, near the contact, conforms closely with these attitudes.

The inter-relation of flow structures and rock types within the intrusion is of particular importance in deducing the emplacement history. First, the contact between the granodiorites (9, 10) in the western part of the batholith cuts gently across the structural trend. Similarly, the contact between the porphyritic quartz monzonite (11) and the granodiorites (9, 10), and between local patches of granodiorite (not mapped) within the porphyritic quartz monzonite trend independently of structural lines. This structural anomaly is consistent with the conclusion stated on page 48 that variations in internal composition are the result of assimilation of wall-rocks and the resultant chemical adjustment within the batholith after emplacement. On the other hand, although the leuco-quartz monzonite is generally conformable and gradational into porphyritic quartz monzonite, it may in places, cut unconformably across pre-existing structural trends. This is clearly shown in cross-section G-H, in the section north of Skookumchuck Creek. There leuco-quartz monzonite cuts sharply across hornblende-biotite granodiorite and porphyritic quartz monzonite. The leuco-quartz monzonite shows no discernible structure as inclusions and phenocrysts, which generally show foliation, are absent and biotite occurs only in small amounts. Structures in the leuco-quartz monzonite may occur exceptionally near intrusive contacts where biotite has apparently been incorporated from the intruded rock. For example schlieren that occur south of Skookumchuck Creek just west of Burnt Creek, are parallel with the almost horizontal contact between porphyritic and leuco-quartz monzonite. The medium-grained quartz monzonite body (14) everywhere cuts and intrudes earlier granodiorites.

Conformity of internal flow layers with the direction of the outer contact and their independence of the rock-type boundaries within the intrusion indicate that the variation in composition has been formed by a process other than multiple intrusion. Otherwise internal flow structures would be expected to parallel rock-type boundaries just as this foliation is now parallel to the main contact with the metamorphic rocks.

It may be considered then, that internal planar flow structure and vertical lineation have been formed during emplacement by movement upward and outward of the interior mobile mass over successively crystallizing zones nearest the border of the intrusion. The western part of the granodiorite crystallized early, but the more leucocratic, mobile, interior leuco-quartz monzonite in the northeast part of the mass cut unconformably across earlier solidified granodiorite and porphyritic quartz monzonite, and represents a local intrusive contact.

The overall gradational nature of the intrusive body is shown by: the rudely concentric arrangement of rock types subparallel with the outer boundary; the universally gradational nature of most contacts of leuco-quartz monzonite and porphyritic quartz monzonite and of all other contacts; and the complete gradation in composition from leucocratic quartz monzonite in the centre to mafic-rich granodiorite in the border area. All of the above points lead to the interpretation of this body as the intrusion of a single unit with structural features formed as indicated above and with variations in rock type formed as a result of the assimilation of varying amounts of wall-rocks (*see* p. 48) such that boundaries of these variations transgress the uniformly trending flow structure pattern.

The intrusion of White Creek batholith as a fluid mass is further indicated by the nature of the contact zone and the external structural relations described below.

CONTACT ZONE

The contact zone is well exposed throughout much of the circumference of White Creek batholith. The character of the contact varies with the competence of, and local structures in, the surrounding Proterozoic rocks. In most places they are irregularly penetrated by granodiorite or porphyritic quartz monzonite, either along fractures parallel to the bedding or along joints cutting the bedding at a large angle (*see* Plates V B and VI A, B, and Figure 4 D). In the latter case offset of the bedding, where discernible, indicates dilation emplacement of the dykes. In some places *lit-par-lit* injection into schistose rocks may be observed. Elsewhere along contacts bounded by competent quartzites, for example along the southwest contact, the granodiorite transgresses the bedding at a very slight angle, though locally it may sharply truncate the bedding for 10 or 20 feet. Invariably, whatever the local detail, the contact between granodiorite and sedimentary rock is sharp, and though apophyses and conformable dykes of granodiorite may be found up to 200 feet or more from the exact contact, there is never doubt as to which is metamorphic rock and which granodiorite.

The planar flow structure in granodiorite or quartz monzonite near a contact or around inclusions near a contact may parallel the actual direction of the contact, but not necessarily the schistosity in nearby wall-rocks or in the inclusion, nor is it necessarily parallel to the biotite foliation a few hundred feet deeper into the intrusion. This lack of conformity between foliation in the intrusive body and that in wall-rock or inclusions near a contact has probably resulted from local irregularities of flow in the magma between the rigid contact and the relatively mobile intrusion.

In metamorphic rocks near a contact, for example northeast of Nowitka Mountain, minor fold axial lines may be nearly vertical at one locality, but horizontal nearby. Moreover, on a small scale, metamorphic rocks at a contact may show regular, wave-like projections with sharp crests that point into the granodiorite for ½ to 1 inch. It therefore appears that the sedimentary rocks at the contact were not only mechanically injected, but were softened and plastically deformed, with no consistent, discernible, local deformational pattern imposed upon them.

The composition and physical character of the granodiorite near the contact is also indicative of fluid intrusion. In many places no inclusions or phenocrysts occur at the contact, though they are plentiful a few feet inside the intrusion. In addition granodiorite or porphyritic quartz monzonite within a few feet of the contact is fine grained, and within less than an inch of the contact most of the granodiorite consists only of felsic minerals. It has been previously noted that the potash feldspar phenocrysts formed late in the crystallization sequence of the batholith, it thus appears that rapid cooling within a few feet of the contact has prevented their formation.

The inclusions were perhaps destroyed by movement along the wall-rocks in the last stages of emplacement, although the enclosing material was evidently so fluid that the component minerals were not sheared or otherwise deformed.

EXTERNAL STRUCTURAL FEATURES

In marked contrast with the continuous and relatively simple internal structures, those immediately beyond the boundary of the batholith are complex and varied. On a regional scale the long axis of White Creek batholith lies athwart the main trend of the Purcell axis. It is indeed rare, however, to find the batholith truncating structures on a large scale, for apparently universal, outward pressure has thrust the local beds, regardless of original attitude, into conformity with the present contact.

Along the western boundary of the biotite granodiorite, strata previously vertical to steeply west dipping are now vertical to steeply east dipping and bend around to follow conformably the bulge at the western tip of the batholith. As the contact is followed northward, the batholith truncates the competent quartzites of the Upper Aldridge. Locally, within 150 feet of the immediate contact, the quartzites are highly metamorphosed, softened and irregularly injected by granodiorite. Local foliation in the metamorphic rocks follows the direction of the contact, though within 100 yards the competent quartzites resume their former northward strike. Immediately west of the pass at the upper end of

White Creek, about 2,500 feet of southward striking, competent quartzites at the base of the Upper Aldridge have been separated from stratigraphically higher beds by a boss of granodiorite, and forced northward in a large fold, so that they now strike east and dip vertically along the contact. The sill below these strata has been much brecciated and intruded by granodiorite dykes, and the area within the fold has been intensely sheared and drag-folded, with axial lines and crenulations that plunge steeply west. The outward pressure of the intrusion is clearly shown by this fold.

Along the central, north boundary of the map-area, Aldridge rocks strike north to northeast and dip 15 to 25 degrees northwest. As the contact with the batholith to the south is approached, the rocks steepen and in places are tightly folded and faulted within 1 mile to 2 miles of the contact. At the contact beds are vertical and conform generally with the trend of the granodiorite. The Lower Aldridge thin-bedded quartzites have been pushed northward, with inferred faults developing down the branch of Findlay Creek north of White Creek, bringing west striking Lower Aldridge into contact with north striking Upper Aldridge.

Eastward down Skookumchuck Creek pendants may be noted in the creek bed or on the hillsides immediately above. These rocks are similar, though they contain minor amounts of skarn, to the Lower Aldridge near the junction of Burnt and Skookumchuck Creeks. Eastward again, in the angle between Skookumchuck and Buhl Creeks, Creston rocks project into the granodiorite. If the pendants across Skookumchuck Creek to the north are correctly identified as Lower Aldridge then there is not sufficient room for the Aldridge between the easternmost pendant and the nearby Creston projection. This spatial relationship may reflect a pre-existing fault through the area now occupied by White Creek batholith or, on the other hand, may have been caused by the emplacement of the batholith. In any case it is notable that the relation here is similar to that found along Hall Lake fault, west of White Creek, and may well mark the line of continuation of the fault before the emplacement of the batholith. This question could perhaps be answered if the fault could be found beyond the east or northeast corner of the batholith.

Although it has not been observed, it is probable that there is a fault up Buhl Creek between the Creston projection and the Kitchener, as some of the Kitchener succession is missing. It appears therefore that Creston rocks have been pushed upward against the overlying Kitchener formation. As may be noted on the geological map, porphyritic quartz monzonite bosses project up into the Creston rocks south of Skookumchuck Creek. Locally, bedding in the Creston and foliation in the granodiorite are conformable along the contact, though ½ mile away the attitudes in the Creston are independent of the contact.

Along the southwest and south contacts, almost to White Creek, the Creston and Kitchener formations, elsewhere in open folds and gently deformed, are in vertical isoclinal folds, and are sheared and drag-folded in the vicinity of the contact. Such folding and cleavage extends to an altitude of 6,500 to 7,000 feet on the hillside east of Buhl Creek, a distance up to 2 miles from the intrusive contact. Along this hillside, minor isoclinal folds with amplitudes a few tens of feet may be found with axial planes dipping steeply eastward. The rocks have been much compressed, apparently by pressure from the west. The effect of this pressure diminishes rapidly eastward, for folds on the hilltops above are in open, gentle undulations. The extent of the shortening or displacement in this zone is impossible to evaluate in these thin-bedded uniform Kitchener rocks (*see* cross-section L-M).

To the south, near the head of Buhl Creek, gently north-plunging Creston rocks near the south boundary of the map-area become increasingly steep as the batholith is approached (*see* cross-section J-K). North striking, symmetrical, open folds become east striking vertical, isoclinal folds in the vicinity of the batholith. Progressively younger strata are encountered near the contact which indicates that pressure was horizontal, resulting in sidethrusting rather than upthrusting for that would have brought up progressively older rocks nearer the contact.

South of the area between White Creek and Irish Queen Mountain, relatively undeformed Upper Aldridge strata strike northward and dip westward at an average of 55 degrees. As the contact with the batholith is approached to the north these rocks may be followed around a major fold with axial plane vertical and roughly parallel with the intrusive contact. The axial line plunges from 35 to 50 degrees northwest, depending on the attitude of the beds. Along the granodiorite contact the competent quartzites, which farther away strike north, strike east to southeast and dip very steeply north, to vertical at the immediate contact. There is some thinning and considerable metamorphism of the rocks of the northeast limb and all former argillaceous partings are there schistose. In addition, the granodiorite cuts across the quartzite bedding a few inches or at most a few feet at a time.

South of the axial plane of the anticlinal structure adjacent to the granodiorite contact, a marked cross cleavage has been developed; in very competent beds, fracture cleavage, in less competent phyllitic beds a series of crenulations with some slip cleavage parallel to the minor axial planes of the crenulations. These axial planes and the associated cleavages are vertical and strike parallel with the axial plane of the large fold, and are therefore parallel with the intrusive contact. This cleavage and crenulaation cut or fold pre-existing cleavage, which is parallel or subparallel with the north striking quartzites and argillites.

The cross-crenulations more than a mile south of the axial area of the major fold may be only $\frac{1}{8}$ to $\frac{1}{2}$ inch in amplitude. Moreover, they occur only in the region directly south of the western extremity of the batholith, and not west of the westernmost Moyie sill in Creston rocks. Within 1 mile of the large fold, subparallel with the southern contact, cross-folds increase in amplitude and cleavage becomes more intense. The cross-folds in the vicinity of the axial plane of the major fold are the dominant structural feature, and may reach an amplitude, in the most competent rocks, of 20 or 30 feet. Just north of the major axial plane there are no minor folds, and the beds are almost uniformly compressed into regular planar units, with, rarely, a large-scale drag-fold with a nearly horizontal axis indicating vertical upward movement to the north.

Thus the crenulations and slip cleavage strike roughly west and are parallel to the axial plane of the large fold which is in turn parallel to the granodiorite contact. All features appear to be related to the emplacement of the intrusion and indicate considerable south directed compression, which is intense near the batholith but gradually diminishes southward.

Further, above Hall Lake fault, the Lower Aldridge is deformed into a series of complex folds and faults. The folds trend northward with nearly horizontal axes and have amplitudes of one hundred to several hundred feet. Intense, related, flow cleavage has been developed in impure quartzites and phyllites. Within a mile of the northwest striking axial plane of the large fold south of the granodiorite, crenulations and a cross-slip cleavage have been imposed on, and folds the earlier formed north striking cleavage. This later cleavage is parallel to the axial plane of the large fold and increases in intensity as this axial area is approached. Finally in the cirque above the major bend in Hall Lake fault, the cross cleavage entirely obliterates the earlier north-trending flow cleavage. In addition at this point the north striking folds in the Lower Aldridge are folded around the axial plane of the large northwest striking fold, and now strike east. Unfortunately outcrop there is poor, and these minor folds can only be traced a short distance in the immediate vicinity of the major fold axis, they then follow into steeply north dipping isoclinal Aldridge strata. These details again indicate compression from the north which has superimposed structures on the earlier north striking regional structures. Again, the intensity of the compression gradually diminishes to the south.

SUMMARY AND DISCUSSION OF EXTERNAL STRUCTURAL FEATURES

The general features of the external structures may be summarized as follows:

1. All structures, for the entire circumference of the batholith, indicate outward pressure from a centre, and vertical flow structures within the intrusion are everywhere conformable with the contact.

2. Structures in the sedimentary rocks in the vicinity of the batholith are superimposed upon, modify, and cut earlier north-trending vertical fold axial planes and, in the west, near-vertical north striking sedimentary strata.

3. In the western half of the map-area north striking Aldridge strata, though cut off by the intrusion, continue along a northerly strike beyond the north contact of the batholith. In addition the line of the contact between Creston and Kitchener rocks along the west boundary of the map-area, continues northward unchanged (*see also*, Rice, 1941, map 603A). There seems little reason then, not to conclude that Aldridge strata have similarly continued northward, unbroken previous to emplacement of the batholith (*see also* page 28, on the structure of pre-batholithic rocks).

4. No intense shattering or brecciation is found in the wall-rocks as would be expected in cold deformation. Delicate injection structures at the contact as well as pegmatites and aplites traced from granodiorite to sedimentary rocks show no brecciation or deformation. Nor do metamorphic minerals, such as staurolite at the contact along relict bedding planes, show evidence of deformation. Therefore, contact structures have not been deformed after the emplacement of the intrusion.

It may be concluded, therefore, that the external structures immediately surrounding this intrusion have formed at the time of emplacement and that they indicate considerable horizontally outward directed pressure.

CONTACT METAMORPHISM

The metamorphic aureole surrounding White Creek batholith extends up to 3,000 feet from the contact, but is intense for only 1,000 feet or less. As the rocks of the Aldridge and Creston formations, which surround most of the batholith, are similar in composition the resulting metamorphism is essentially the same throughout the circumference of the contact. The only exceptions occur along the southeast border where dolomitic and calcareous rocks of the Kitchener are at the contact.

In general, as the intrusion is approached argillaceous rocks grade to crenulated phyllites, and quartzitic rocks grade to phyllitic quartzites. Generally within 1,500 to 2,000 feet of the contact the phyllites and the phyllitic quartzites are further recrystallized and contain some porphyroblasts of chlorite and biotite. Within a few hundred feet of the contact clots of concentrations of biotite are developed and the rock becomes a 'knotted' schist.

The most notable change in the quartzites and impure quartzites is the gradual increase in grain size. In crenulated biotite-muscovite-oligoclase-quartz schists in the Lower Aldridge north of the batholith elongate grains of quartz and mica may reach 0·5 mm., an increase of over ten times the average grain size of similar minerals in the unmetamorphosed equivalents. Rock types within a few hundred yards of the contact vary according to the original composition and are: oligoclase-hornblende schist, cordierite-mica-quartz schist, tourmaline-quartz hornfels, staurolite-mica-quartz schist, and biotite-muscovite quartz schist. In places oligoclase-andesine appears and forms 15 to 20 per cent of the rock, previously an impure quartzite. Over a mile from the nearest contact, within the fold in Upper Aldridge above the curve in Hall Lake fault, there is a conspicuous cordierite-mica-quartz schist in the Lower Aldridge

In staurolite schists the staurolite is commonly altered to a very fine-grained, interwoven patch of sericite, the original mineral only being identifiable by cruciform twins of sericite aggregates relict after the staurolite. Similarly, circular patches up to 1 mm. in diameter of very fine sericite aggregates (pinite) may be found that are pseudomorphous after cordierite. More rarely patches of sericite in needle-like form are found that may possibly be altered sillimanite. Unaltered sillimanite was found in only one thin section of the many examined. The formation of pseudomorphs, such as described above, is considered to indicate a period of retrograde or hydrothermal metamorphism following the high-grade contact metamorphism.

The nomenclature of the metamorphic rocks at the contact presents some difficulties. Schist, gneiss, and hornfels alternate depending primarily on the physical character and composition of the parent rock rather than on any particular condition or environment involved in their formation. Thus, thin-bedded argillaceous and impure quartzitic rocks are now schists whereas nearby, less argillaceous beds are hornfelsic. The massive, impure quartzites of the Creston formation along the west border of the granodiorite south of Nowitka Mountain are hornfelsic. These rocks occur in massive, blocky outcrops and from a distance are indistinguishable from the nearby granodiorite, for the colour of the lichen-covered rocks and the jointing are the same in both. In hand specimen the rock is somewhat crumbly, with irregular patches of both biotite and muscovite. Thin sections show quartz and oligoclase in an equidimensional granoblastic mosaic.

Alteration of Kitchener rocks follows closely features common to many granitic-carbonate rock contacts. Alternate bands of fine-grained garnet, epidote, quartzite, rare marble, and some tremolite-actinolite schist, may be found in close proximity depending on the initial composition of the individual beds. Southwest of Sawtooth Peak, just at the Kitchener-granodiorite contact there is a conspicuous band of cordierite-anthophyllite-mica schist. Farther from the contact Kitchener rocks consist of a confused, recrystallized mass of fine quartz, mica, and carbonate.

Metamorphism of the immediate contact aureole is of medium grade, falling into the cordierite-anthophyllite and staurolite-kyanite subfacies of the amphibolite facies. The grade rapidly decreases outward to albite-epidote-amphibolite facies and greenschist facies (biotite-chlorite or muscovite-chlorite subfacies) and recrystallized sediments of the surrounding region (*see* page 21).

It is notable that such minerals as altered staurolite are not deformed or smeared on surfaces between layers of different composition. Thus, other than the late hydrothermal activity that has altered staurolite, cordierite, and sillimanite, no major deformation has occurred after emplacement of the intrusion. Furthermore it is again apparent that the structures were formed concurrent with emplacement and the contact metamorphic minerals were formed during, or immediately succeeding the structural derangement associated with the emplacement of the batholith.

Summary and Conclusions Regarding Emplacement of White Creek Batholith

The evidence for forceful emplacement of a fluid magma may be summarized as follows:

1. Much of the sedimentary rock, previously within the region now occupied by White Creek batholith, is still to be found around the present borders of the mass, compressed and forced outward from its previous position.

2. The universal sidethrusting of bordering sedimentary rocks may be interpreted as indicating that the magma was extremely mobile (fluid or plastic) as intrusion of a solid mass would more probably have arched upward and brecciated gently inclined surrounding sedimentary rocks, particularly those around the eastern half of the batholith. Furthermore, a part of the mass remained mobile over a long period, as shown by late intrusion of some of the interior part into the earlier solidified exterior part.

3. The character of the contact (*see* page 53) further indicates fluidity of the magma as instanced by the following:

(a) Uniformity and decrease of grain size at contact.

(b) Lack of phenocrysts at immediate contact. This indicates early cooling (*see* page 54).

(c) Universal sharp contacts with dilation emplacement of dykes and irregular apophyses (*see* page 53, and Plate VI A).

4. Planar flow and linear flow structures as well as related joints and dykes everywhere indicate an integral structural pattern within the batholith, consistent with upward and outward movement.

5. Internal planar flow structure patterns are independent of internal compositional boundaries, indicating that the structural patterns had formed prior to the post-emplacement reactions that have produced the variation of rock types within the batholith.

6. The overall arrangement of the flow-structure elements and compositional variations within the intrusion are parallel to subparallel with the present outer contact and not parallel with pre-existing northerly trends of fold or compositional patterns in the surrounding sedimentary rocks.

It is conceivable that Hall Lake fault and perhaps other east-west faults (extension of Findlay Creek fault?) have localized and guided the intrusion in the initial stages of its emplacement so that its long axis lies across the general trend of the regional folding. It is also notable that Bayonne batholith (*see* Figure 1), to the south, lies similarly across the regional folding, and that a pre-existing fault extends beyond the south and east sides of the batholith (Rice, 1941, p. 49). Therefore both White Creek and Bayonne batholiths appear to occur at, or near, a curve in a major fault. Movement on such a curved fault could clearly give rise to openings that would serve to localize the intrusion.

Vertical upward movement and outward pressure of the magma apparently forced the surrounding rocks into conformity with the contact of the intrusion, though intrusive rocks may locally cut across the bedding in the wall-rocks. The magma remained sufficiently mobile to a late stage so that flow structures within the intrusion now conform to all irregularities in the outer boundary. The magma further remained so mobile that late inclusions, removed from the roof or wall of the chamber, could be rotated even though they were not completely reworked or 'dioritized'. It may also be noted that there was sufficient heat in the intrusion after the structural deformation for a medium grade of metamorphism to be imposed on the structurally deformed wall-rocks. No deformation has taken place after the metamorphism; for neither metamorphic minerals nor delicate wall-rock injection structures have been smeared or broken by deformation after the emplacement of the batholith.

A universal, continuous, planar flow structure has been formed within the batholith as a result of the alignment of basic remnants of assimilated wall-rocks (*see* page 48), biotite folia, and hornblende crystals by vertical upward and, horizontal outward pressure of the interior, still mobile parts of the intrusion against successive layers of cooling, partly crystalline outer layers. Such alignment of inclusions and biotite folia has occurred independent of compositional boundaries, and the internal flow structure is parallel with the outer boundary of the intrusion rather than with rock boundaries within the batholith. This composition variation between biotite and hornblende-biotite granodiorite and porphyritic granodiorite and between them and the leuco-quartz monzonite are interpreted as being due solely to different amounts of wall-rock assimilated during emplacement and subsequent reaction of this material with the original quartz monzonite magma after emplacement (*see* page 48).

Vertical upward movement at a later stage within the batholith may be indicated by the dilation emplacement of pegmatites and aplites in inward dipping tensional joints (*see* page 51). Similar upward impulses are interpreted here as causing the still mobile part of the interior of the mass to intrude already solidified granodiorite and porphyritic quartz monzonite, both north and south of upper Skookumchuck Creek. Elsewhere the interior solidified without further intrusion and the contact with the border granodiorite or porphyritic quartz monzonite is gradational.

CHAPTER IV

ECONOMIC GEOLOGY

No significant mineral deposits have yet been discovered within the map-area. There has been some prospecting, particularly by Consolidated Mining and Smelting Company, in the southeast corner of the map-area, north of Kimberley, and in the southwest corner, north of St. Mary River. In these areas small vein showings of chalcopyrite, galena, and sphalerite have been noted in Creston argillaceous or phyllitic quartzites and in Moyie sills. Beyond the west and northwest contact of White Creek batholith rare traces of chalcopyrite or of malachite stain may be found in discontinuous pods and veins of crystalline white quartz in highly folded Creston phyllitic quartzite. Most quartz pods are barren, but some contain disseminated chalcopyrite and pyrrhotite with some rusty carbonate. Such a body occurs at altitude 6,400 feet east of lower Dewar Creek about $2\frac{1}{2}$ miles north of the south boundary of the map-area. This zone is 200 to 300 feet long and 30 feet wide and occurs just below a diorite sill.

Just north of Skookumchuck Creek, below its junction with Burnt Creek, pyrite, chalcopyrite, and massive pyrrhotite occur in narrow, discontinuous veins, in lenses of quartz in a small shear zone in quartzite. A small adit 15 feet deep in Lower Aldridge quartzite and near a metadiorite sill exposes the shear, which strikes about south 80 degrees east and dips 37 degrees south.

To the northwest, on the hillside north of Burnt Creek, quartz-tourmaline veins are common in the more competent beds of quartzite as well as in the Moyie sills.

The Sullivan lead-zinc orebody, which lies a few miles south of the southeast corner of the map-area, occurs near the top of the Lower division of the Aldridge formation, and its present position may be due partly to favourable beds and partly to favourable structural conditions. It is interesting to note that lenses of conglomerate, probably intraformational, similar to those associated with the Sullivan orebody were noted near the top of the Lower Aldridge at the cirque-head south of the large lake about 1 mile north of the 8,930-foot triangulation point west of White Creek, and at a similar stratigraphic horizon at the headwaters of the Middle Fork of Findlay Creek north of upper Skookumchuck Creek. Although the general stratigraphic horizon of the Sullivan orebody may be traced throughout Dewar Creek map-area, no lead-zinc mineralization has yet been observed along it. In spite of this, however, the most favourable area for further prospecting for mineral deposits probably lies north of White Creek batholith, in the area underlain by the Aldridge formation.

All through the area surrounding the interior leuco-quartz monzonite phase of White Creek batholith, particularly east of White Creek, are swarms of pegmatite and aplite dykes. Most of the pegmatites are regular, tabular bodies of great lateral extent, varying in thickness from 1 inch to 2 feet. Minutely shattered tourmaline and beryl crystals, up to 1 inch in diameter though generally much smaller, are common in these pegmatites. In addition, much shattered, poorly crystallized tourmaline occurs in the pegmatite body in the Lower Aldridge west of the curve in Burnt Creek. Some molybdenite is scattered through quartz and pegmatite dykes near the granodiorite contact north of upper Skookumchuck Creek. Concentrations of microcline phenocrysts form, in places, more than 60 per cent of the rock volume north of Skookumchuck Creek, below the junction with Burnt Creek. These phenocrysts are almost pure potash feldspar, containing only a few per cent of visible, exsolved albite, and a few other enclosed mineral impurities.

Great Dane Prospect

The Great Dane prospect lies north of St. Mary River in the southwest corner of the map-area, at an elevation of 6,900 feet. An adit has been driven about 65 feet along vertical, north striking, Creston phyllitic quartzites. The mineralization occurs only at the portal, in pods and discontinuous stringers up to five feet wide, of galena, chalcopyrite, spalerite, pyrite, and siderite. This mineralization continues for only 15 or 20 feet where it either ends abruptly, or has been cut off by a small shear in Creston rocks. A crosscut has been driven in barren quartzite from the face of the adit for 225 feet at north 80 degrees west. Small amounts of galena occur on the hillside above as thin, anastomosing, veinlets, few over 1 inch wide. There has been some trenching along these veins.

It is of interest to note that directly northward along strike of the Creston rocks on the north side of the same ridge as the Great Dane, similar mineralization occurs. There a shallow trench has been dug for 100 feet along a rusty, mineralized zone at elevation 6,300 feet above Coppery Creek. Ore minerals comprise chalcopyrite, pyrite, pyrrhotite, and galena in order of abundance, with much siderite in irregular stringers. These sulphides occur as small stringers and irregular pods and masses up to 3 inches wide surrounding fragments of brecciated sedimentary rocks or as disseminated flecks throughout the rock over a width of 15 feet. Most of the pyrrhotite occurs as masses up to 2 feet in size.

Hot Springs

A hot spring occurs just southeast of the junction of Buhl and Skookumchuck Creeks. It is exactly the correct temperature for bathing, and is used by the loggers of C. Wenger's camp nearby.

Another hot spring occurs on Dewar Creek, about 3 miles upstream from the west boundary of Dewar Creek map-area near the Kitchener-Fry Creek granitic contact. The water issuing from this spring is so hot that the hand can be dipped in for only a fraction of a second.

Several cold mineral springs are found on the west side of Dewar Creek 2 or 3 miles above the junction of Coppery Creek (*see* Rice, 1941, p. 83).

CHAPTER V

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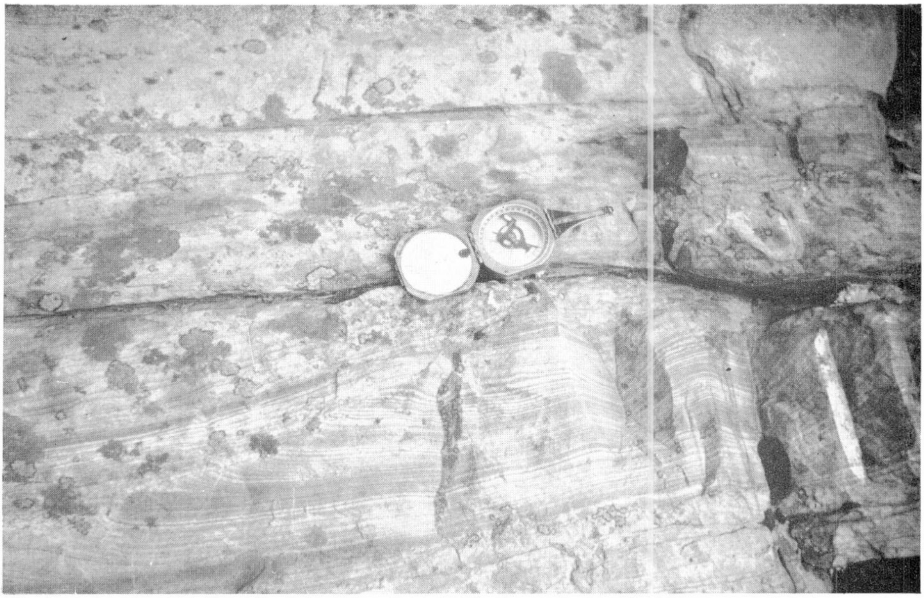
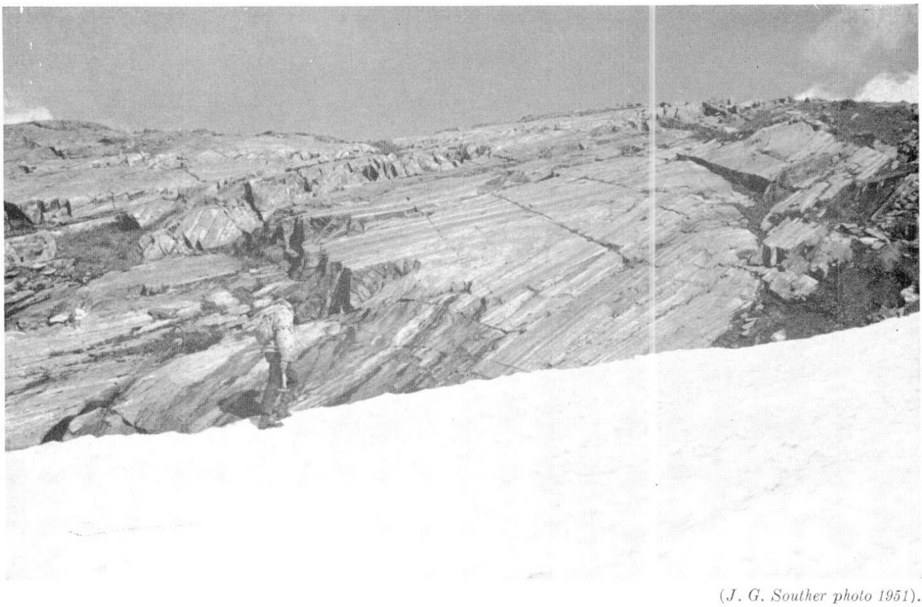
PLATE II



109188

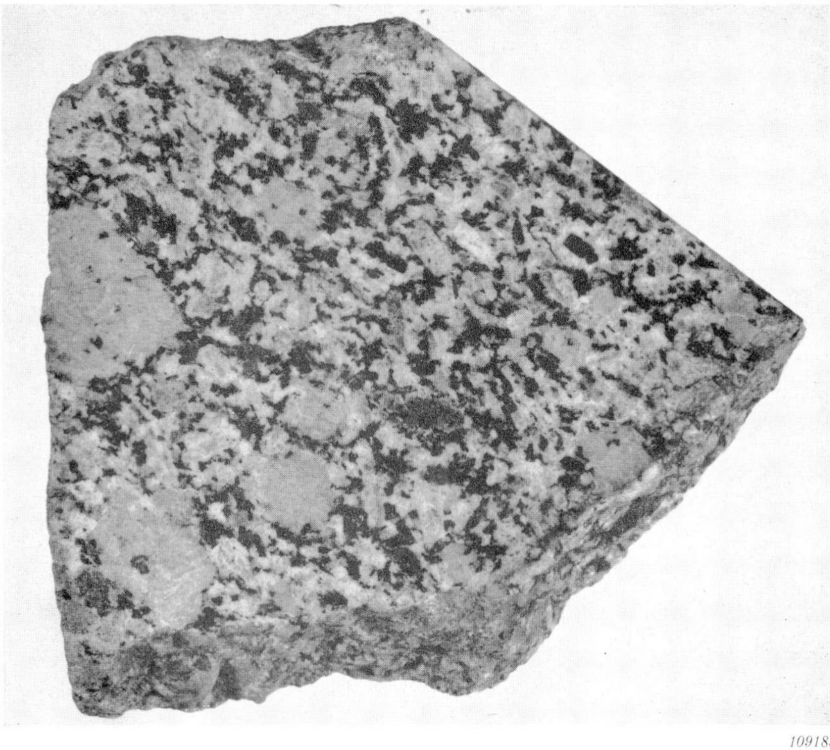
A. Characteristic laminations in Creston rocks commonly highly contorted and irregular, particularly near top or bottom of a bed.



(*J. G. Souther photo 1951*).

B. Vertical to slightly overturned isoclinal fold in Creston rocks at head of Dewar Creek. Photo taken on steep hillside. Axial plane of fold strikes north 5 degrees west, and dips 75 degrees west. Axial line plunges 10 degrees south.

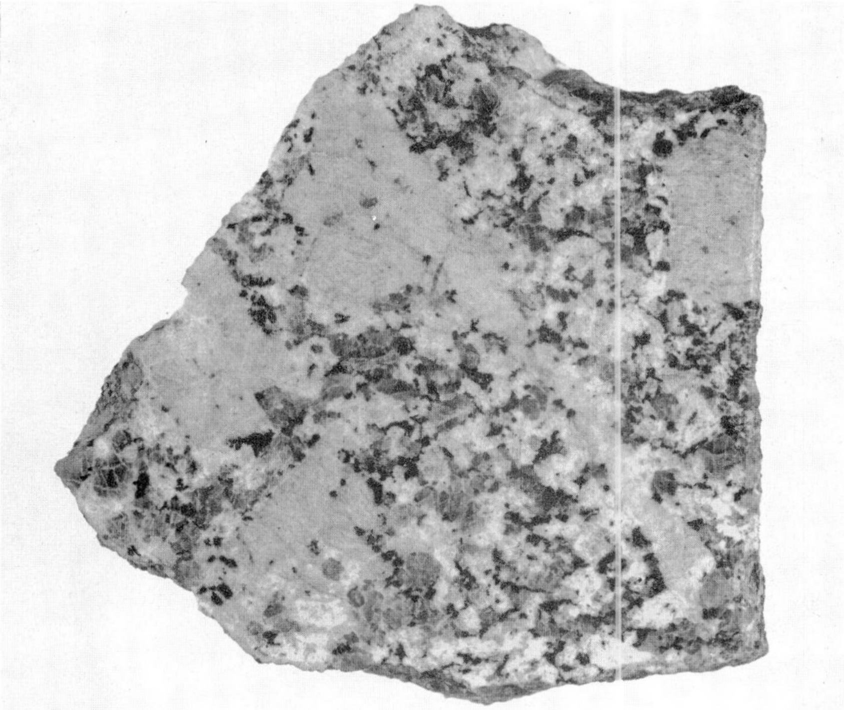
PLATE III



109189

A. Biotite-hornblende granodiorite x$\frac{3}{4}$. Note small mafic clot in lower right centre, p. 33.

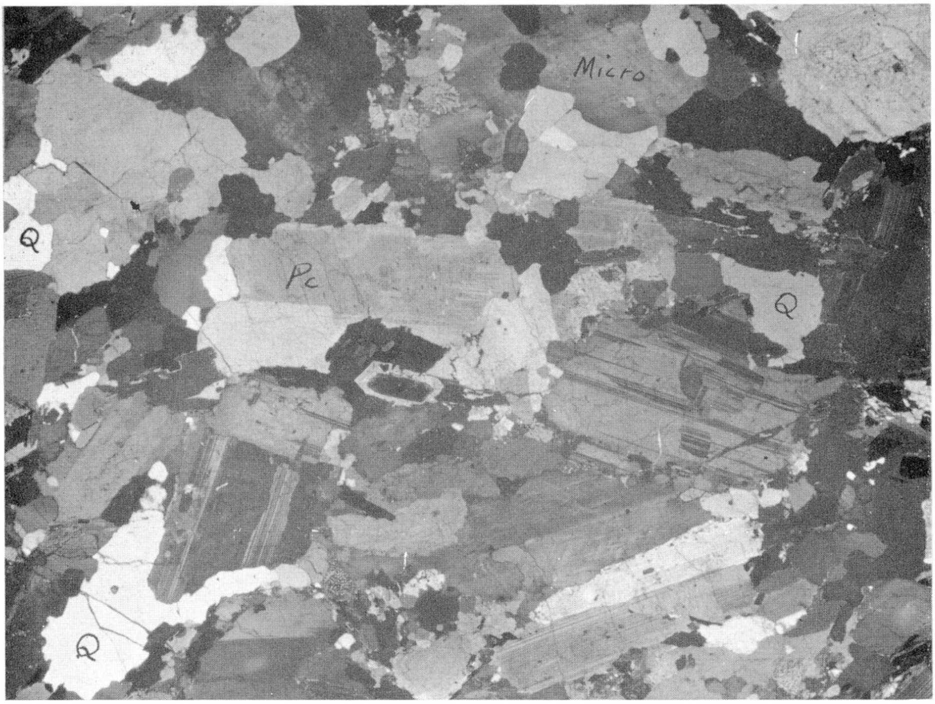
PLATE III



109190

B. Porphyritic (microcline) quartz monzonite x$\frac{3}{4}$. Dark grey quartz, white plagioclase. Note microcline 'phenocrysts' with some edges idiomorphic and some irregularly enclosing surrounding minerals, pp. 40, 41.

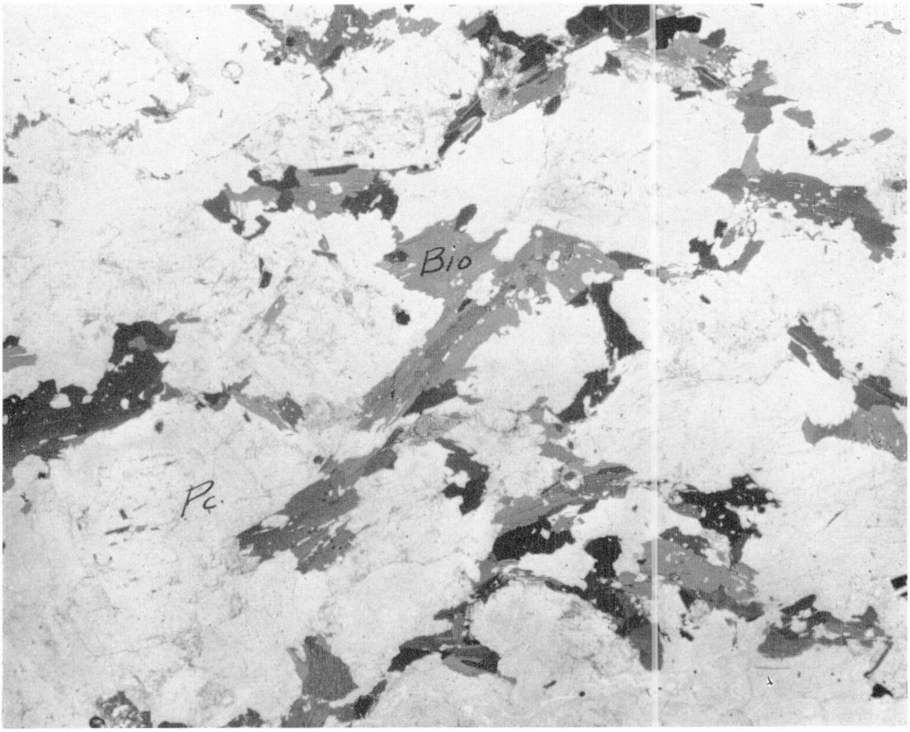
Plate IV



109191

A. Photomicrograph showing grain relations and microscopic character of the biotite granodiorite. Q — quartz, Pc — plagioclase, Micro — microcline. Note in centre of photo euhedral grain of brown epidote (allanite?) surrounded by clear epidote, pp. 33, 36. (Crossed Nicols X10.)

PLATE IV



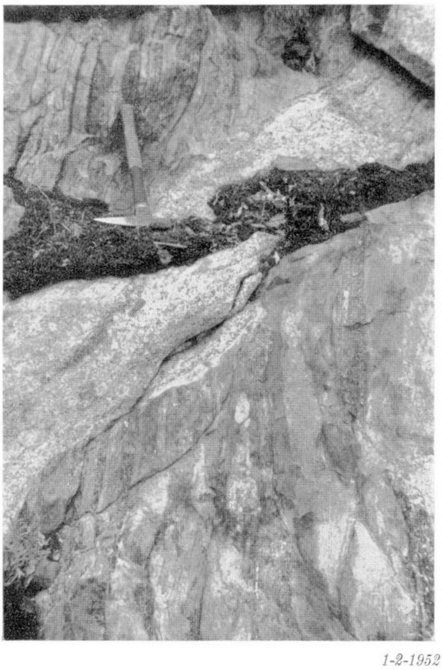
109192

B. Photomicrograph showing characteristic occurrence of mafic minerals in granodiorites from western part of batholith. Note patches of biotite interstitial to plagioclase and quartz, p. 33. (Plane light X10.)

PLATE V

109193

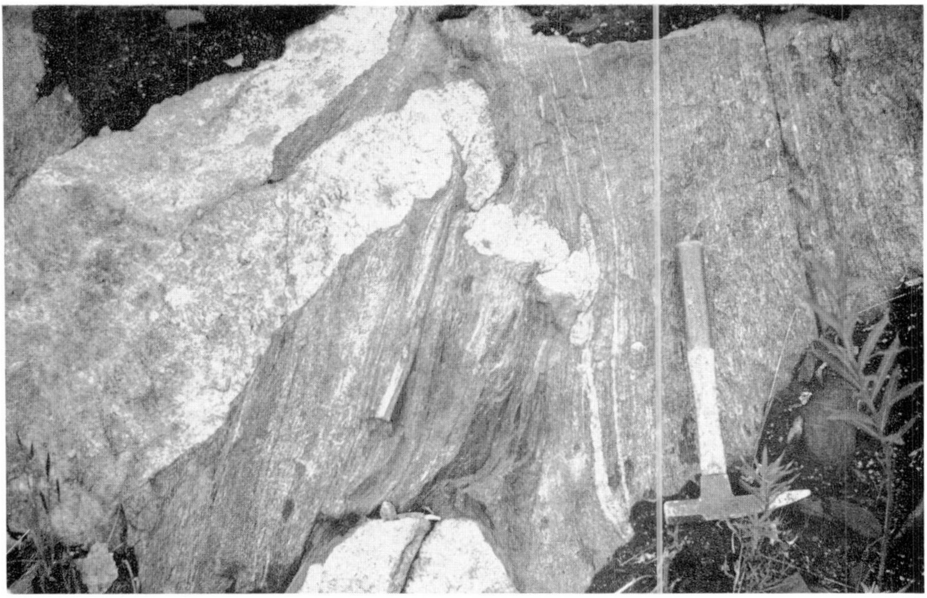
A. Porphyritic (microcline) quartz monzonite north of Skookumchuck Creek. Note alignment of phenocrysts, pp. 40, 41.



1-2-1952

B. Quartz monzonite dyke cutting hornfels showing relict bedding. Note foliation in dyke parallel with dyke contact, p. 53.

PLATE VI



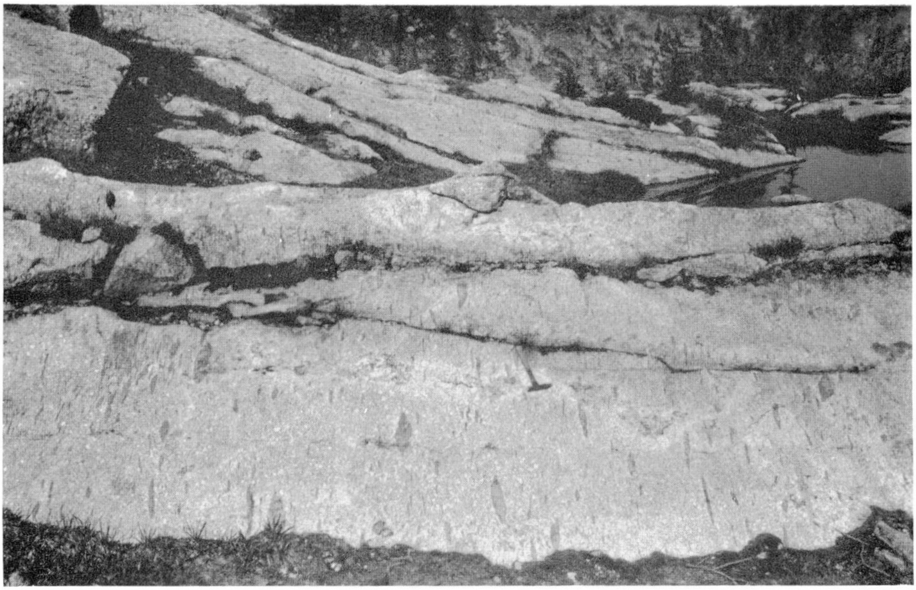
109194

A. Quartz monzonite showing local crosscutting relations of mafic-poor contact phase, near junction of Skookumchuck and Burnt Creeks. Note that earlier gneissic banding of quartzo-feldspathic material and metamorphic rock is bent and displaced, p. 53.

109195

B. Irregular, sharp contact of medium-grained quartz monzonite west of upper White Creek. Note ghost-like, indefinite, borders of biotite granodiorite inclusions below and right of centre. Such inclusions disappear entirely within a few feet of the contact, p. 39.

PLATE VII



109196

A. Inclusions in biotite granodiorite near southwest contact. Note variety of shapes and sizes, although most are roughly plate-shaped in plane of foliation.

2-3-52

B. Elongate inclusions showing vertical lineation in hornblende-biotite granodiorite at head of Buhl Creek. Note gently north dipping, healed joints, called here "inward dipping marginal fissures".

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