THE GEOLOGY OF VULCAN RIDGE
DEWAR CREEK AREA
BRITISH COLUMBIA

by

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ABSTRACT

The rocks underlying Vulcan Ridge are mainly Proterozoic metasediments of the Lower and Middle Division of the Aldridge formation, and Proterozoic (or later) Moyie intrusives.

Most of the metasediments are fine-grained quartzites, phyllites, schists and hormfelses composed mainly of quartz, biotite, muscovite and little feldspar. Tourmaline is a minor constituent of most metasediments but in the upper part of the Lower Aldridge it commonly forms up to 30 percent of the rocks. It is believed to have formed metasomatically by solutions derived from the White Creek batholith.

A lens-like deposit of breccia-conglomerates makes up the upper most part of the Lower Aldridge. Most of the deposit is composed of unsorted material - angular to subangular fragments of Aldridge type metasediments imbedded in abundant fine-grained matrix of similar composition. This deposit is believed to have formed by subaqueous slides or mudflows.

The Moyie intrusives are sill-like bodies of dioritic and gabbroic rocks composed essentially of hornblende, plagioclase and variable amounts of quartz. Most of the variations in texture and composition apparent in some of the intrusives are probably due to alteration but some may also be due to magmatic differentiation and to assimilation of country-rocks.

The metasediments in the southern part of the area have been subjected to regional metamorphism and are of low metamorphic grade. In the northern part of the area the rocks have been contact metamorphosed.

Within approximately 1½ mile of the White Creek batholith they have been metamorphosed to phyllites, schists and hornfelses which attained or closely approached a medium grade of metamorphism characteristic of the hornblende hornfels facies. Retrogressive metamorphism is extensive in the rocks near the contact of the batholith and is attributed to hydrothermal solutions derived from that intrusive.

Structure of the rocks south of the White Creek batholith is dominated by northeasterly trending folds which have been refolded into a large anticline near the batholith, and by northeasterly striking, steep dipping faults.

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CHAPTER I

INTRODUCTION

This thesis is based on the field work done by the author for the Consolidated Mining and Smelting Company of Canada during the summer of 1958, and on laboratory study completed during the 1958-1959 winter session of the University of British Columbia. It deals mainly with petrology, structure, and metamorphism of the rocks underlying an area of about 12 square miles immediately south of the White Creek batholith.

LOCATION AND ACCESSIBILITY

Dewar Creek area in the Purcell Mountains of southeastern British Columbia, may be reached by a good gravel road along St. Mary River from Kimberley which lies about 25 miles southeast of the area.

Vulcan Ridge itself is accessible by three pack trails (figure 1). The trail from the road east of White Creek, leads to Diorite Lake and the West Basin. Another trail from an old timber road at the southern extremity of the ridge rises to an elevation of 4,500 feet along its eastern slope. The trail along Dewar Creek provides the only access to the western slope of Vulcan Ridge.

CLIMATE AND VEGETATION

The average precipitation near Kimberley and Crambrook is 15 to 20 inches per year (Reesor, 1952).[1] Precipitation in the Dewar Creek area, however, is much heavier with frequent wet summer months. Exceptionally dry summer months are also known in this area.

[1] Dates in parentheses refer to bibliography on page 68.

Figure 1. Location and accessibility of Vulcan Ridge.

Most of the timber on Vulcan Ridge has been burned off so that the ridge is sparsely forested, but heavy deadfall, and in places thick underbrush persists to an elevation of about 5,000 feet. No trees are present about 7,500 feet, but a few open stands of coniferous trees are present just below that elevation.

TOPOGRAPHY AND DRAINAGE

Vulcan Ridge is in the deeply dissected eastern part of the Purcell Range, which rises to 9,500 feet above sea level. The ridge is typical of the mountains in this area. It has steep, but somewhat rounded lower parts, in places cut deeply by V-shaped valleys of the tributaries of White and Dewar Creeks. Its upper reaches have been deeply carved by glaciers that cut cirques with steep head-walls, sharp ridges and mountain peaks.

Small lakes still occupy some of the cirques at or above 7,000 feet. The area is drained by numerous creeks which flow into White and Dewar Creeks - the tributaries of St. Mary River.

GEOLOGICAL INVESTIGATIONS

The work of H.M.A. Rice (1941) in the Nelson Map area, east half, covers the part of the Dewar Creek area mapped by the author. Detailed work was done by J.E. Reesor (1958) who mapped the Dewar Creek area in 1950, 1951 and 1952 on a scale of 1 inch to 1/2 mile. O.E. Owens, geologist of the Consolidated Mining and Smelting Company of Canada, mapped the area on a scale of 1 inch to 1,000 feet in 1956. Mapping of the area by the author was done on the same scale.

GLACIATION

The large and numerous cirques are the most prominent glacial features in the area. They represent the latest stage of alpine glaciation which was so strong that above 6,500 feet it almost completely obliterated all signs of the pre-existing Cordilleran ice sheet which, in Wisconsin time, covered most of the Purcell Range to its present elevation of about 8,000 feet. (Daly 1915, Part II).

The somewhat rounded slopes below 5,000 feet still bear the sign of the Cordilleran glacier and the scattered glacial erratics indicate that it reached an elevation of at least 6,300 feet. Its former presence above that elevation is suggested only in places by flat or rounded ridges below 7,500 feet.

Southerly movement of the glacier in the valleys is clearly indicated by the presence of glacial erratics of porphyritic granodiorite south of the White Creek batholith from which they were derived.

A notable feature in the vicinity of Vulcan Ridge is the scarcity of glacial deposits. Glacial erratics and small amounts of poorly sorted gravels and silts (possibly derived from re-worked glacial drift) are the only remnants of glacial deposits on Vulcan Ridge. The valleys of Dewar and White Creeks contain some glacial drift, most of which has been re-worked by the streams.

TABLE I. TABLE OF FORMATIONS
(Modified after Reesor, 195[illegible])

Era	Period	Rock Unit	Lithology
Cenozoic	Recent and Pleistocene		Stream and glacier deposits
Mesozoic and/or Cenozoic	Jurassic or later	White Creek batholith	Quartz monzonite, Hornblende-biotite granodiorite, biotite granodiorite.
		INTRUSIVE CONTACT	
Proterozoic or later		Moyie Intrusives	Meta-diorite, meta-quartz diorite, meta-quartz gabbro.
		INTRUSIVE CONTACT	
Proterozoic	Lower Purcell	Creston formation	Green-grey weathering quartzites, argillaceous quartzites and argillites.
		Aldridge formation Upper Division	Rusty weathering argillites and argillaceous quartzites.
		Aldridge formation Middle Division	Grey weathering quartzites, argillaceous quartzites and minor argillites.
		Aldridge formation Lower Division	Grey-rusty weathering breccia-conglomerates. Grey weathering quartzites. Grey and rusty weathering argillites and argillaceous quartzites.

CHAPTER II

PETROLOGY

METASEDIMENTS

The metasediments outcropping on Vulcan Ridge are largely composed on quartzites, phyllites, schists and hornfelses. They belong to the Lower and Middle divisions of the Aldridge formation, and are the metamorphic equivalents of quartzites, argillites and argillaceous quartzites present in other less metamorphosed parts of the formation. Although of higher metamorphic grade, they will be described as quartzites, argillites and argillaceous quartzites to indicate their relation to equivalent but less metamorphosed Aldridge rocks in other areas. To simplify description, argillite will refer to micaceous rocks with less than 50 percent of quartz, and argillaceous quartzite to similar rocks with 50 to 75 percent of quartz. Quartzite will denote rocks predomimantly made up of quartz with less than 25 percent of micaceous material. This classification is adhered to throughout this report.

In Dewar Creek area, the Aldridge formation is divided into Lower, Middle and Upper divisions mainly on the basis of colour of weathered rocks and on the dominance of argillites or quartzites in each division.

LOWER ALDRIDGE DIVISION

The Lower Aldridge rocks in this area may be easily sub-divided into two types: Bedded rocks and breccia-conglomerates.

Bedded Rocks

The bedded rocks which make up most of the Lower Aldridge represent a series of thin-bedded argillites, thick and thin-bedded argillaceous quartzites and thick-bedded quartzites.

The argillites are light grey, brownish grey, in places dark grey and typically rusty weathered rocks made up predominantly of biotite, muscovite and lesser amounts of quartz. They are generally fine-grained, massive or slightly foliated (hornfelses and phyllites) but become medium-grained and schistose where highly deformed. All of them are thin-bedded (beds less than 1 foot thick). The individual beds, which are commonly from 1/4 to 4 inches thick, are inter-bedded singly or in groups, with quartzites and argillaceous quartzites. The groups of thin-bedded argillites are commonly made up of beds of similar thickness, texture and composition and may be from 1 to 20 feet thick. Graded and current bedding are not uncommon in many of the thin-bedded argillites. The former is recognized in the field by an increase of quartz towards the bottom, and mica, particularly biotite, towards the top of the beds. Some of the argillaceous beds also have a crinkled upper surface which may represent ripple marks.

Argillaceous quartzites are similar to the argillites but are generally thicker bedded and show fewer changes in composition within the beds.

Quartzites, unlike argillites and some of the argillaceous quartzites, are thick-bedded (beds commonly 2 to 3 feet thick) and invariably massive. Individual beds show little change in composition along strike or from the top to bottom of a bed. No graded bedding, ripple marks, or cross-bedding was ever observed in any of the quartzites in the field. A notable distinction of some of the quartzites is their very light grey colour, coarser grain and the presence of biotite clusters (a fraction of an inch in diameter) which give these rocks a distinct "spotty" appearance. A few concentrically zoned quartz-mica concretions, 2 to 3 inches in diameter are also present in these beds.

In thin-section, the quartzites, argillites and argillaceous quartzites are seen to be composed mainly of biotite, muscovite and quartz, which appear in various proportions in the different rock types. The argillaceous quartzites consist of small (.03 - .2 mm.) angular, commonly irregularly shaped, partially interlocked quartz grains and varying amounts of interstitial biotite and (or) muscovite. Argillites, under the microscope, are similar to argillaceous quartzites except that they contain more mica. Most of the mica is fine grained but a few large, stubby, commonly poikiloblastic crystals of biotite and muscovite are also present, in places oriented at right angles to the foliation. In foliated argillites (phyllites and schists) the micas are coarser grained than quartz or other minerals and well oriented. Quartzites resemble argillites and argillaceous quartzites in thin-section but contain distinctly more quartz and are somewhat coarser grained (grains in a few places up to .5 mm.).

Feldspars[1] can be seen in thin-sections of various rock-types, but in most of them they do not form more than 5 percent of all the minerals.

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[1] Albite, microcline and orthoclase appear to be the most common feldspar. Oligoclase-andesine was identified in several thin sections but it was difficult to estimate the amount of this plagioclase as most of it is very fine grained and poorly twinned so that it could have been mistaken for quartz.

Figure 2. Tourmaline bearing metasediments of the Lower Aldridge. Note the distribution of tourmaline parallel to the bedding and concentration of the mineral near the top of beds (upper left). The specimen on the lower right, in addition to tourmaline and quartz contains about 50 percent of feldspar. (Specimens are natural size).

Exceptions are the rocks near contacts of the Moyie intrusives where the feldspars (essentially albite) increase appreciably in amount and commonly form up to 20 percent of the rock. A few feldspathic quartzites and argillaceous quartzites are also present in the upper part of the Lower Aldridge, where some of these rocks contain 10 to 20 percent or more (figure 2) of albite and K-feldspar. The feldspars (especially albite and orthoclase) are in places very fine grained, highly intergrown (figure 3) and appear to form an interstitial matrix of the quartz grains.

The increase of albite in the metasediments near the contacts of Moyie intrusives, is related to the intrusives rather than to any particular bed or rock-type. This suggests that at least some of the albite in these metasediments was introduced from the intrusives. Considering that the intrusives have been at least partially albitized (p. 36) it is likely that the metasediments at their contacts were similarly affected. The abundance of feldspar in the quartzites and argillaceous quartzites, in the upper part of the Lower Aldridge, cannot be related in the field to any intrusives,veins or pegmatites but, the interstitial texture of feldspar in these rocks is similar to that formed by some of the albite in the albitized quartzites near Moyie intrusives, and is almost identical to that formed by feldspar in the "granitized" quartzites at Bingham, Utah, (Stringham, 1952). Since the feldspar in both of these places has apparently been introduced from nearby intrusives it is possible that the interstitial feldspar in the upper part of the Lower Aldridge was also introduced from outside sources. Introduction of feldspar from outside sources would explain the high concentration of feldspar in these rocks, which has not been reported from any other parts

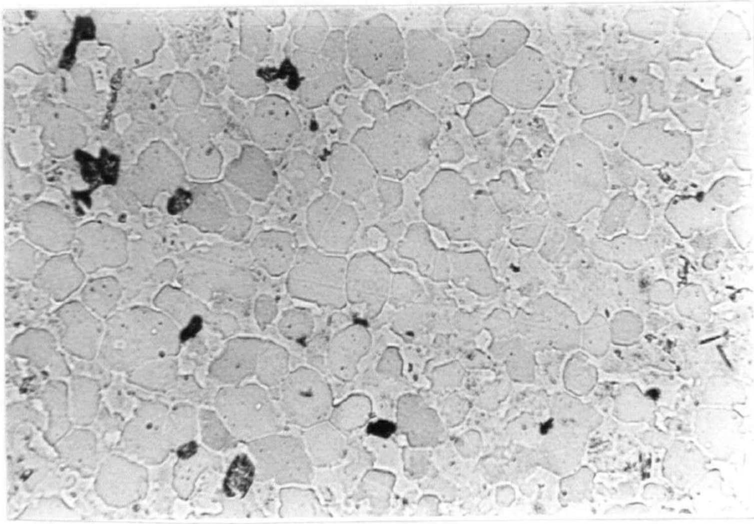


Figure 3. Interstitial feldspar in feldspathic quartzite. The rounded grains are quartz. x 150

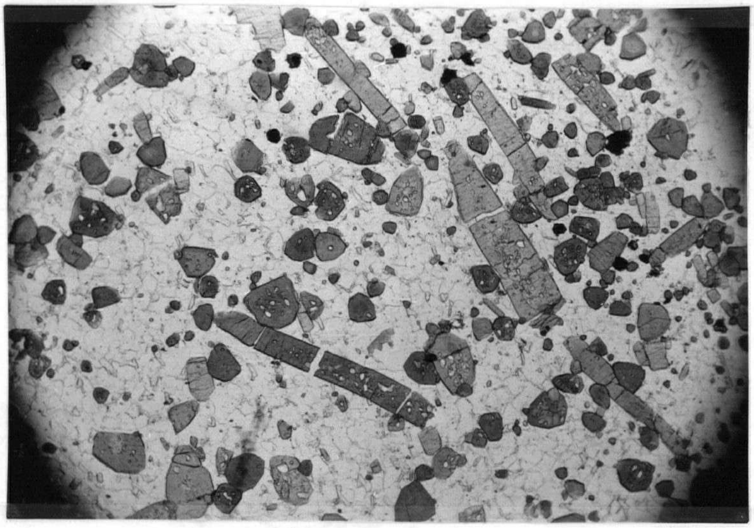


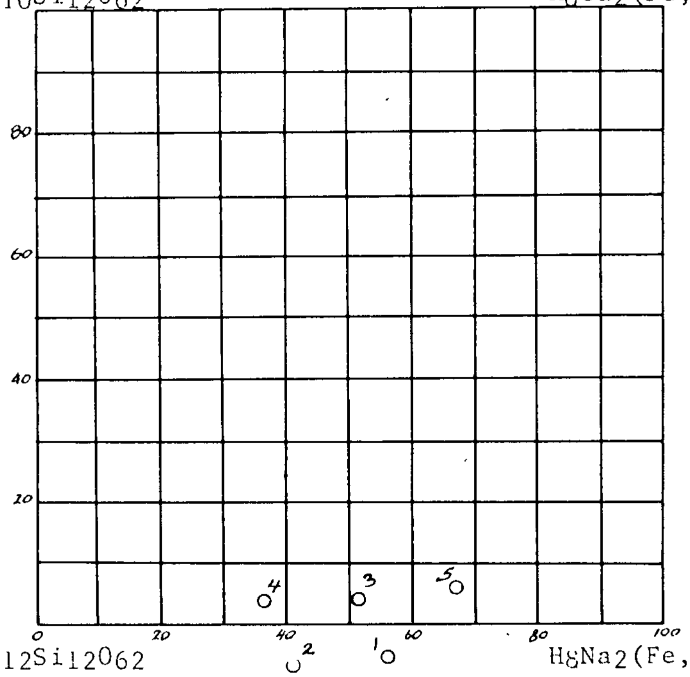
Figure 4. Typical texture of tourmaline in the Aldridge metasediments. x 50

TABLE II OPTICAL PROPERTIES OF TOURMALINE

No.	Occurrance	Colour in handspecimen	Indeces of refraction		Pleochroism		Bİref-ringence
			n_o	n_ϵ	n_o	n_ϵ	
1	Pegmatite	Black	1.662	1.634	Dark blue	colourless	.028
2	Vein	Black	1.655	1.628	Blue-green	colourless	.027
3	Vein	Brown	1.661	1.634	Brown bluish green	colourless	.027
4	Metasediments	Black	1.654	1.628	Green-brown	Very light yellow to colourless	.026
5	Metasediments	Dark brown	1.666	1.638	Brown	Very light yellow to colourless	.028

TABLE III COMPOSITION OF TOURMALINE ACCORDING TO ITS OPTICAL PROPERTIES

$H_8Ca_2Mg_8B_6Al_{10}Si_{12}O_{62}$ $H_8Ca_2(Fe,Mn)_8B_6Al_{10}Si_{12}O_{62}$



$H_8Na_2Mg_6B_6Al_{12}Si_{12}O_{62}$ $H_8Na_2(Fe,Mn)_6B_6Al_{12}Si_{12}O_{62}$

(After Winchell, 1951)

TABLE IV QUALITATIVE SPECTROGRAPHIC ANALYSES OF TOURMALINE

	Major Elements	Minor Elements	Trace Elements
1	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
2	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
3	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
4	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
5	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)

? Questionable as only 1 line was identified on spectrographic plate of the Aldridge formation, except those near intrusives and centres of hydrothermal activity.

Minor constituents of the argillites, quarzites and argillaceous quartzites are iron oxides, pyrite, graphite, apatite, sphene, leucoxene and zircon. Garnet was only found in two thin-sections, in which it formed less than 1 percent of all the minerals. Chlorite is only common in the southern part of the map area where some argillites contain up to 15 percent of the mineral.

Tourmaline

Tourmaline is a common constituent of Aldridge rocks and deserves special comment. The mineral is most abundant in the upper part of the Lower Aldridge, but is also present in some pegmatites, veins and other rocks in the area.

In pegmatites it appears as plumose aggregates or single jet-black crystals up to 3 inches long, imbedded in a coarse-grained quartz feldspar matrix. The crystals are invariably shattered and commonly transgressed by small quartz-feldspar veinlets.

Tourmaline bearing veins are found in various parts of the area. Most of them are less than one inch thick, but a few quartz-tourmaline veins up to 1 foot thick are also present. The veins are commonly vuggy, have sharp contacts with unaltered wall-rocks, and frequently contain no other minerals besides tourmaline and quartz. Most of the tourmaline is confined to the veins and rarely extends for more than a few inches into the adjacent rocks. Two types of tourmaline are found in the veins: black and brown (TableII). The black tourmaline occurs in most veins as irregularly stacked, vuggy aggregates of slender crystals (up to ¼ inch

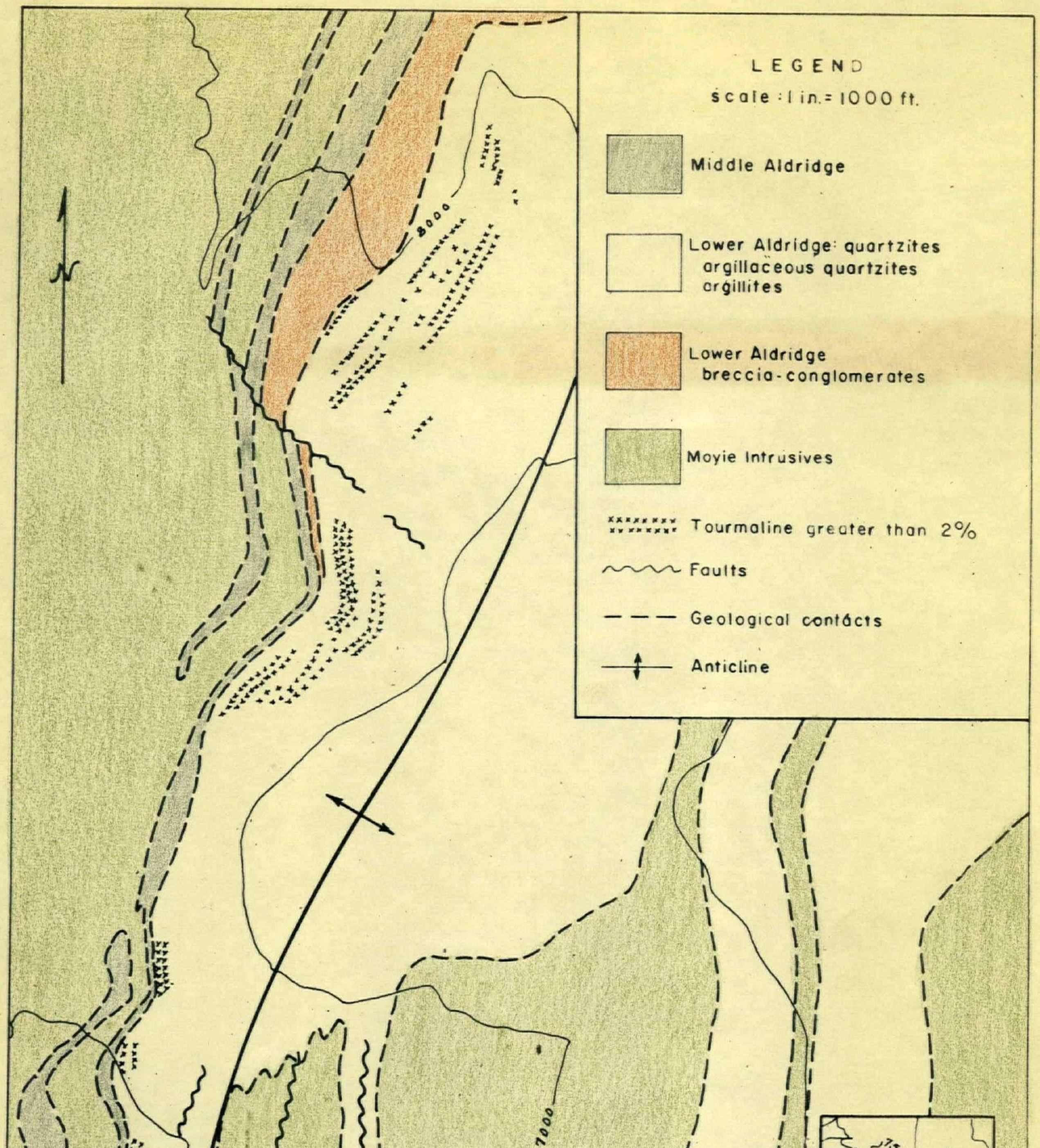


Figure 5. Sketch map showing distribution of tourmaline in the Lower Aldridge sediments.

long) and less commonly as radiating clusters. The brown needle-like tourmaline, on the other hand, is more commonly found in tightly stacked columnar groups which project at right angle to the vein contacts. The two tourmalines are rarely found together. In a few places where both of them were present in the same vein, the black tourmaline appeared to be the latest mineral to have developed as it formed coatings and encrustations on the brown tourmaline and the other minerals present.

Although tourmaline is found in most metasediments in the area it rarely forms more than 1 or 2 percent of these rocks. Notable exceptions are the argillites and argillaceous quartzites in the Upper Lower Aldridge (figure 5), many of which contain 20 to 30 percent (in beds less than 6 inches thick) and, in a few places, as much as 60 percent (in beds less than 1 inch thick) of the mineral. Tourmaline in these rocks is of the two types which are distinguished by their black and dark brown colour, (in thin-section by pleochroism, see Table II). Both tourmalines, of which the dark brown variety is the most common, are haphazardly intermingled in the same bed or occur in separate beds entirely unassociated with one another. Both occur as dominantly euhedral, needle-like crystals (average crystal 5 mm. in diameter, 3 mm. long), commonly with abundant inclusions of quartz and feldspar (figure 4). Many of the crystals are fractured and separated along the base, and commonly well oriented parallel to the bedding and foliation. They are either uniformly distributed throughout a bed or concentrated into bands parallel to the bedding, in places duplicating such sedimentary features as ripple marks, current and graded bedding (figure 2). In some beds tourmaline also appears in streaks, lenses and irregular patches which were never seen to extend across contacts of adjacent beds. Such irregular concentrations are not very common. In most beds, lateral changes in tourmaline content are gradational and in most places insignificant. A group of beds (approximately 4 feet thick) in Orange Tent Basin, similar to those in figure 2,for instance, were followed in continuous outcrop for about 150 feet without apparent change in content and distribution of tourmaline. Variations of tourmaline content from bed to bed, however, are abrupt and commonly great, so that a bed containing over 25 percent of tourmaline may be adjacent to one with less than 1 or 2 percent of the mineral. Such alternating tourmaline-rich and tourmaline-deficient beds are common throughout the "tourmaline zone" in the upper part of the Lower Aldridge.

Origin of Tourmaline

The distribution and abundance of pegmatites are directly related to the White Creek batholith and there can be little doubt that these pegmatites and the tourmaline within them were derived from that source. The tourmaline in veins was probably also derived from the batholith. The alternate possibility that tourmaline was "sweated out" of tourmaline bearing metasediments during metamorphisms seems improbable. Not only is most of the tourmaline in the metasediments different from that in the veins, but the veins themselves are not restricted to, or especially concentrated in tourmaline rich rocks. Some of them occur hundreds of feet away from any rocks rich in that mineral.

The origin of tourmaline in Aldridge metasediments is not as clear. Four possible origins could be suggested: detrital, authigenic, metamorphic and metasomatic.

Tourmaline is a fairly common detrital mineral, and some grains like those described by Reesor (1958, p. 8) could be of this origin. Most tourmaline, however, is definitely not detrital. If the tourmaline was detrital one would expect it to concentrate along the bottom of graded beds of argillite and argillaceous quartzite, but the converse is true (figure 2). In addition, the crystals of tourmaline are euhedral, much larger than any grains in the surrounding rock and much too abundant to be of detrital origin.

Small amounts of authigenic tourmaline are known to occur in some sediments, (Alty 1933, Krynine 1946), but were never identified in any of the rocks in this area. Even if authigenic tourmaline was originally present and then recrystallized during metamorphism to its present form, the small quantities in which it occurs in sediments (Pettijohn 1957, p. 670) could not account for the high concentration of tourmaline in the local metamorphic rocks.

Formation of tourmaline by metamorphism of boron rich sediments is another possibility. Goldschmidt and Peters (Turner, 1948), found that some marine clays contain up to .1 percent of B_2O_3 and suggested that tourmaline in metamorphic equivalents of such rocks could be derived from their original boron content and would not necessarily indicate metasomatism. This view is upheld by Helmquist and Elligtsgaard-Ramussen (Frondel 1957) who attributed tourmaline in some metamorphic rocks in Sweden and Greenland to metamorphism rather than to metasomatism. Frondel (1957) also admits that tourmaline in some metamorphic rocks could be of this origin.

A similar origin of tourmaline in Aldridge metasediments might be suggested by the following:

(a) The highest concentration of tourmaline is in the upper part of the Lower Aldridge, where its distribution is stratigraphically controlled.

(b) The abundance of tourmaline in this area is not visibly related to any one of its possible sources - veins, pegmatites or the White Creek batholith.

(c) The tourmaline in metasediments shows various signs of deformation (commonly well aligned, fractured and separated along the base), as well as do the rocks in which it occurs. Tourmaline veins and veinlets present in the same rocks, however, bear no sign of deformation. Even the smallest, vuggy veinlets are not fractured or displaced and neither are most of the fragile, needle-like crystals within them. Obviously, most of the tourmaline veins formed after deformation of the adjacent rocks and therefore, could not have been the source of tourmaline in metasediments.

Although the above evidence might favour metamorphic origin of the tourmaline in metasediments, such origin cannot very well explain the abundance of the mineral in these rocks. The tourmaline commonly makes up to 30 percent of the rocks in the upper part of the Lower Aldridge, which would have had to contain originally about 3 percent of B_2O_3. This amount is about thirty times greater than the highest concentration of B_2O_3 in sediments reported by Goldschmidt and Peters (.1 percent B_2O_3 in marine clays). The difference becomes even greater for argillites and argillaceous quartzites which contain up to 60 percent of tourmaline especially if one considers that these rocks were not clays originally. One could still argue and suggest that even if a small amount of boron was present in the original sediments it could have been "mobilized" and concentrated in certain rocks during metamorphism. Such method of concentration seems possible considering the high mobility of boron, but magmatic concentration of the element is more likely.

Evidently, the magma of the white creek batholith was able to concentrate baron. This is indicated by the presence of tourmaline in miarolitic cavities[1] within the batholith and by the presence of tourmaline in veins and pegmatites undoubtedly derived from it. It seems unnecessary, therefore, to assume a metamorphic origin of tourmaline, especially when the original boron content of the metasediments cannot be proved. Certainly large quantities of boron in the original sediments cannot be assumed as most of them were not marine clays, in which boron is known to be high, but sandstones and sandy siltstones in which boron, if present at all, would have been only in very small quantities (Rankama and Sahama, 1950). It is true of course, that the tourmalines in veins and pegmatites derived from the batholith, are not identical to those in the metasediments. They are, however, similar in composition (Table IV). This similarity suggests that the tourmalines were formed by somewhat similar solutions which were probably derived from a common source - the White Creek batholith.

It is not clear why tourmaline is highly concentrated in the upper part of the Lower Aldridge. The abundance of argillites in this part of the Aldridge may be part of the answer as the field evidence

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[1] Personal communication. J.V. Ross, Assistant Professor, University of British Columbia.

clearly shows that tourmaline has preferentially replaced argillaceous rocks. The availability of rocks favorable for replacement, however, cannot alone explain the abundance of tourmaline in the upper part of the Lower Aldridge. This part of the Aldridge, is more argillaceous than some other parts of the formation (Middle Aldridge, central part of the Lower Aldridge), but argillaceous rocks, even though not as abundant, are present in many other parts of the formation where tourmaline is present only in small amounts. This, and the fact that tourmaline replacement proceeds parallel to bedding rather than across it, would make it necessary for the feeder or feeders of tourmaline bearing solutions to be directly connected to the now tourmalinized beds. No such connections could be found in the field, but they could be present at depth, down-dip from the present location of tourmaline rich metasediments. This possibility is not unlikely, considering that the tourmaline zone in the upper part of the Lower Aldridge is not far away from a large anticlinal structure which plunges towards the batholith and is in a favourable position to be intercepted by veins, pegmatites or off-shoots from the batholith.

The differences in temperatures and pressures of the solutions which deposited tourmaline can probably explain why the black and brown tourmaline was deposited in veins and why the dark brown tourmaline was formed in metasediments. The vuggy and crustified nature of the veins suggests that the solutions which deposited the black and brown tourmaline were at low temperature and pressure. Therefore these solutions were probably not able to extensively penetrate and replace country-rocks so that most of the tourmalines that formed were deposited in veins. The dark brown tourmaline, on the other hand, was the earliest tourmaline to form (pp.16,19). Therefore, it seems likely that the solutions from which it was formed were at higher temperature and pressure than the later solutions and were, therefore, more capable of penetrating and replacing solid rock.

Breccia-Conglomerates

Breccia-conglomerates occur only on or just below the Lower Aldridge-Middle Aldridge contact. They appear in the form of a lens-like deposit which can be traced in outcrop from east of Diorite Lake Basin for approximately 2½ miles to the Orange Tent Basin. Small outcrops of breccia-conglomerates which appear in the same stratigraphic horizon south of Orange Tent Basin, suggest that this deposit extends to the southern extremity of Vulcan Ridge and has a total length of approximately 5 miles. The thickest part of the deposit is in Diorite Lake Basin where the total thickness of breccia-conglomerates is from 500 to 1000 feet. To the south and to the east of this basin, the deposit continuously decreases in thickness and finally disappears.

The deposit as a whole appears to be conformable with the surrounding metasediments. Wherever the lower contact appears in outcrop it is parallel to the adjoining strata. Where it cannot be observed directly, its position in most places can be inferred within a few feet. In these places it also appears to be parallel to the bedding of the adjacent rocks. If small irregularities are present on its surface they cannot be detected. The upper contact of the deposit is not very well exposed but where it does appear in outcrop, it is seen to be conformable to the overlying rocks.

The deposit within the boundaries just described consists almost entirely (95 percent or more) of breccia-conglomerates in which the fragments of various sizes and shapes are haphazardly distributed throughout an abundant, fine grained matrix. These breccia-conglomerates will be referred to as "unsorted breccia-conglomerates". The rest of the deposit is made up of several thin beds of argillites and argillaceous quartzites, and of a few small but distinct bodies composed of well sorted fragments. The latter will be referred to as "sorted breccia-conglomerates".

The fragments which make up about 30 percent of the unsorted breccia-conglomerates, are angular, subangular, in places highly contorted and rarely well rounded. They vary in length from a fraction of an inch to 3½ feet. Those less than 2 inches long constitute over 80 percent of all the fragments. Composition of most of thefragments as well as their texture and colour, are very similar to the massive argillites and argillaceous quartzites of the Lower Aldridge. Fragments of Aldridge type quartzites and a few fragments of biotite schists are also present. The most unusual "fragments" are the large boulders exposed in Diorite Lake Basin which consist mainly of quartz and calcic plogioclase. Most of them are rounded and commonly very irregular in outline. Some of them are spindle-shaped and resemble volcanic bombs.

The matrix which surrounds the fragments in the unsorted breccia-conglomerates is grey, commonly rusty on weathered surface, fine-grained and typically massive. Its average composition, based on the modal analyses of five specimens from various parts of the breccia-conglomerates is given below:

Quartz	51%
Feldspar	5%
Biotite	23%
Muscovite	18%
Tourmaline	1%
Sphene Zircon Pyrite Iron Oxides Apatite	2%

This composition is very similar to the composition of many fragments in the breccia-conglomerates and to the composition of many argillites and argillaceous quartzites in the Lower Aldridge. The composition, colour and fine-grained texture of the matrix and of the fragments are so similar in many places that the two can barely be distinguished from one another on a fresh, unweathered surface of the rock.

The distribution of fragments in the matrix of any one part of the deposit of breccia-conglomerates, appears to be entirely haphazard. Considering the deposit as a whole, however, it is apparent that the distribution of fragments has a definite pattern. It is evident that the largest fragments are generally most abundant in the thickest part of the deposit. The fragments larger than 2 inches are most abundant in Diorite Lake Basin where the deposit is the thickest. This part of the deposit also contains the largest fragments which are up to 3½ feet long. East of this basin where the deposit diminishes in thickness to less than 200 feet and finally disappears, the largest fragments are 3 inches long. Similarly, the largest fragments immediately south of the basin are up to

1 foot long, and in Orange Tent Basin where the deposit is about 200 feet thick the largest fragments are only up to 6 inches long. South of Orange Tent Basin where the breccia-conglomerates are only 2 to 70 feet thick, the largest fragment is not longer than 1 inch.

The sorted breccia-conglomerates which form less than 5 percent of the whole deposit are present only in a few places. These breccia-conglomerates have the shape of throughs or lenses or of very irregularly shaped masses (figure 6,7). They are composed of well sorted, angular, subangular and rounded fragments, with various amounts of well to moderately well sorted sandy-argillaceous material. A characteristic feature of all sorted breccia-conglomerates is the striking similarity of the fragments and their matrix to the fragments and matrix of the surrounding unsorted breccia-conglomerates.

An unusual type of "fragmental" material appears within the unsorted breccia-conglomerates in Diorite Lake Basin. In outcrop this material occupies an oval-shaped area, approximately 100 feet long and 20 feet wide, elongated roughly at right angle to the strike of the bedding above and below the breccia-conglomerates in which it occurs. This "fragmental" material consists of 1/2 to 4 inch fragments surrounded by a fine-grained matrix. The fragments which make up approximately 50 percent of this deposit are rounded, subangular and very commonly highly contorted. Many of the fragments have very indistinct or gradational boundaries with the surrounding matrix.

Both fragments and the matrix are made up almost entirely of three minerals: medium-grained, fibrous and radiating actinolite, fine to

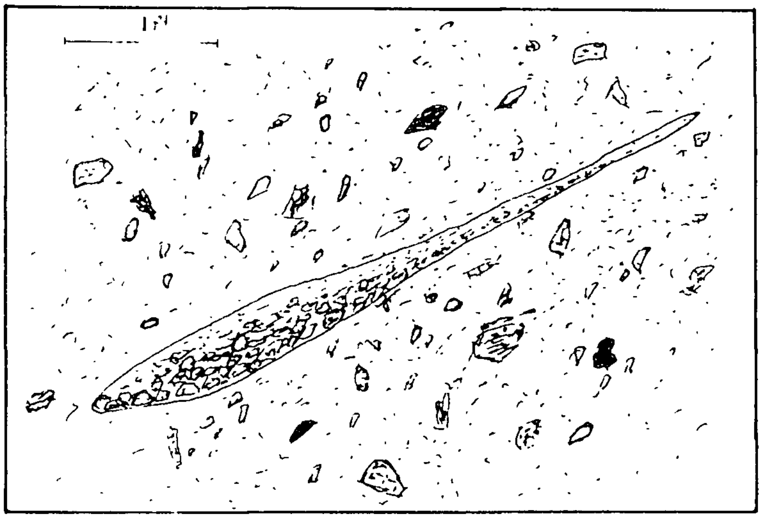


Figure 6. Sketch of an outcrop in Orange Tent Basin showing a lens-like body of sorted breccia-conglomerate surrounded by unsorted breccia-conglomerate.

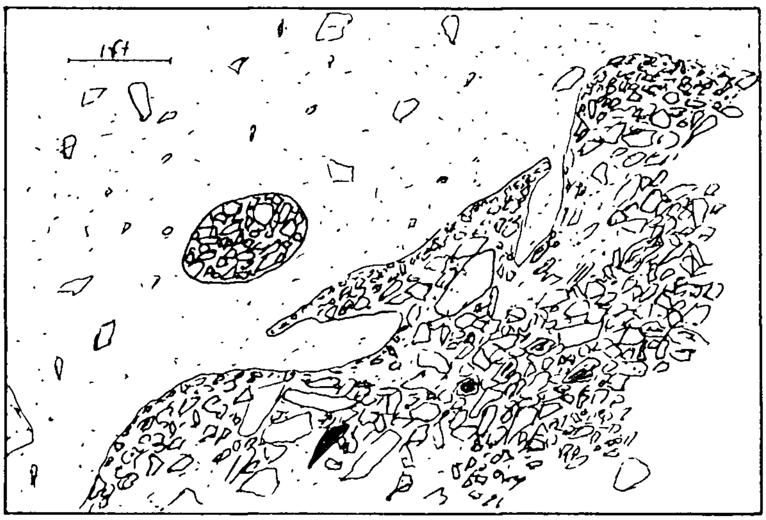


Figure 7. Sketch of an outcrop in Diorite Lake Basin showing irregularly shaped body of sorted breccia-conglomerate.

medium-grained quartz, and calcic plagioclase (labradorite to anothite). Smaller amounts of biotite and clinozoisite are also present. Small disseminated grains which appear in some fragments and the surrounding matrix are apatite, zircon, sphene, pyrite, pyrrhotite, galena and scheelite. The composition of this rock, with the exception of actinolite, scheelite and some of the sulphides, is similar only to the large, irregular boulders in the unsorted breccia-conglomerates and to a few of the concretions near the White Creek batholith. No other rocks of similar composition could be found in the map area.

Of some interest are the 2 inch to 3 feet thick groups of thin-bedded and laminated argillites and argillaceous quartzites, which occur in a few places within the unsorted breccia-conglomerates. Although widely separated from one another, these beds have very similar texture, composition and structure. They are fine-grained, thinly bedded and roughly parallel to the contacts of the breccia-conglomerates with the underlying or the overlying bedded rocks. They are rather uniform in thickness and have sharp contacts with the surrounding unsorted material. Most of these beds could not be traced in outcrop for more than a few tens of feet and their terminations were seen only in two places (both in Diorite Lake Basin) where the beds ended abruptly along the strike in unsorted breccia-conglomerates. Composition and texture of these beds is almost identical to similar beds underlying the deposit of breccia-conglomerates.

Origin of the Breccia-conglomerates

The lack of sorting, abundance of fine-grained matrix and the lack of stratification within most of the breccia-conglomerates in this area might suggest an origin similar to that of glacial till. However, the possibility that these rocks are glacial deposits is very slight. Glacial tillites are characterized by some, if not all of the following: underlying striated surface, striated and often faceted fragments, varied size and lithology of the fragments, structureless matrix and association with varied clays and other bedded sediments which contain rafted pebbles or debris. The lack of these features in the breccia-conglomerates and in the bedded rocks with which they are associated, precludes glacial origin. Furthermore, if a glacier did exist in the area occupied by these breccia-conglomerates, one would expect to find some evidence of glaciation along the same stratigraphic horizon in other areas. Such evidence, however, has not been found in this or any other part of the Aldridge formation.

The only other deposits which would closely resemble the breccia-conglomerates in this area would be those formed by mudflows or subaqueous slides. The latter would seem more probable as there is no evidence which would suggest that the surface on which the breccia-conglomerates were deposited, was ever exposed above water. If the deposits were formed by mudflows - the mudflows must have been subaqueous. Slides and mudflows are not uncommon in subaqueous environment (Pettijohn 1957, Kuenen 1957) and would best explain the lack of sorting and stratification in most of the breccia-conglomerates, the striking similarity of its fragments and matrix to the underlying Aldridge metasediments, and the presence of contorted fragments. A series of such slides or flows, superimposed on one another with occasional intervals of normal sedimentation, could explain the thickness and shape of the deposit, and the presence of thin-bedded argillites and argillaceous quartzites within it. The bedded argillites and argillaceous quartzites would represent the periods of normal deposition (evidently the same as the conditions under which similar rocks immediately below the breccia-conglomerates were deposited), and the shape of the deposit would correspond to a section roughly at right angle to the direction of flow of the slides. The thickest part of the deposit probably represents areas where the flows had the greatest velocity and were able to carry the largest amount of material and the coarsest fragments.

The lenticular or channel-like deposits of sorted breccia-conglomerates were probably formed either by small streams which flowed over parts of the deposit briefly exposed above water, or by subaqueous turbidity currents. To form such deposits, the subaerial or subaqueous currents needed only to remove some of the fine grained matrix of the unsorted breccia-conglomerates and partially redistribute the remaining fragments. This method of formation is suggested by the similarity of the fragments and the matrix of the sorted breccia-conglomerates to those of the adjacent unsorted breccia-conglomerates. The irregularly shaped masses of sorted breccia-conglomerates were probably formed by slumping of lenticular or channel-like deposits of sorted material previously formed by the currents.

The origin of the actinolite-plagioclase rock (described on page 25) is uncertain but the presence of highly contorted fragments suggests soft sediment deformation. This deposit, therefore, might represent a slumped, possibly muddy calcareous sediment, later metamorphosed and modified by hydrothermal solutions to a rock of the present composition.

MIDDLE ALDRIDGE DIVISION

This part of the Aldridge formation consists of a series of thick and thin-bedded argillites, quartzites and argillaceous quartzites which are similar in most respects to the equivalent rocks of the Lower Aldridge. The division as a whole differs from the Lower Aldridge in that it contains more quartzites and fewer thin-bedded argillites and argillaceous quartzites. Its grey, rather than rusty weathering also serves to distinguish it from the Lower Aldridge Division. Another distinct characteristic of the Middle Aldridge, especially of its lower part, is the abundance of concretions and "spotted" quartzites.

The concretions are most abundant in massive quartzites, commonly near the centre of the beds. They were not seen in any thin-bedded argillaceous beds or in any beds of quartzite less than 4 inches thick. These concretions are ellipsoidal bodies, half an inch to 1½ feet long and elongated parallel to the bedding, composed of one to several alternating zones. The zones are from 1/10 to 1 inch wide, black, white, dark to light grey, concentric, in most places sharply defined and rarely discontinuous. In most of the concretions the zones appear to be outside of the core of the concretion but in many of them the contacts of the core with the surrounding rock are not distinct, so that the position of the zones in relation to the cores cannot be definitely determined. Differences between various parts of the concretions are mainly due to the content and distribution of biotite, muscovite and quartz - the three main minerals of the rocks in which these concretions occur.

Feldspar, sphene, pyrite, iron oxides, apatite, tourmaline and carbonate also appear in these concretions but only in small amounts. Sphene is more common in biotite rich parts of the concretions, and carbonate is invariably confined to the core. In one concretion albite appeared to be more common in the quartz rich (white) zones than in any other parts of the concretion or the surrounding quartzite.

Origin of the concretions is probably epigenetic as indicated by their restricted occurrence within quartzites (the best sorted and originally the most porous rocks) and by the similarity of their composition to the surrounding quartzites. They were probably formed by circulating ground waters which redistributed the cement of quartz grains in the original sandstones.

Spotted quartzites are light grey, massive, equigranular rocks with scattered rounded "clusters" of biotite. In thin-section, most of the biotite "clusters" are seen to be composed of a biotite-rich core which is surrounded by a quartz or quartz-muscovite zone. Some of the clusters have a central part made up essentially of quartz, and surrounded by a rim of biotite. In two thin-sections, the biotite clusters are seen to be surrounded by three alternating biotite rich and biotite deficient zones. A biotite cluster in another thin-section is seen to consist of biotite rich core which also contains carbonate and small amount of sphene. This core is surrounded by a quartz rich, biotite deficient zone in which apatite is more abundant than in any other part of the same rock. This zone, in turn, is surrounded by a narrow biotite rim. All of the above described zones are concentric and well defined.

The shape of these clusters is spheroidal or ellipsoidal. Most of the ellipsoidal clusters are elongated parallel to the bedding and some are two to three times as long as they are wide. All of the biotite clusters observed by the writer, measured less than 1/2 inch in their longest dimension.

Spotted quartzites have been reported in other parts of the Aldridge formation by Rice (1937) and Hoadley (1947), both of whom attributed the origin of the biotite clusters to contact effects of the Moyie intrusives. Some of the spotted quartzites in this area are also present near Moyie intrusives, but identical rocks are also found hundreds of feet away from these intrusives and as far as 5 miles south of the White Creek batholith. Clearly, the development of spotted quartzites is not only a contact metamorphic phenomena. On the contrary, the concentric zoning, composition, shape and occurrence of some of the clusters are similar to those of the large concretions in quartzites. This similarity of biotite clusters and concretions suggests a common origin of both of these concretionary forms. Although metamorphism and possibly hydrothermal solutions have, at least partially, modified the composition of the small biotite "clusters" and large concretions, and accentuated some differences in their structure, it is doubtful whether any of these agents were the principal cause of their formation.

IGNEOUS ROCKS

MOYIE INTRUSIVES

The intrusives referred to as Moyie sills (Daly, 1912), Purcell sills (Schofield 1915), Purcell intrusives (Rice 1935, 1937, 1941) and Moyie intrusions (Reesor 1952) have been described by these authors from various parts of the Purcells in south-western British Columbia. Similar intrusives in the area of Vulcan Ridge will be referred to by the author as Moyie Intrusives.

Structure

Most of the intrusives, exposed in good outcrop on both slopes of Vulcan Ridge, are sill-like bodies, in general concordant to the intruded country-rocks. In detail, however, their concordance is not perfect. Even the most sill-like bodies commonly cut across a few feet of bedding. The upper contact of one sill cuts about 30 feet of the adjacent metasediments at an angle of about 60 degrees to their strike. In places where the sills branch out they cross-cut even greater thickness of rock and become dyke-like. Such discordant intrusives are most common in highly deformed parts of the area, but not all of their discordant contacts are intrusive. Some, undoubtedly, were formed by post intrusive folding and faulting of the surrounding rocks rather than by emplacement of the intrusives.

All of the intrusives in the area have well defined contacts and are easily distinguished from the adjacent metasediments. Most of them are irregularly jointed and massive in appearance. Foliation is well developed only near faults, in some highly folded parts of the intrusives and near some of their contacts.

Inclusions of country rocks are found near some of the contacts of the intrusives, especially where the intrusives cut sharply across the bedding of the adjacent metasediments. Most of these inclusions have well defined contacts and do not appear to have moved very far from the parent rock. In other parts of the intrusives, inclusions are few and appear to be at least partly "digested" by the intrusives as indicated by their diffuse and gradational contacts with the surrounding rocks.

Texture and Composition

In outcrop the intrusives are dark green to light greyish green and massive in appearance. Their weathered surface is generally smooth but becomes pitted where feldspars have weathered out of the rock. On fresh surface the rocks are grey to light greenish grey and are seen to be composed of dark green hornblende set in a light grey to white matrix in which feldspar and a few grains of quartz may be distinguished with a hand lens. Most of these rocks are medium-grained and roughly equigranular, but fine-grained, foliated, porphyritic and coarse-grained varieties are also present.

Thin-sections show the rocks to be composed essentially of hornblende, plagioclase and the always present but variable amounts of quartz and epidote. Biotite and chlorite appear in most of the sections but are only abundant in those of highly altered rocks. Sphene, leucoxene, ilmenite, magnetite, pyrite, zircon and apatite are also present but only in small quantities.

Hornblende is the most abundant and characteristic constituent of the intrusives. It commonly makes up 40 to 60 percent of the rocks but local concentrations of up to 80 percent are not uncommon. In a few parts of the intrusives it forms less than 10 percent of the rock and is absent from some of the highly altered rocks and most inclusions. The strong to moderate pleochroism (x = pale green, y = green, z = bluish green) is characteristic of all hornblende in the intrusives of this area.

Texturally, hornblende shows greater variation than any other constituent of the intrusives. It is fine to very coarse-grained, euhedral to anhedral, stubby or acicular, uniformly distributed throughout the rock or concentrated into patches of haphazardly intergrown crystals (figure 8), radiating clusters or fan-like aggregates. Needle-like inclusions in other minerals particularly plagioclase are common (figure 9). Sieve textures,

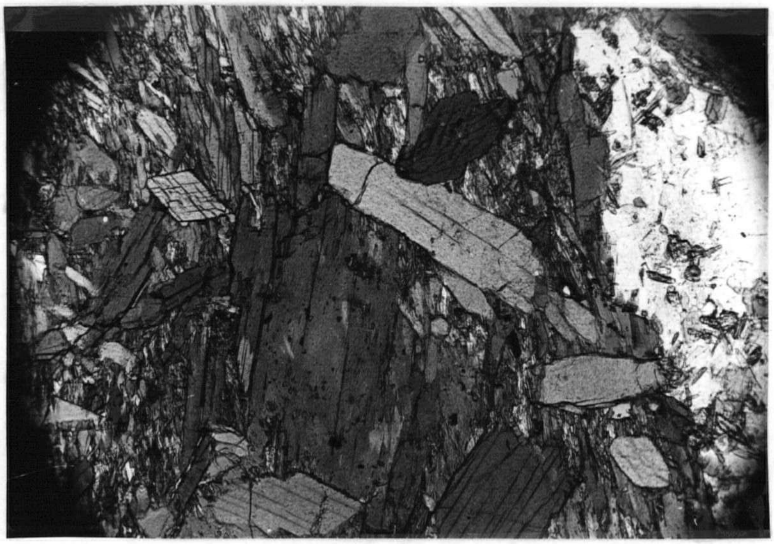


Figure 8. Haphazardly intergrown crystals of hornblende. x55

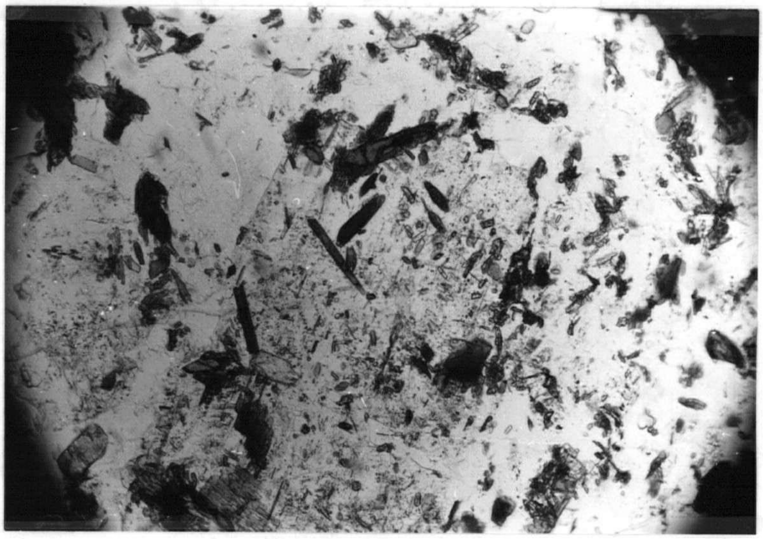


Figure 9. Inclusions of hornblende (dark, prismatic crystals) in plagioclase. x100

formed by numerous inclusions of quartz are also abundant.

Plagioclase is the next most abundant constituent after hornblende and commonly forms 10 to 20 percent of the rocks. It occurs as subhedral to anhedral, dominantly lath-like crystals, .5 to 3 mm long. Inclusions of quartz and epidote are common and in places almost completely replace the mineral.

Plagioclase varies from albite (approximately An_5) to labradorite (An_{68}). Such variation in composition may occur within one intrusive (table V).

Zoning is best developed in calcic plagioclase and is of the normal type. It consists of 1 or at the most 3 sharply defined zones which become progressively more sodic away from the cores of the crystals. Zoning in sodic plagioclase is very irregular. It appears as wide, diffuse sodic rim which grades into a more calcic, commonly mottled and highly corroded core (figure10). Most of the albite crystals are not zoned. The corroded relicts of calcic plagioclase in albite-oligoclase crystals, indicate that at least some plagioclase in the intrusives was albitized (Turner and Verhoogen, 1951, p. 202). Most of the unzoned albite was probably also produced by albitization of calcic plagioclase.

Quartz commonly forms 5 to 20 percent of the intrusive rocks but in places up to 60 percent or more of the mineral may be present. It is most abundant immediately on the contact of some intrusives, near partially "digested" quartzite inclusions, and in the upper parts of some of the sills. Texturally, quartz shows less variation than any other mineral. It is invariably fine grained and roughly equigranular. It occurs most commonly as irregular clusters of roughly equidimensional grains

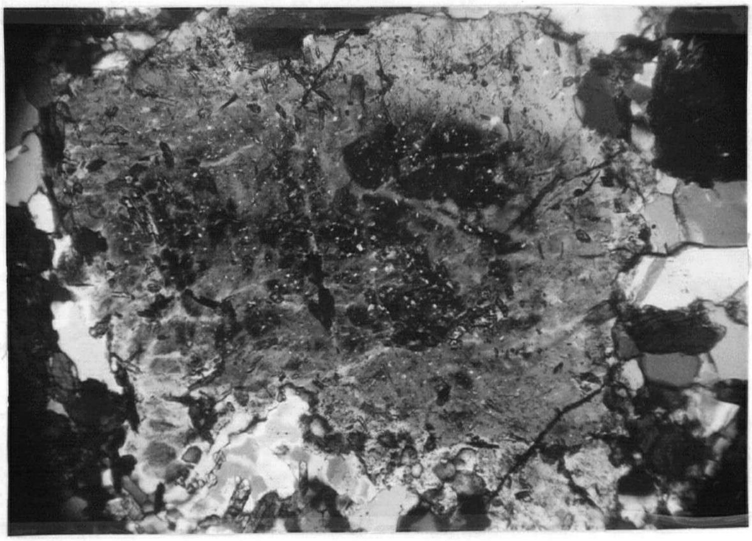


Figure 10. Corroded grain of plagioclase.
x 100

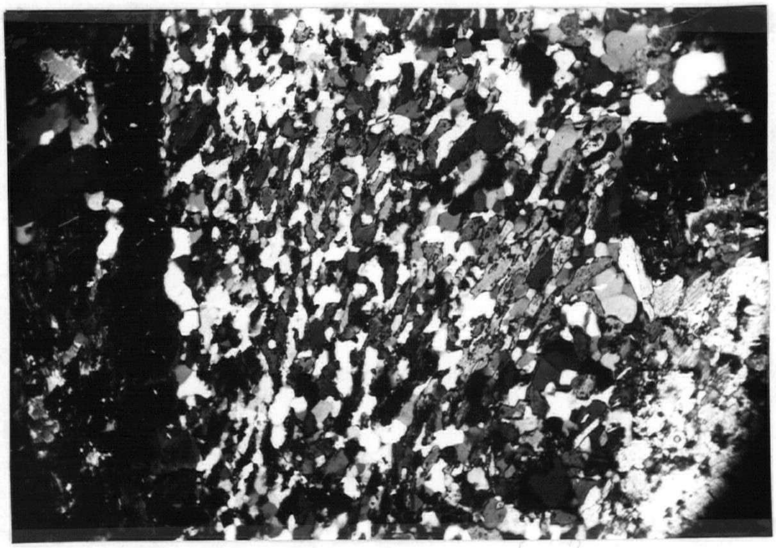


Figure 11. Myrmekitic intergrowth of quartz and plagioclase (crossed nicols). x 120

(commonly associated with plagioclase) and as inclusions in other minerals. A few myrmekitic intergrowths of quartz and plagioclase are also present. Quartz in these intergrowths is not optically oontinuous and forms irregular patterns (figure 11), suggesting replacement rather than eutectic crystallization of the two minerals.

Biotite and chlorite appear to be formed by alteration of hornblende. In some of the highly altered rocks near some faults and hydrothermal veins, biotite and chlorite have entirely replaced this mineral.

Epidote was seen in all specimens of the intrusives. It is invariably associated with plagioclase, in places almost completely replacing it and forming imperfect pseudomorphs with quartz.

A small amount of actinolite is present in two intrusives. It is probably an alteration product of hornblende.

Sphene and ilmenite are the most common accessory minerals of the intrusives. Sphene occurs as small disseminated grains, as clusters of grains and as rims around ilmenite. Two veinlets of the mineral were also seen in thin-section. Ilmenite occurs as scattered irregular grains commonly associated with sphene.

Apatite which is the least common constituent of the rocks appears as small fractured prismatic crystals, commonly separated and replaced by quartz along the fractures parallel to the base.

Zircon was not definitely identified but its presence is suggested by strong pleochroic halos around minute grains in biotite and hornblende.

Classification of Rocks

Depending on the amount of quartz and the composition of plagioclase, the rocks may be classified as quartz gabbros, diorites and quartz diorites. Since most of these rocks have undergone considerable alteration, the names meta-diorite, meta-quartz gabbro and meta-quartz diorite would be appropriate. For convenience of description however, the shorter names will be used in further discussion of these rocks.

Variations in Texture and Composition

The most apparent changes in composition and texture of the intrusives are due to hornblende which shows great variation in texture and distribution (p. 34). Many of these changes can be seen on close examination of most outcrops of the intrusives.

The greatest changes in texture and distribution of hornblende are in the upper part of sill I (figure 12) where porphyritic rocks are present. These rocks are in the form of irregular and discontinuous lenses which are roughly parallel to the upper contact of the sill. They are composed of various amounts of fine to very coarse, fan-like aggregates of hornblende, set in a medium-grained, roughly equigranular quartz-plagioclase matrix. Similar porphyritic rocks occur near some of the quartz veins in other intrusives in the area and in the upper parts of some of the intrusives described by Rice (1941, p. 25).

In addition to the local variations in texture and distribution of hornblende, sills I, II and IIa (figure 12) show changes in composition which have a definite trend. Some of these changes are evident from the modal analyses tabulated on page 40 , which show that in general, the

TABLE V. MODAL ANALYSES OF MOYIE INTRUSIVE ROCKS

Intrusive	Sill I						Sill II				Sill IIa			
Sample No.	1	2	3	4	5	6	1	2	3	4	1	2	3	4
Hornblende	51	54	10	42	32	38 *	68	49	43	44	66	65	49	59
Plagioclase	12	14	20	10	30	22	14	12	18	21	20	13	21	18
Quartz	17	15	31	13	27	8	8	15	24	19	4	5	12	7
Biotite	7	6	23	8	5	4	2	6	8	8	3	2	4	8
Epidote	3	2	14	24	4	24	1	8	4	4	4	7	8	3
Sphene	3	3	1	1		2	3	2	x	2	x	5	4	1
Ilmenite	4	5		x	1	x	3	5	2	x	2	2	2	1
Chlorite	1	1		x		1	1	1		x				2
Apatite	1		x	x	x	x		2	x	1	x	x		x
Carbonate	x													
Approximate average anorthite content	20	22	5	52	12	68	10	22	25	20	23	15	8	30

* actinolite and hornblende
x less than 1 percent

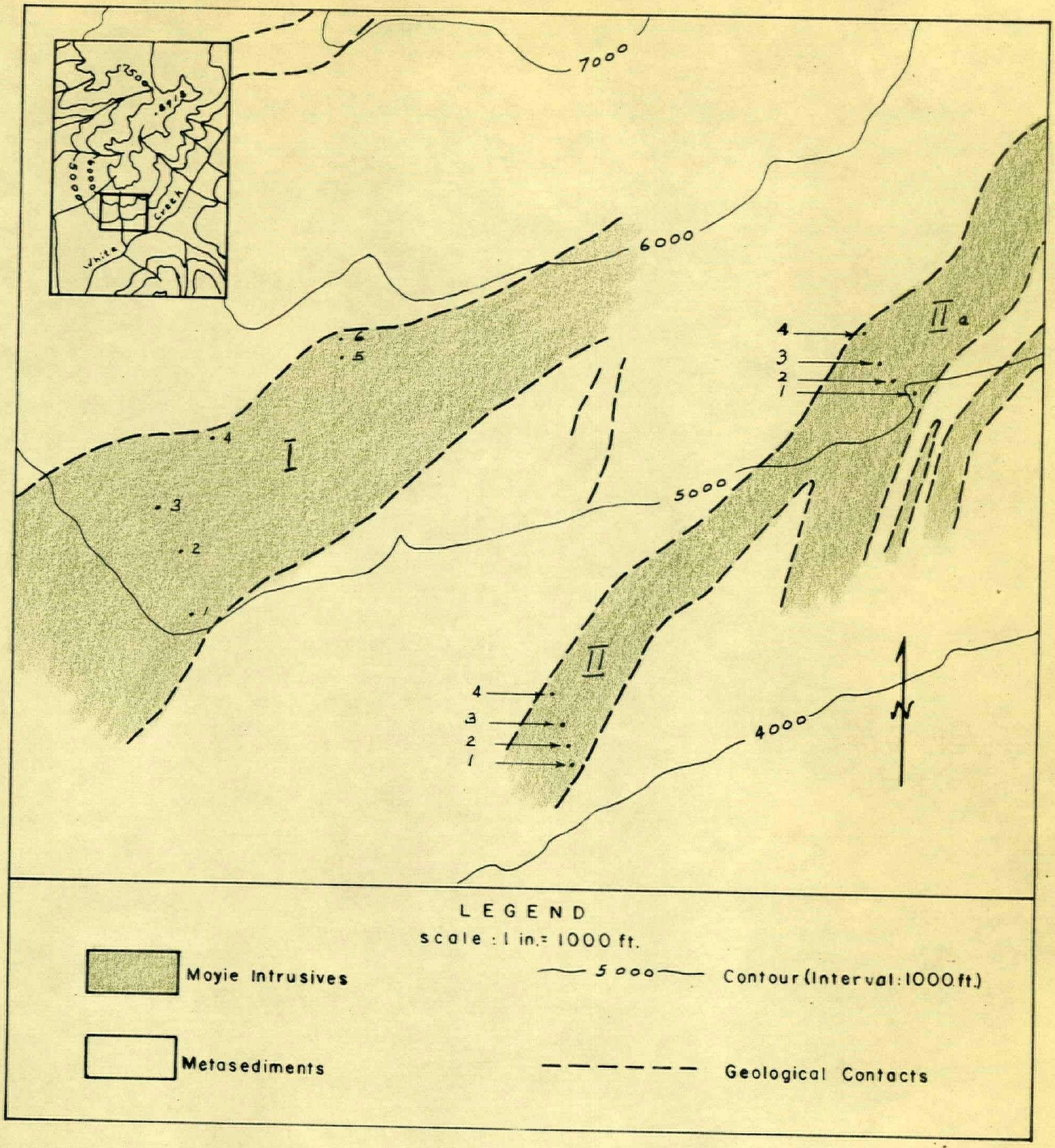


Figure 12. Sketch map showing location of specimens for modal analyses of Moyie intrusive rocks.

content of quartz and plagioclase increases and the content of hornblende decreases in the upper parts of these sills. These changes are also evident in the field except that they are not as gradational or progressive as some of these analyses might suggest.

Textural changes in sills I, II and IIa are commonly very erratic and cannot be related to any particular part of the sills. However, in general these sills are coarser grained in their central and upper parts than they are at their contacts with metasediments.

The thick sill immediately west of Hall Lake fault, was examined in several places, but did not show any great changes in texture or composition except in places along its upper contact, where it was directly adjacent to a quartz-feldspar pegmatite. Near the pegmatite, the hornblende in the sill is almost entirely replaced by biotite, and the content of quartz and plagioclase is considerably higher than in most other parts of this sill. Small amounts of orthoclase and actinolite also appear near the pegmatite. Away from the pegmatite this rock grades sharply into "normal" diorite and quartz diorite of the sill.

Textural and compositional changes in other intrusives in the area are minor. They appear as local concentrations of hornblende or quartz and plagioclase, as quartz-rich partly "digested" inclusions of country rock or as biotite-chlorite alterations near some veins and faults. These variations appear to have no relation to the shape or contacts of the intrusives and may appear in any parts of the sills or dykes.

Origin

The origin of Moyie intrusives has been discussed in detail by Daly (1912), Schofield (1915) and Rice (1934, 1937). They all believed these rocks to be derived from a common parental magma, but differed in their interpretations of the changes in composition within the intrusives.

Daly proposed assimilation of inclusions of the surrounding sedimentary rocks and differentiation of the magma by gravity as the mechanism by which the various gabbroic to granitic rocks of the intrusives originated.

In Schofield's opinion assimilation of country rocks contributed little to the composition of the intrusives, but differentiation was important. He assumed a partially differentiated reservoir from which basic and acidic magmas were intruded in the forms of sills and dykes. After emplacement, the basic intrusives differentiated further into basic and acidic phases while the basic intrusives consolidated without much further change.

Rice agreed that differentiation could produce some of the basic and acidic portions of the sills, but also proposed the diffusion of volatiles, due to thermal gradients within the intrusives, as a method by which some of the differentiates may have originated.

Some of the theories concerning the origin of the intrusives, proposed by these authors, could explain some of the differences in composition within the intrusives in this area. Differentiation by gravity could explain the increase of hornblende towards the lower contacts and the corresponding increase in plagioclase and quartz content in the upper parts of sills I, II and IIa. Assimilation of quartz rich sediments might also account for the abundance of quartz in the upper portions of some of the sills. Most of the variations in texture and composition of the sills in this area, however, are probably due to alteration rather than to any of the primary processes proposed by Daly, Schofield and Rice.

Hornblende, which is the most abundant mineral in the Moyie intrusives, has been clearly shown by Schofield to be the alteration product of pyroxenes. Similar hornblende in the Beltian intrusives of Idaho has been shown by Gibson, Russel and Jenks (1938) to have formed by hydrothermal alteration of pyroxenes. Rice (1941) agrees with their conclusions. No direct evidence has been found in the intrusives of this area to prove this type of alteration, but the plumose radiating and fan-like textures of hornblende do suggest, secondary-hydrothermal rather than primary mode of its origin. The great and commonly rapid variation in grain size, needle-like protrusions and disseminations of hornblende in other minerals and in some of the sediments near contacts of the intrusives also favour hydrothermal origin. The occurrence of porphyritic rocks with fan-like aggregates of hornblende near some of the hydrothermal veins which cut across intrusives of uniform texture, clearly shows that at least some hydrothermal solutions were capable of recrystallizing and redistributing some of the constituents in the intrusives.

The presence of gabbros, diorites and quartz diorites within the same intrusive and gradation of one rock-type into another, does not necessarily prove magmatic differentiation. The main difference between some of these diorites and gabbros is the composition (albite content) of the plagioclase. Since most of the plagioclase in these rocks has been at least partially albitized, some of the diorites probably formed by albitization of the pre-existing gabbros and not by magmatic differentiation. Some of the quartz in the quartz diorite might have been introduced by hydrothermal solutions, as suggested by the replacement-like myrmekitic intergrowths of quartz and plagioclase and by some of the embayed and "corroded" minerals in contact with the quartz. Orthoclase and some of the quartz in the biotite quartz diorite at the upper contact of the sill described on page 42, certainly appears to have been derived from the adjacent pegmatite.

The foregoing evidence shows that most of the differences in composition of the sills are due to secondary alteration and indicates that most of these alterations were hydrothermal. Association of the alterations with some of the veins and pegmatites, which were probably derived from the White Creek batholith, suggests this batholith as their source. The alterations of the intrusives, however, are not local but are known to extend into other areas far removed from any intrusives or other centres of hydrothermal activity. This, as pointed out by Scott (1954) would suggest deuteric origin of these solutions.

WHITE CREEK BATHOLITH

The White Creek batholith occupies an oval-shaped area of approximately 140 square miles in the central part of the Dewar Creek map-area (Reesor, 1958). According to Reesor, the batholith consists mainly of gradational, roughly concentric zones of biotite granodiorite, hornblende-biotite granodiorite, porphyritic quartz monzonite and leuco-quartz monzonite, arranged in that order from the outer to the inner part of the batholith. Reesor believes the batholith to have originated by intrusion of a highly mobile quartz monzonite magma which forced aside and partially assimilated the surrounding country rocks. The differences in composition within the batholith 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" (Reesor, 1958, p. 61).

A part of the outer zone of this batholith is exposed on the northern extremity of Vulcan Ridge. It is composed of a grey, porphyritic biotite granodiorite, which consists of 5 to 15 percent of microclene phenocrysts (up to 1 inch long) set in a medium-grained, equigranular matrix of plagioclase and smaller amounts of microclene, quartz and biotite. Minor constituents, distinguished in thin section, are hornblende, epidote, albite and sphene.

Numerous biotite rich inclusions are present throughout the biotite granodiorite near the contact of the batholith with the Aldridge metasediments. The inclusions are elongated in vertical or steeply southward dipping planes which roughly parallel the contact of the batholith.

CHAPTER III

METAMORPHISM

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...mineral assemblages are characteristic of the lowest grade of metamorphism, and belong to the biotite-chlorite or muscovite-chlorite subfacies of the green schist facies" (Reesor, 1958, p. 21).

The only rocks of the Vulcan Ridge map-area which may fall into this lowest grade category are the Aldridge metasediments in the southern part of this area (figure 13). The metasediments are fine-grained massive quartzites, and argillites and argillaceous quartzites most of which have been metamorphosed to fine grained quartz-biotite-muscovite phyllites and schists. A notable similarity of these rocks is the presence of chlorite which in some of them forms up to 15 percent of all the minerals. The presence of chlorite and the evidence of deformation in these metasediments corresponds well with similar regionally metamorphosed rocks in other parts of the Dewar Creek map-area described by Reesor.

The metamorphic grade of metasediments in the central part of the Vulcan Ridge area is uncertain. Quartz-biotite-muscovite is the typical mineral assemblage of metasediments in this area but plagioclase and small amounts of chlorite are also present. Albite is the most common plagioclase in these rocks but in a few of them it is oligoclase or andesine. Mineral assemblages such as these are not characteristic of any one metamorphic facies but the dominance of biotite-muscovite assemblage, small amount of chlorite and the presence of oligoclase-andesine in these rocks suggests that they are of somewhat higher metamorphic grade than the rocks in the southern part of the Vulcan Ridge area.

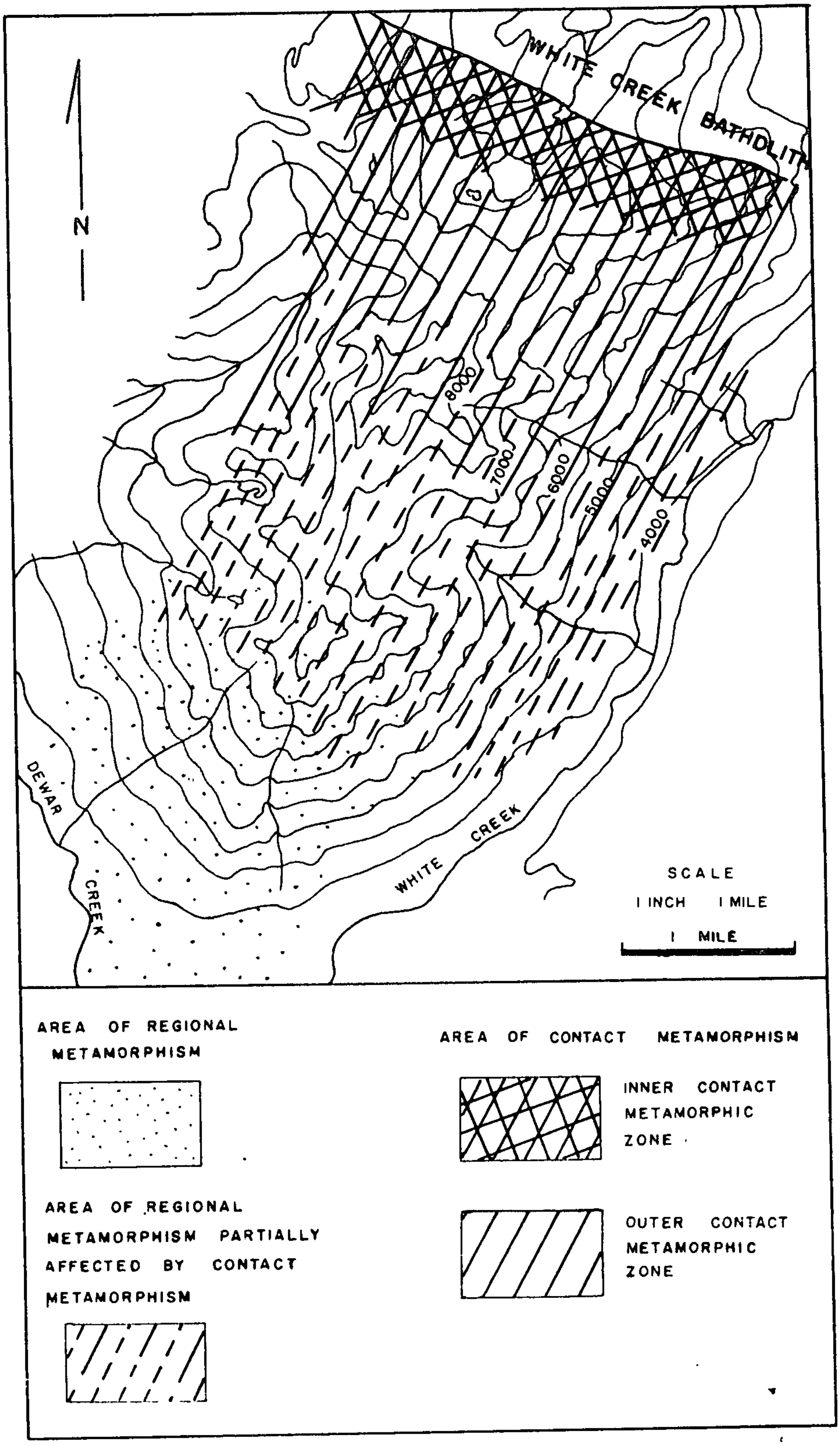


Figure 13. Sketch map showing areas of regional and contact metamorphism.

The intensity of metamorphism in this area may be due to strong deformation, clearly evident in the Lower Aldridge metasediments on the eastern slope of the ridge, or to contact metamorphic effects of the White Creek batholith.

CONTACT METAMORPHISM

The area of contact metamorphism near the White Creek batholith extends along Vulcan Ridge for at least 1½ to possibly 2½ miles south of the batholith. This area can be divided into an inner and an outer contact metamorphic zone (figure 13). The inner zone is composed essentially of fine to medium-grained, commonly "knotty" schists and hornfelses and the outer zone of mainly fine-grained phyllites, hornfelses and schists. The transition of the inner into the outer zone is sharp but the transitions of the outer zone into regionally metamorphosed areas is very gradational.

OUTER CONTACT METAMORPHIC ZONE

In outcrop, the phyllites schists and hornfelses of this zone, with exception of some concretions and of some zoned fragments and boulders in the breccia-conglomerates, are texturally very similar to the regionally metamorphosed sediments of the area. The only textural change in the metasediments of this zone seen in thin-section, is the appearance of granoblastic texture in some of these rocks and the presence of mica porphyroblasts, which in some phyllites and schists are oriented at right angle to foliation.

The most characteristic feature of the metasediments in the outer contact zone is the almost complete absence of chlorite. Of the 22 thin-sections of various metasediments from this zone, only two contain chlorite, and in both of them its presence can be attributed to retrogressive metamorphism induced by hydrothermal solutions. Also characteristic of the rocks in this zone is the first appearance of highly calcic plagioclase, garnet, actinolite, hornblende, diopside and possibly cordierite.

The most unusual rocks of this contact zone are some of the boulders and zoned fragments in the breccia-conglomerates and some of the concretions in quartzites.

The zoned fragments are of various sizes, shapes and composition. They consist of a central fragment of argillite, argillaceous quartzite or less commonly quartzite, surrounded by one or several (commonly 1 to 3) biotite rich zones (1/8 to 1/4 inch wide), roughly parallel to the outline of the fragment (figure 14).

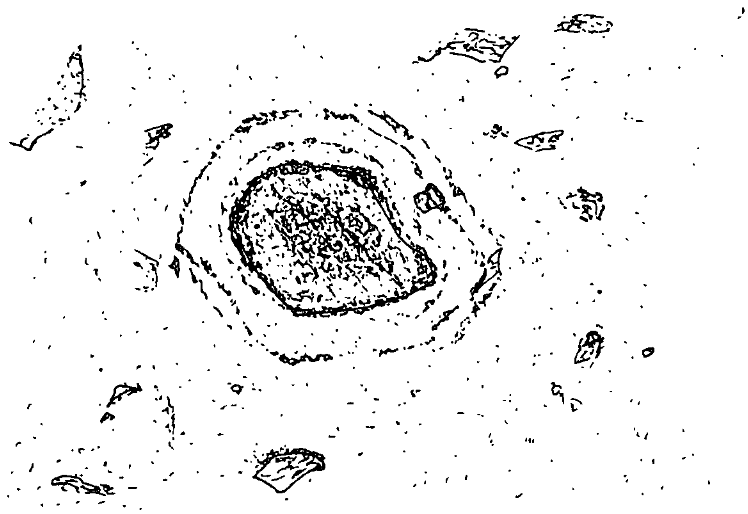


Figure 14. Zoning of a biotite rich fragment within unsorted breccia-conglomerate. The main difference between the light and dark zones is in their biotite content.

Some fragments are also surrounded by a light grey (biotite deficient) zone which may be up to several inches wide. Zoning inside of the fragments consists of a biotite rich zone, along the periphery of the fragments, which grades inward into a biotite deficient zone and then again into a biotite rich core of the fragment. Some fragments have only one biotite zone along the contact of the fragments with the surrounding rocks.

The zones around the fragments are similar to the zones of some of the concretions, whose primary origin is attributed to percolating ground waters (p. 31). Ground waters may have also redistributed the cement of the material surrounding the fragments to produce concentric zones which were further accentuated and developed by metamorphic differentiation. The zones within the fragments may have been produced by metamorphic differentiation alone. They may have formed by diffusion of biotite towards the boundaries of the fragments, and by secretion of the mineral into the fractures which might have existed on the contacts of the fragments with the surrounding rocks (Barth 1952, p. 317). The zones on the inside and on the outside of the fragments may have also originated by diffusion similar to the manner in which "Liesegang rings" are produced in some gels (Carl and Amstutz, 1958).

The most conspicuous zoned rocks within the breccia-conglomerates are some of the boulders exposed in Diorite Lake Basin (figure 15). The boulders have a characteristic light grey to white-weathered surface which makes them stand out from the grey or rusty-weathered breccia-conglomerates. Unweathered parts of the boulders are light grey to brownish-grey, fine-grained, dense, massive and difficult to scratch or break with a hammer. Biotite is the only mineral which can be recognized in hand specimen. It is irregularly distributed throughout the boulders or concentrated near the cores and (or) near the boundaries of the boulders.

Thin-sections show that the boulders are made up almost entirely of quartz, calcic plagioclase and biotite. Other minerals are minor (tableVI). The quartz and plagioclase (average grains .1 mm in diameter) form an even-grained mosaic throughout which are scattered randomly oriented grains

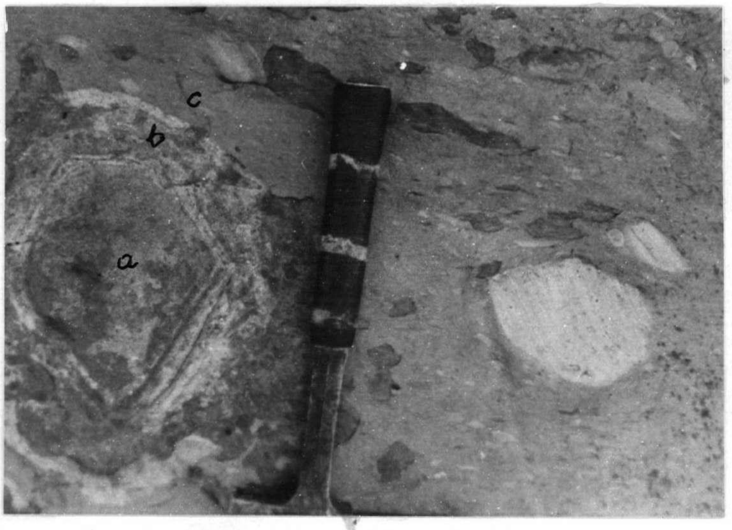


Figure 15. Zoned quartz-plagioclase boulder (a). Note the sharp transition of the reaction zone (b) into the surrounding unsorted breccia-conglomerate (c).

Figure 16. Polished specimen of a zoned boulder. (a = boulder, b = reaction zone; see analyses 3a and 3b on page 53). Note the distribution of biotite (black). The wide biotite band defines the contact between the boulder and the reaction zone.

TABLE VI. MODAL ANALYSES OF METAMORPHOSED BOULDERS, CONCRETION AND OF ASSOCIATED ROCKS

	Boulders								Concretion	
	1a	1b	1c	2a	2b	2c	3a	3b	4k	4n
Quartz	69	41	65	54	40	55	41	29	55	60
Plagioclase	13	43	6	13	36	1	18	47	23	8*
Biotite	7	8	24	25	12	35	32	14		10
Clinozoisite	2	6	x	x	5		1	4	5	
Garnet	3	x		3	x				3	
Hornblende									10	
Diopside									3	
Sphene		x	2	1	1	2	2	2	x	x
Zircon				x	x	x	x	x	x	x
Apatite	x			x	x	x	1		x	x
Tourmaline	x									x
Pyrite	x	x		1	2		1	x		
Pyrrhotite	4	x		2	2		3	x		
Galena	x									
Unidentified opaque material			2			5		2	x	x
Anorthite content	75	?	??	62	?	??	92	??	85	

a = boulder
b = reaction zone
c = breccia-conglomerates surrounding reaction zone
k = concretion
n = quartzite surrounding concretion
x = less than 1 percent
? = probably labradorite-anorthite
?? = probably oligoclase-andesine
* albite or K-feldspar

of biotite (.2 to 1.0 mm in diameter). Clinozoisite is commonly associated with plagioclase, and sphene and zircon, if present, are most abundant in biotite rich parts of the rocks. The remaining minerals are randomly distributed throughout the quartz-plagioclase matrix. A few rhombic to roughly equidimensional, polysynthetically twinned grains, in one of the boulders, resemble cordierite but cannot be definitely identified. X-ray powder photographs of portions of the rock where the mineral is most abundant give only patterns of plagioclase (closest to anorthite) or of plagioclase and quartz.

All of the above described boulders are surrounded by single zones which extend a fraction of an inch to several inches away from the boulders and in most places grade abruptly into the surrounding unsorted breccia-conglomerates. These zones are commonly of uniform thickness and closely follow the outline of the boulders. In outcrop, the zones are almost identical to the boulders they surround.

Thin-sections of the zones show that the zones are similar in composition to the adjacent boulders (table VI). They consist of quartz-plagioclase and quartz-plagioclase-biotite fragments surrounded by an unequigranular matrix composed mainly of quartz, plagioclase and various amounts of biotite. The quartz grains are of various sizes and randomly distributed. The plagioclase is typically very fine-grained (average grains are .01mm in diameter), roughly equigranular and is commonly associated with euhedral to subhedral, randomly oriented prismatic crystals of clinozoisite. The plagioclase is commonly interstitial. Biotite (up to 1.2 mm in diameter) is haphazardly distributed throughout the zones, but in places it is concentrated into discontinuous and poorly defined bands parallel to the outlines of the boulders.

The textures of these zones, in general, resemble the textures of the surrounding breccia-conglomerates. Composition is the main difference between the two rocks (table VI). The fragments and the unequigranular matrix of the breccia-conglomerates are essentially made up of quartz and biotite whereas similar fragments and matrix of the zones are mainly composed of quartz and plagioclase.

A few metamorphosed concretions in some of the Middle Aldridge quartzites, approximately 3000 feet south of White Creek batholith, are similar in texture and composition to the previously described boulders.

These metamorphosed concretions, similar in shape and distribution to those described on page 30, are composed of one to two green to grey, disjointed, concentric zones, enveloped in a white to light grey, fine-grained matrix.

Composition of one of these concretions is given in table VI. Hornblende, diopside, garnet and clinozoisite occur mainly in the concentric zones of the concretions. They are commonly anhedral and intergrown with quartz and plagioclase. These intergrowths are very similar to the "amoeboid" textures in metamorphosed calcareous concretions described by Conybeare (1951). The fine-grained matrix which envelopes the concentric zones and constitutes most of the concretions is composed mainly of fine-grained, roughly equigranular quartz and placioglase. The texture and composition of this matrix is almost identical to the quartz-plagioclase matrix of the zoned boulders.

This similarity of boulders and concretions suggests that both of them were formed by similar processes from rocks of similar composition. The concretions were probably formed by thermal metamorphism of calcareous quartzite concretions, and the boulders by thermal metamorphism of boulders of calcareous quartzite. The quartz-plagioclase zones which surround the boulders were probably formed during metamorphism by reaction of the calcareous boulders with the surrounding argillaceous breccia-conglomerates.

INNER CONTACT METAMORPHIC ZONE

The metasediments in this zone are schists and hornfelses which are the metamorphic equivalents of Middle Aldridge quartzites, argillites and argillaceous quartzites.

In hand specimen, the schists and hornfelses are grey to light grey rocks composed mainly of quartz, biotite and muscovite. The schists are fine to medium-grained and commonly strongly foliated. The hornfelses are typically fine-grained and massive. Many of the schists, and a few of the hornfelses, have a characteristic "knotted" appearance due to elongate, commonly cigar-shaped or in places roughly equidimensional mica clusters. Most of the clusters are less than 1/4 inch in length, although a few of the cigar-shaped clusters are up to 2 inches long.

In thin-section (figure17) most of the elongate clusters are seen to consist almost entirely of felty masses of sericite. These clusters probably represent altered porphyroblasts of andalusite. A few of the elongate clusters made up of biotite-muscovite or biotite-muscovite-chlorite may be altered porphyroblasts of staurolite. The roughly equidimensional clusters composed of biotite and muscovite or of biotite, muscovite and chlorite may possibly be altered porphyroblasts of cordierite.

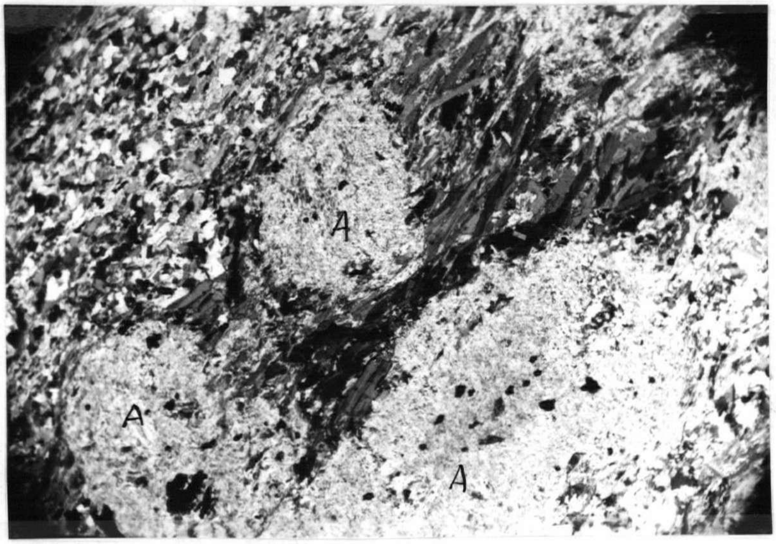


Figure 17. Clusters of haphazardly intergrown sericite (A) in quartz-biotite-muscovite schist. These clusters are probably altered porphyroblasts of andalusite (crossed nicols). x 50

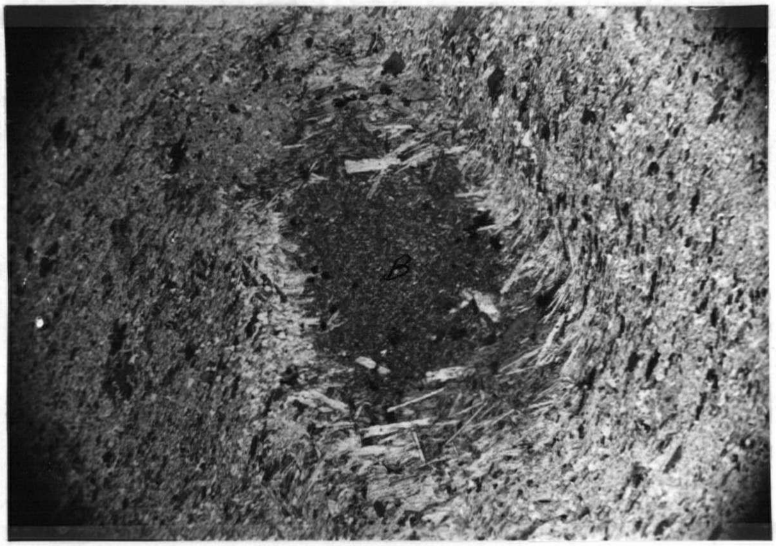


Figure 18. Cluster of haphazardly intergrown biotite and muscovite (B) in quartz-biotite-muscovite schist. This cluster could possibly be altered porphyroblast of cordierite or staurolite. x 50

None of the above porphyroblasts is sheared or otherwise deformed, indicating that most of the contact metamorphic rocks in the area have undergone little or no structural deformation after contact metamorphism.

Quartz is the most common constituent of most hornfelses and schists in the inner contact zone. It is fine-grained and commonly forms a roughly equidimensional mosaic of partly interlocked grains. Fine, dust-like inclusions are common in the central parts of some of the grains. The inclusion free borders of these grains probably represent the quartz which was added to the original quartz grains during metamorphism.

A characteristic feature of many schists and hornfelses in the inner metamorphic zone, is the appearance of myrmekitic intergrowths of quartz and plagioclase, especially along the grain boundaries of the feldspar. The intergrowths are widely distributed but generally do not form more than 1 or 2 per cent of any one rock.

Biotite and muscovite are the next most common constituents after quartz. In hornfelses, biotite and muscovite are fine-grained and randomly oriented. In schist, the diameter of an average grain of biotite or muscovite is about .15 mm but in a few schists it is up to ten times that size. Biotite in all schists, with exception of the biotite in altered porphyroblasts of staurolite and cordierite, is commonly well oriented parallel to the planes of foliation. Muscovite, on the whole, shows less preferred orientation than biotite. In some schists, both randomly and preferentially oriented muscovite plates are present. The discordant orientation of muscovite indicates that at least some of the muscovite in schists has crystallized after the rocks have been deformed. Late crystallization is certainly true of sericite which shows no preferred orientation whatsoever. Late formation of these minerals is further indicated by the presence of small veinlets of muscovite and sericite in some of the highly deformed rocks. These veinlets are not sheared or displaced, clearly indicating that the veinlets and the minerals within them formed after the deformation of the surrounding rocks.

Plagioclase is present in all thin sections of the rocks from the inner contact zone and commonly forms 5 to 20 percent of all the minerals. Two specimens of quartz-plagioclase-mica schist contain approximately 40 and 55 percent of the mineral. Most plagioclase, in specimens from various parts of this zone, is of a remarkably uniform composition. It is oligoclase, varying from An_{20} to An_{27} in different specimens. Andesine and albite are rare.

In several specimens, the oligoclase grains have a narrow zone of a more sodic or a more calcic plagioclase along the grain boundaries. The zone is commonly less than .05 mm wide and closely follows the outline of the plagioclase grain. Its origin is probably metamorphic, representing the adjustment of the plagioclase composition to the composition of the surrounding rock. The above described zoning is apparent only in rocks of the inner contact metamorphic zone.

Chlorite is present in many schists and hornfelses but in most of them it does not make up more than 5 percent of all the minerals. It occurs commonly as subhedral, randomly oriented plates, disseminated throughout the rock or concentrated into partly radiating clusters. In a few rocks it is present as incipient alteration of biotite. In one thin-section it was seen as extensive replacement of garnet.

The presence of chlorite in the inner contact zone can probably be attributed to hydrothermal solutions derived from the White Creek batholith.

Microclene and orthoclase are absent from most of the hornfelses and schists but form 1 to 5 percent of the minerals in some of the rocks near the contact of the batholith.

Garnet appears in one thin-section. It occurs as anhedral grains which are strongly altered to chlorite.

Accessory constituents of the schists and hornfelses are sphene, zircon, apatite, tourmaline, epidote, pyrite, pyrrhotite and specularite.

An unidentified radioactive mineral is a minor (commonly less than 1 percent) but widespread constituent of the schists and hornfëlses in the inner contact metamorphic zone. It occurs as euhedral to subhedral, short prismatic or possibly tabular crystals, on the average about .1 mm long, commonly associated with chlorite and in places with altered porphyroblasts of andalusite. It has a high positive relief and is commonly surrounded by strong pleochroic halos in chlorite and biotite. It is biaxial and slightly pleochroic (pale yellow to almost colourless). In polarized light it is yellow to grey, apparantly isotropic in places. This mineral was probably introduced by hydrothermal solutions derived from the White Creek batholith.

A rock different from the above described schists and hornfelses, appears at the contact of the batholith in the northwestern part of the map-area. The rock occupies about 20 to 50 feet wide, 100 to 200 feet long area, elongated parallel to the contact of the batholith. In hand specimen the rock is a greenish-grey, fine- to coarse-grained migmatite composed of a highly contorted mixture of thin-bedded metasediments (bedding commonly disjointed and barely perceptible in places) and of feldspathic bands and veinlets. In thin-section, the migmatite is seen to consist mainly of quartz, plagioclase, potassium feldspar, biotite and chlorite. Chlorite forms up to 20 percent of the rock in a few places.

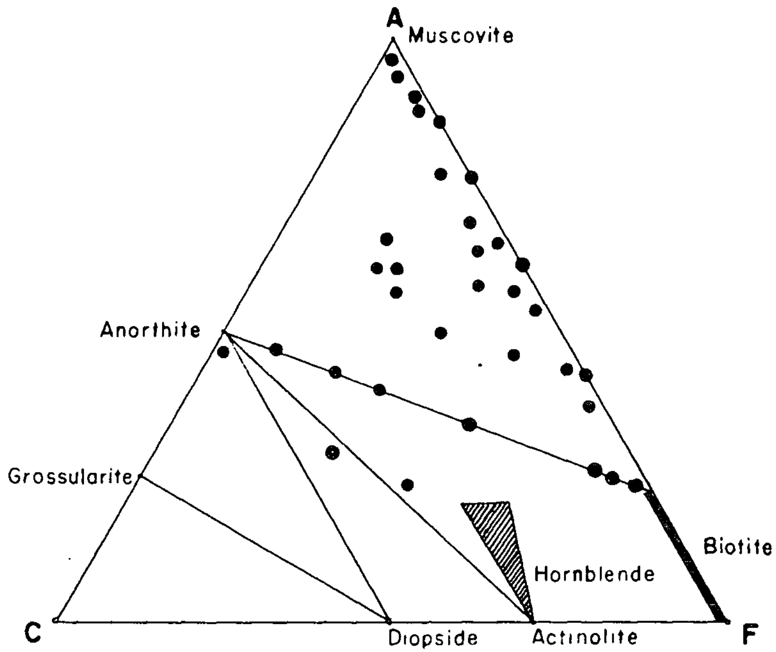
GRADE OF METAMORPHISM

The present, complete mineralogical assemblages of the contact metamorphic rocks, are not in equilibrium as these rocks have undergone various stages of retrogressive metamorphism. Subsequently, they cannot be classified according to a specific metamorphic facies of a definite metamorphic grade. Disregarding the retrograde changes in these rocks, however, the following metamorphic changes and metamorphic grade can be deduced.

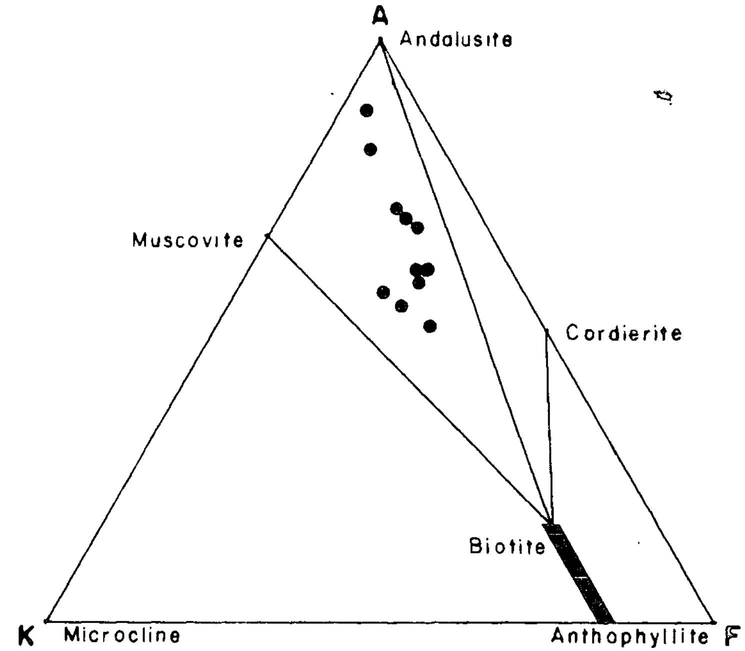
The Aldridge rocks within approximately 1½ miles of the batholith, depending on their composition at the time of metamorphism, were metamorphosed to phyllites, schists and hornfelses most of which attained or closely approached the following assemblages: quartz-biotite-muscovite, quartz-plagioclase-biotite-muscovite and quartz-plagioclase-biotite-muscovite-andalusite (with cordierite in a few places). In the calcareous concretions and boulders the assemblages probably were: quartz-plagioclase, quartz-plagioclase-biotite and quartz-plagioclase-diopside (with garnet or hornblende in places). These assemblages would belong to the hornblende hornfels facies (figure 19) and indicate a medium grade of metamorphism.

RETROGRESSIVE METAMORPHISM

Retrogressive metamorphism is extensive in the rocks of the inner



Hornblende Hornfels Facies. ACF Diagram for Rocks with Excess SiO_2 and K_2O



Hornblende Hornfels Facies. AKF Diagram for Rocks with Excess SiO_2 and Al_2O

Figure 19. Mineral assemblages of contact metamorphic rocks disregarding the changes produced by retrogressive metamorphism. Circles represent various rocks from the inner and outer contact metamorphic zones. (Diagrams after Fyfe, Turner and Verhoogen, 1958).

contact metamorphic zone. It is indicated by the abundance of completely altered porphyroblasts of andalusite, cordierite and stourolite, and by the widespread occurrance of chlorite. The retrograde changes in the rocks of the outer contact zone are suggested only in a few places by the presence of unstable mineral assemblages such as clinozoisite-calcic plagioclase, clinozoisite-calcic plagioclase-diopside-hornblende or biotite-muscrite-chlorite.

Most of the retrograde changes in both of the contact metamorphic zones are undoubtedly due to hydrothermal solutions derived from the White Creek batholith. Little retrogressive metamorphism can be attributed to deformation, as most of the contact rocks in the area have not undergone much structural deformation after contact metamorphism (p.58).

CHAPTER IV

STRUCTURAL GEOLOGY

FOLDS

The Lower Aldridge rocks in the Vulcan Ridge area have been folded into large and small northeasterly trending folds and then refolded into a large anticlinical structure near the White Creek batholith.

Two large open folds - an anticline and a syncline (cross-sections I-II, III-IV) form the main structure of the Lower Aldridge. In the central parts of the area, the axial planes of these folds are nearly vertical and their axes which strike approximately north 25 degrees east are horizontal or plunge gently northward. In the northern part of the area the axis of the syncline swings around to the east as the fold becomes refolded with the rest of the Aldridge rocks near the White Creek batholith. The anticline is probably refolded in a similar manner.

Small folds (see geological map of the area) with amplitudes of 5 to 30 feet (two such folds had amplitudes of 50 to 60 feet) are numerous in the Lower Aldridge, especially near the folded parts of the Moyie intrusives and near the crest and the trough of the two large folds described above. The axial planes of most of these folds are vertical or dip steeply northeast or southwest, and their axes strike north to north 45 degrees east. The plunge of their axes varies from 12 degrees southwest to 25 degrees northeast. On the whole, these folds are roughly parallel to the two main folds in the Lower Aldridge.

The size, shape and abundance of many of the small folds is clearly related to the Moyie intrusives. This is evident in many places in the field where relatively undisturbed metasediments within the two main folds in the area become progressively more and more folded as they approach the intrusives so at their contacts the metasediments become tightly folded. In places this change from unfolded to folded rocks is very abrupt. These folds probably formed at the same time as the two main folds in the area when the less competent metasediments were compressed against the more competent Moyie intrusives.

Folds, comparable in size to those described above, but not as tightly folded, are also abundant at the head of Diorite Lake Basin and West Basin. Here the attitude of the folds varies considerably from place to place, but on the whole these folds form an irregular "anticlinorium" within the large anticlinal structure near the White Creek batholith.

The Middle Aldridge rocks in the map area are dominated by a large anticlinal structure formed by the intrusion of the White Creek batholith which changed the strike of the Aldridge strata from northeast to southwest. With the exception of this fold and a few minor folds near some of the intrusives, the Middle Aldridge appears to be little folded. In the southern part of the area its beds strike north 20 degrees east and dip 50 to 70 degrees northwest. In the northern part of the area, in general, they strike north 60 degrees west and are vertical or dip steeply northeast or southwest.

FAULTS

Northeasterly striking faults are the most common faults in the area. Most of them strike north 10 to 25 degrees east and are vertical or dip steeply northwest. These faults are most abundant in the highly folded parts of the Lower Aldridge where they commonly parallel the axial planes of folds.

Hall Lake fault is the largest northeasterly striking fault in the area. According to Reesor (1958) this fault extends northward along the west side of White Creek, swings eastward in the northern part of the area and terminates against the White Creek batholith. He estimates the displacement along this fault of at least 1500 feet.

Two steeply dipping faults with an apparent displacement of 100 to 150 feet, are roughly parallel to the axial plane of the large, northwesterly trending anticlinal structure near the White Creek batholith. Very small shears, with attitude similar to that of the above described faults, are common near the crest of the same anticlinal structure. These northwesterly striking shears and faults probably formed during the emplacement of the White Creek batholith as the metasediments were pushed southward and folded into the large anticlinal structure.

JOINTS AND FOLIATION

There are two prominent sets of joints in the area. One is roughly parallel to the axial planes of the northeasterly trending folds in the area, and the other to the axial plane of the large fold near the White Creek batholith. The former, is the most prominent and the most intense of the two. It is so intense on the lower, southeastern slope of Vulcan Ridge and near the crest of the main northeasterly trending anticline in the Lower Aldridge, that it obscures the bedding of the thin-bedded argillites and argillaceous quartzites. The joints which roughly parallel the plane of the fold near the White Creek batholith are most common near the crest of that fold. There are other numerous joints in the area particularly in the Moyie intrusives, which cannot be related to any of the major folds in the area.

The most prominent foliation in the metasediments of the area is developed parallel to the bedding. It is best developed in highly folded, argillaceous (micaceous) rocks. The most intense foliation parallel to the bedding, is found in the metasediments within approximately 2000 to 3000 feet of the White Creek batholith. The intensity of foliation in the rocks of this area is probably due to the aligment of biotite and muscovite caused by the shearing and compression of the rocks during the emplacement of the White Creek batholith, and also to the continued growth of biotite and muscovite, in the already established planes of foliation, during contact metamorphism after emplacement.

Cross foliation is developed only locally near faults and near the crests and throughs of folds. On the whole it is much less prominent than the foliation parallel to the bedding.

CHAPTER V

BIBLIOGRAPHY

Alty, S.W., 1933, Some properties of authigenic tourmaline from Lower Devonian Sediments: Am. Mineral. vol. 18, pp. 351-355.

Barrel, J., 1925, Marine and terrestrial congromerates: Geol. Soc. America Bull. 36, pp. 291-341.

Barth, Tom. F.W., 1952, Theoretical petrology: New York, Willey & Sons.

Billings, M.P., 1942, Structural geology: New York, Prentice-Hall.

Blackwelder, E., 1932, An ancient glacial formation in Utah: Jour. Geol. vol. 40, pp. 289-304.

Brown, C.B., 1938, On theory of gravitational sliding applied to Tertiary of Ancon, Equador: Geol. Soc. London Quart. Jour. vol. 94, pp. 359-370.

Carol, J.D., and Amstutz, G.C., 1958, Three-dimensional Liesegang rings by diffusion in a colloidal matrix and their significance for the interpretation of geological phenomena: Geol. Soc. America Bull., vol. 69, pp. 1467-1468.

Conybeare, C.E.B., 1951, An occurrance of orbicular structure of metasomatic origin in the Gold Coast: Geol. Mag., vol. 88, pp. 145-147.

--------- 1951, On significance of metamorphosed calcareous concretions in Lower Birrimian schists of the Gold Coast: Geol. Mag., vol. 88, pp. 267-272.

Crowell, J.C., 1955, Directional-current structures from the pre-Alpine flysh, Switzerland: Geol. Soc. America Bull. vol. 66, pp. 1351-1384.

--------- 1957, Origin of pebbly mudstones: Geol. Soc. America Bull., vol. 68, pp. 993-1010.

Daly, R.A., 1912, Geology of the 49th parallel: Geol. Surv. Canada, Mem. 76, Part I, II.

De Sitter, L.V., 1959, Structural geology: New York, McGraw-Hill.

Dixon, E.E.L., and Hudson, R.G.S., 1931, A mid-Carboniferous boulder bed near Settle: Geol. Mag., vol. 68, pp. 81-92.

Emmons, W.H., and Lancy, F.B., 1926, Geology and ore deposits of the Ducktown mining district: U.S. Geol. Survey, Prof. Paper 139, pp. 19-21, plates VIII to XIV.

Escola, P., 1938, On esboitic crystallization of orbicular rocks: Journ. Geol., No. 3, pp. 448-486.

Frondel, C., and Collette, R.L., 1957, Synthesis of tourmaline by reaction of mineral grains with $NaCl-H_3BO_3$ solutions, and its implications in rock metamorphism: Am. Mineral., vol. 42, pp. 754-758.

Fyfe, W.S., Turner, F.J., and Verhoogen, J., 1958, Metamorphic reactions and metamorphic facies: Geol. Soc. America, Mem. 73.

Gibson, Russel and Jenks, W.F., 1938, Amphibolitization of sills and dykes in the Libby quadrangle, Montana: Am. Mineral., vol. 23, pp. 302-313.

Goodspeed, G.E., 1942, Orbicular rock from Buffalo Hump, Idaho: Am. MineraL, vol. 27, pp. 37-47.

Hoadley, J.W., 1947, The metamorphism of the rocks of the Aldridge formation Kimberley, B.C.: M.A. Sc. thesis (unpublished), University of British Columbia.

Hutton, C.O., 1939, The significance of tourmaline in the Otago schists: Roy. Soc. New Zealand, Trans., vol. 68, pt. 4, pp. 405-406.

Jones, O.T., 1937, On the sliding and slumping of submarine sediments in Denbighshire, North Wales, during Ludlow period: Geol. Soc., London, Quart. Jour. vol. 93, pp. 241-283.

Kindle, C.H. and Whittington, H.B., 1958, Stratigraphy of the Cow Head Region, Western Newfoundland: Geol. Soc. America Bull., vol. 69, pp. 315-342.

Krumbein, W.C., 1933, Textural and lithologic variations in glacial till: Jour. Geol., vol. 41, pp. 382-408.

---------- 1940, Flood gravel of San Gabriel Canyon, California: Geol. Soc. America Bull, vol. 51, pp. 639-676.

Krynine, P.D., 1946, The tourmaline group in sediments: Jour. Geol., vol. 54, pp. 65-87.

Kuenen, Ph. H., 1950, Marine geology: New York, John Wiley & Sons.

---------- 1952, Turbidity currents and submarine slumps: Am. Jour. Sci., vol. 250, pp. 849-873.

Kuenen, Ph. H., and Magliorini, C.I., 1950, Turbidity currents as cause of graded bedding: Jour. Geol., vol. 35, pp. 91-127.

Mansfield, G.R., 1906, The characteristics of various types of conglomerates: Jour. Geol., vol. 14, pp. 550-555.

McWhae, J.R.H., 1950, Carboniferous breccia of Billefjorgen, Vestspitzbergen: Geol. Mag., vol. 87, pp. 287-298.

Norton, W.H., 1917, A classification of breccias: Jour. Geol., vol. 25, pp. 160-194.

Pettijohn, F.J., 1949, Sedimentary rocks: New York, Harper.

Rankama, K., and Sahama, Th. G., 1950, Geochemistry: University of Chicago Press.

Reesor, J.E., 1952, Dewar Creek, map-area: Geol. Surv. Canada, Paper 52-14.

----------- 1958, Dewar Creek map-area with special emphasis on the White Creek batholith, British Columbia: Geol. Surv. Canada, Mem. 292.

Reny, O., Lakeman, R., and Van der Meulen, E., 1955, Submarine sliding in western Venezuela: Am. Assoc. Pet. Geol. Bull., vol. 39, pp. 2053-2067.

Reynolds, S.H., 1928, Breccias: Geol. Mag., vol. 65, pp. 97-106.

Rice, H.M.A., 1934, The geology and economic geology of the Cranbrook district, British Columbia: Ph. D. thesis (unpublished) California Institute of Technology.

----------- 1935, Emphibole from the Purcell sills, British Columbia: Am. Mineral., vol. 20, pp. 507-509.

----------- 1937, Geology of Cranbrook area: Geol. Surv. Canada, Mem. 207.

----------- 1941, Geology of Nelson map-area, east half: Geol. Surv. Canada, Mem. 228.

Schofield, S.J., 1915, Geology of Cranbrook map-area: Geol. Surv. Canada, Mem. 76.

Scott, B., 1954, The Diorite Complex beneath the Sullivan Orebody with its associated alterations: M. Sc. thesis (unpublished), Queen's University.

Snyder, F.G., and Odell, J.W., 1958, Sedimentary breccias in the southeast Missouri lead district: Geol. Soc. America Bull., vol. 69, pp. 899-926.

Stringham, B., 1953, Granitization and hydrothermal alteration at Bingham, Utah: Geol. Soc. America Bull., vol. 64, pp. 945-992.

Swanson, C.O., and Gunning, H.C., 1945, The geology of Sullivan mine: Canadian Inst. Min. Met., vol. 48, pp. 645-667.

Turner, F.J., 1948, Mineralogical and structural evolution of the Metamorphic rocks: Geol. Soc. America, Mem. 30.

Turner, F.J., and Veerhoogen, 1951, Igneous and metamorphic petrology: New York, McGraw-Hill.

Twenhofel, W.H., 1950, Principles of sedimentation: New York, McGraw-Hill.

Winchell, N.W., and Winchell, H., 1951, Elements of optical mineralogy: Part II, New York, McGraw-Hill.

Woodford, A.O., 1925, The san Onofre breccia: University of California Publication, Geology, vol. 15, pp. 195-280.

TABLE I. TABLE OF FORMATIONS
(Modified after Reesor, 1958)

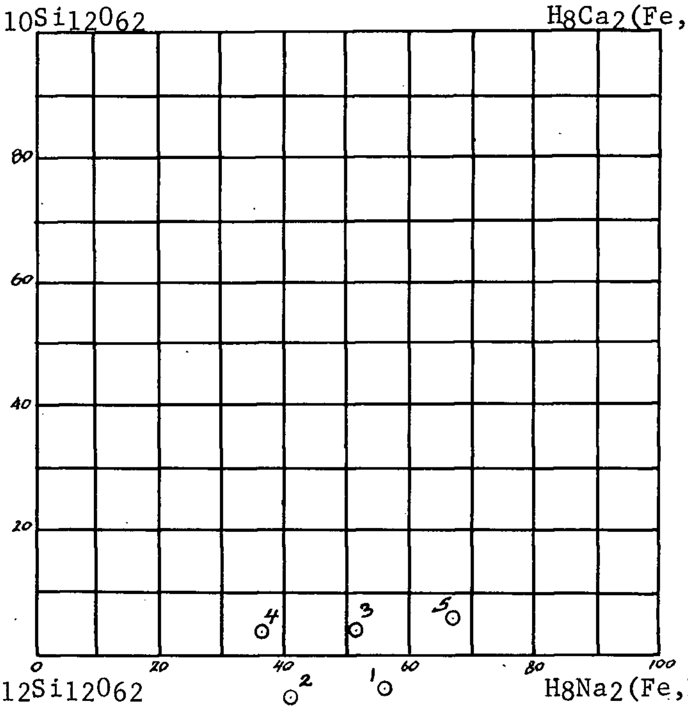
Era	Period	Rock Unit	Lithology
Cenozoic	Recent and Pleistocene		Stream and glacier deposits
Mesozoic and/or Cenozoic	Jurassic or later	White Creek Batholith	Quartz monzonite, Hornblende-biotite granodiorite, biotite granodiorite.
INTRUSIVE CONTACT			
Proterozoic or later		Moyie Intrusives	Meta-diorite, meta-quartz diorite, meta-quartz gabbro.
INTRUSIVE CONTACT			
Proterozoic	Lower Purcell	Creston formation	Green-grey weathering quartzites, argillaceous quartzites and argillites.
		Aldridge formation Upper Division	Rusty weathering argillites and argillaceous quartzites.
		Aldridge formation Middle Division	Grey weathering quartzites, argillaceous quartzites and minor argillites.
		Aldridge formation Lower Division	Grey-rusty weathering breccia-conglomerates. Grey weathering quartzites.. Grey and rusty weathering argillites and argillaceous quartzites.

TABLE II OPTICAL PROPERTIES OF TOURMALINE

No.	Occurrance	Colour in handspecimen	Indeces of refraction		Pleochroism		Birefringence
			n_o	n_ε	n_o	n_ε	
1	Pegmatite	Black	1.662	1.634	Dark blue	colourless	.028
2	Vein	Black	1.655	1.628	Blue-green	colourless	.027
3	Vein	Brown	1.661	1.634	Brown bluish green	colourless	.027
4	Metasediments	Black	1.654	1.628	Green-brown	Very light yellow to colourless	.026
5	Metasediments	Dark brown	1.666	1.638	Brown	Very light yellow to colourless	.028

TABLE III COMPOSITION OF TOURMALINE ACCORDING TO ITS OPTICAL PROPERTIES

$H_8Ca_2Mg_8B_6Al_{10}Si_{12}O_{62}$ $H_8Ca_2(Fe,Mn)_8B_6Al_{10}Si_{12}O_{62}$



$H_8Na_2Mg_6B_6Al_{12}Si_{12}O_{62}$ $H_8Na_2(Fe,Mn)_6B_6Al_{12}Si_{12}O_{62}$

(After Winchell, 1951)

TABLE IV QUALITATIVE SPECTROGRAPHIC ANALYSES OF TOURMALINE

	Major Elements	Minor Elements	Trace Elements
1	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
2	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
3	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
4	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)
5	Si,Al,B,Fe,Mg,Na	-	Ca, Li (?)

? Questionable as only 1 line was identified on spectrographic plate

TABLE V. MODAL ANALYSES OF MOYIE INTRUSIVE ROCKS

Intrusive	Sill I						Sill II				Sill IIa			
Sample No.	1	2	3	4	5	6	1	2	3	4	1	2	3	4
Hornblende	51	54	10	42	32	38 *	68	49	43	44	66	65	49	59
Plagioclase	12	14	20	10	30	22	14	12	18	21	20	13	21	18
Quartz	17	15	31	13	27	8	8	15	24	19	4	5	12	7
Biotite	7	6	23	8	5	4	2	6	8	8	3	2	4	8
Epidote	3	2	14	24	4	24	1	8	4	4	4	7	8	3
Sphene	3	3	1	1		2	3	2	x	2	x	5	4	1
Ilmenite	4	5		x	1	x	3	5	2	x	2	2	2	1
Chlorite	1	1		x		1	1	1		x				2
Apatite	1		x	x	x	x		2	x	1	x	x		x
Carbonate	x													
Approximate average anorthite content	20	22	5	52	12	68	10	22	25	20	23	15	8	30

* actinolite and hornblende
x less than 1 percent

TABLE VI. MODAL ANALYSES OF METAMORPHOSED BOULDERS, CONCRETION AND OF ASSOCIATED ROCKS

	Boulders								Concretion	
	1a	1b	1c	2a	2b	2c	3a	3b	4k	4n
Quartz	69	41	65	54	40	55	41	29	55	80
Plagioclase	13	43	6	13	36	1	18	47	23	8*
Biotite	7	8	24	25	12	35	32	14		10
Clinozoisite	2	6	x	x	5		1	4	5	
Garnet	3	x		3	x				3	
Hornblende									10	
Diopside									3	
Sphene		x	2	1	1	2	2	2	x	x
Zircon				x	x	x	x	x	x	x
Apatite	x			x	x	x	1		x	x
Tourmaline	x									x
Pyrite	x	x		1	2		1	x		
Pyrrhotite	4	x		2	2		3	x		
Galena	x									
Unidentified opaque material			2			5		2	x	x
Anorthite content	75	?	??	62	?	??	92	??	85	

a = boulder
b = reaction zone
c = breccia-conglomerates surrounding reaction zone
k = concretion
n = quartzite surrounding concretion
x = less than 1 percent
? = probably labradorite-anorthite
?? = probably oligoclase-andesine
* = albite or K-feldspar

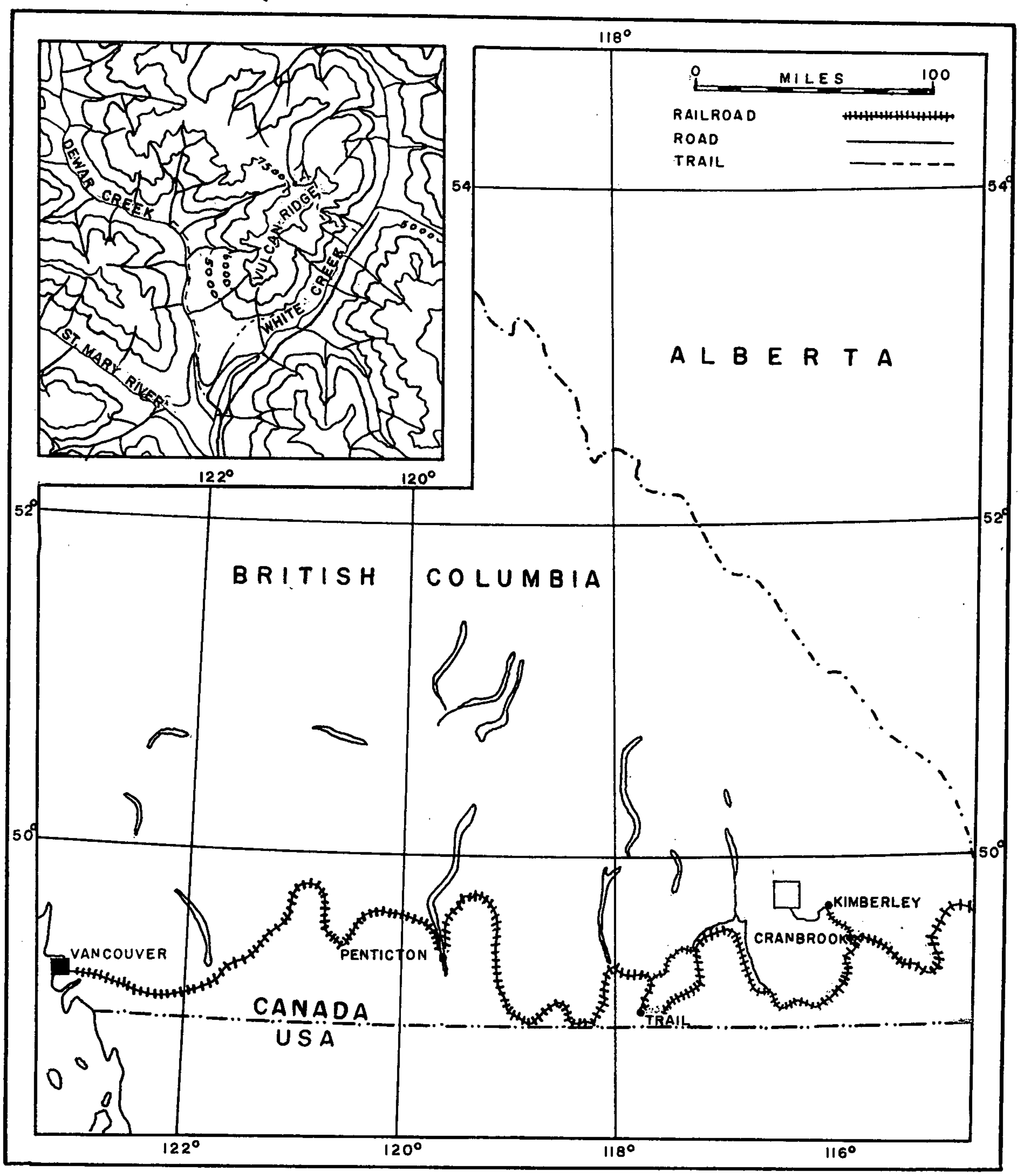


Figure 1. Location and accessibility of Vulcan Ridge.

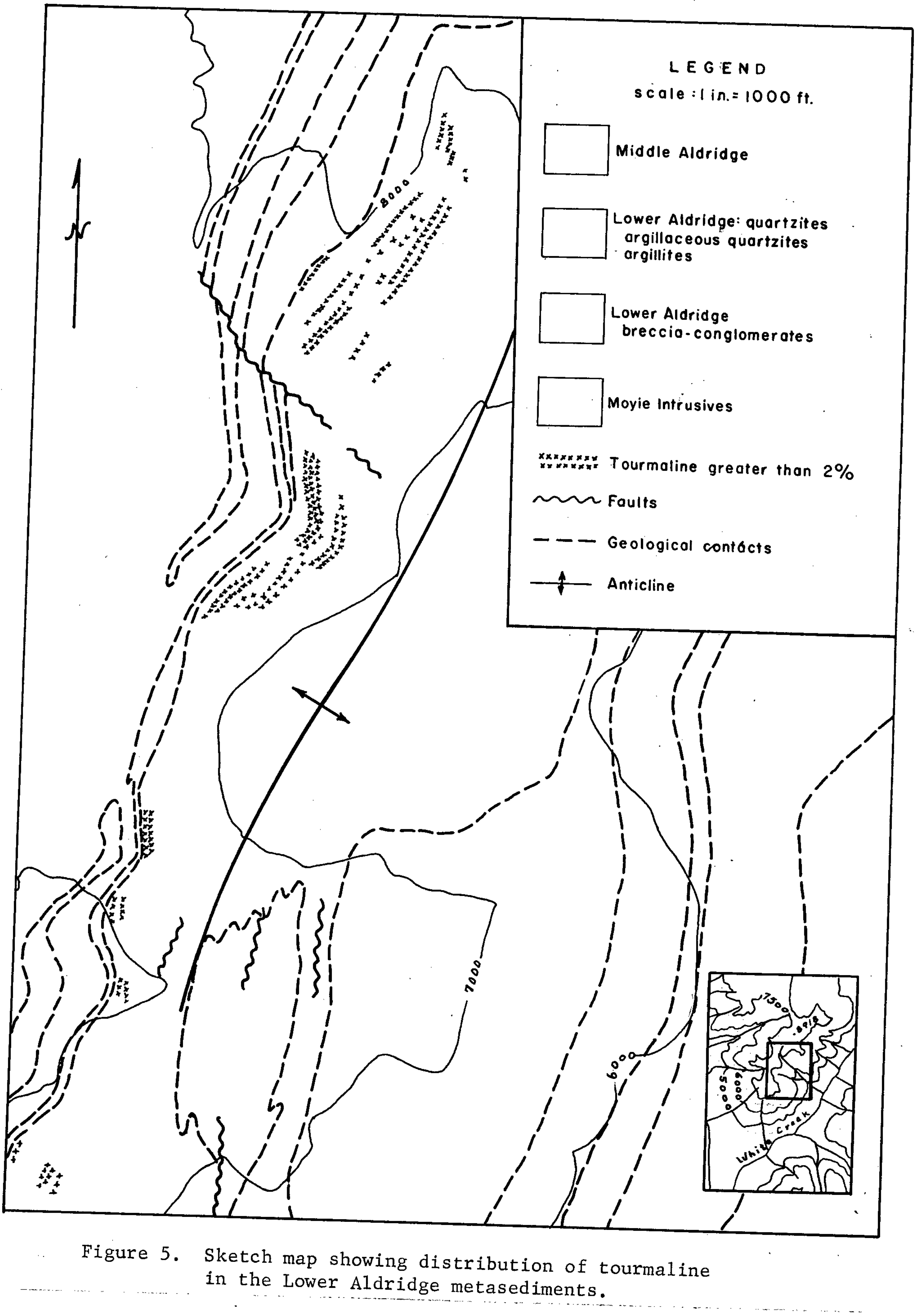


Figure 5. Sketch map showing distribution of tourmaline in the Lower Aldridge metasediments.

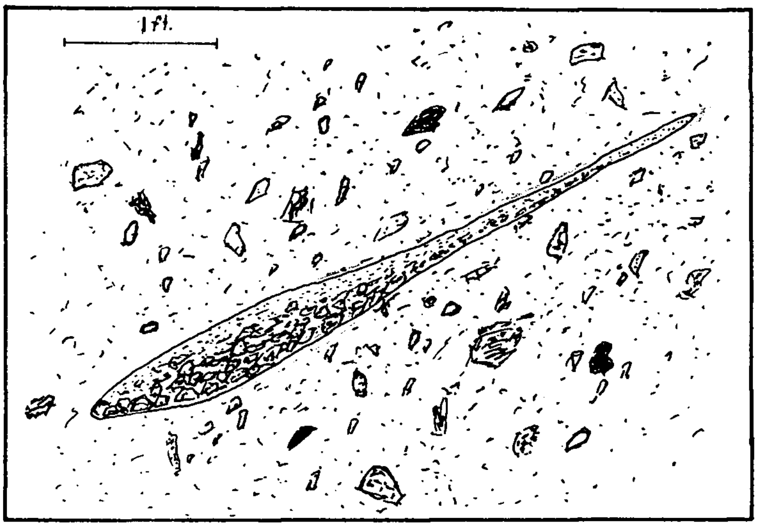


Figure 6. Sketch of an outcrop in Orange Tent Basin showing a lens-like body of sorted breccia-conglomerate surrounded by unsorted breccia-conglomerate.

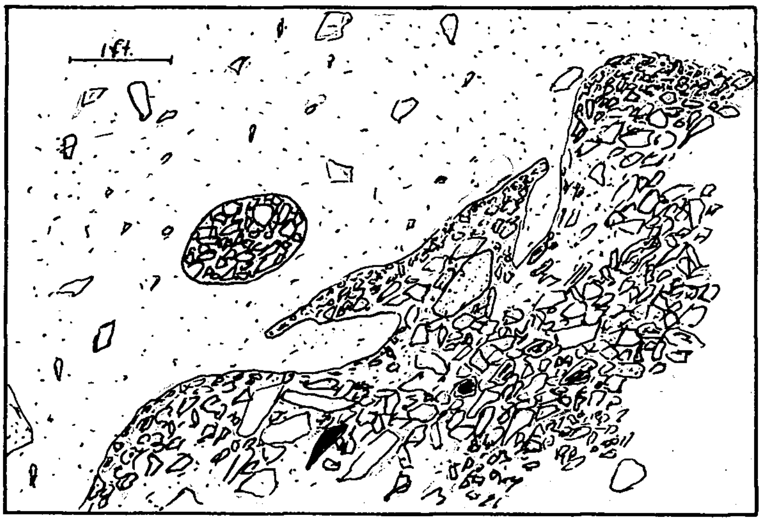
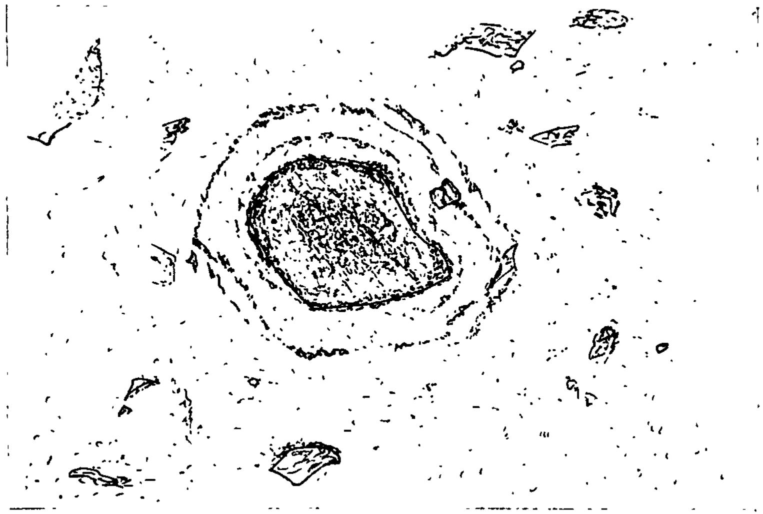


Figure 7. Sketch of an outcrop in Diorite Lake Basin showing irregularly shaped body of sorted breccia-conglomerate.



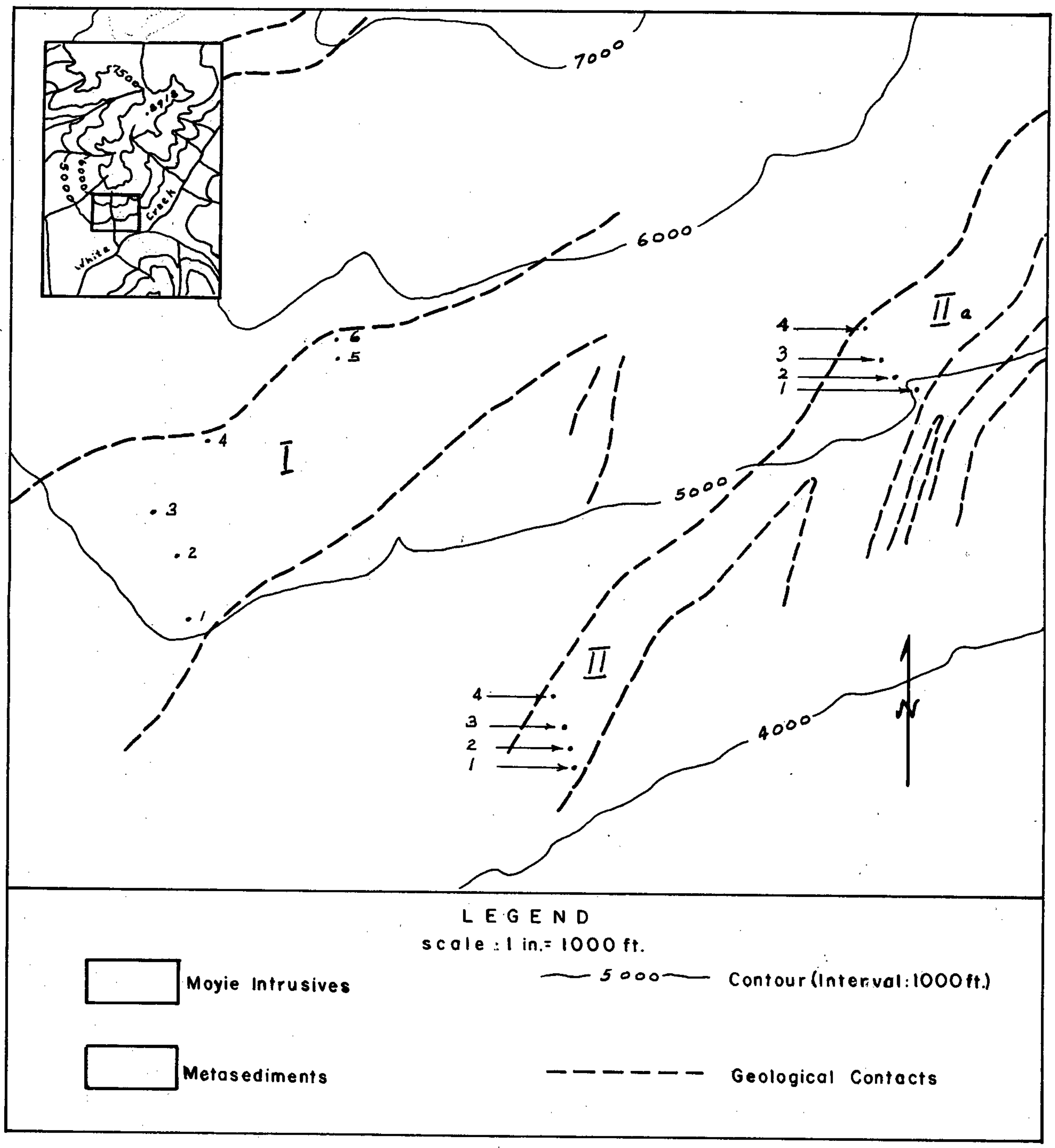


Figure 12. Sketch map showing location of specimens for modal analyses of Moyie intrusive rocks.

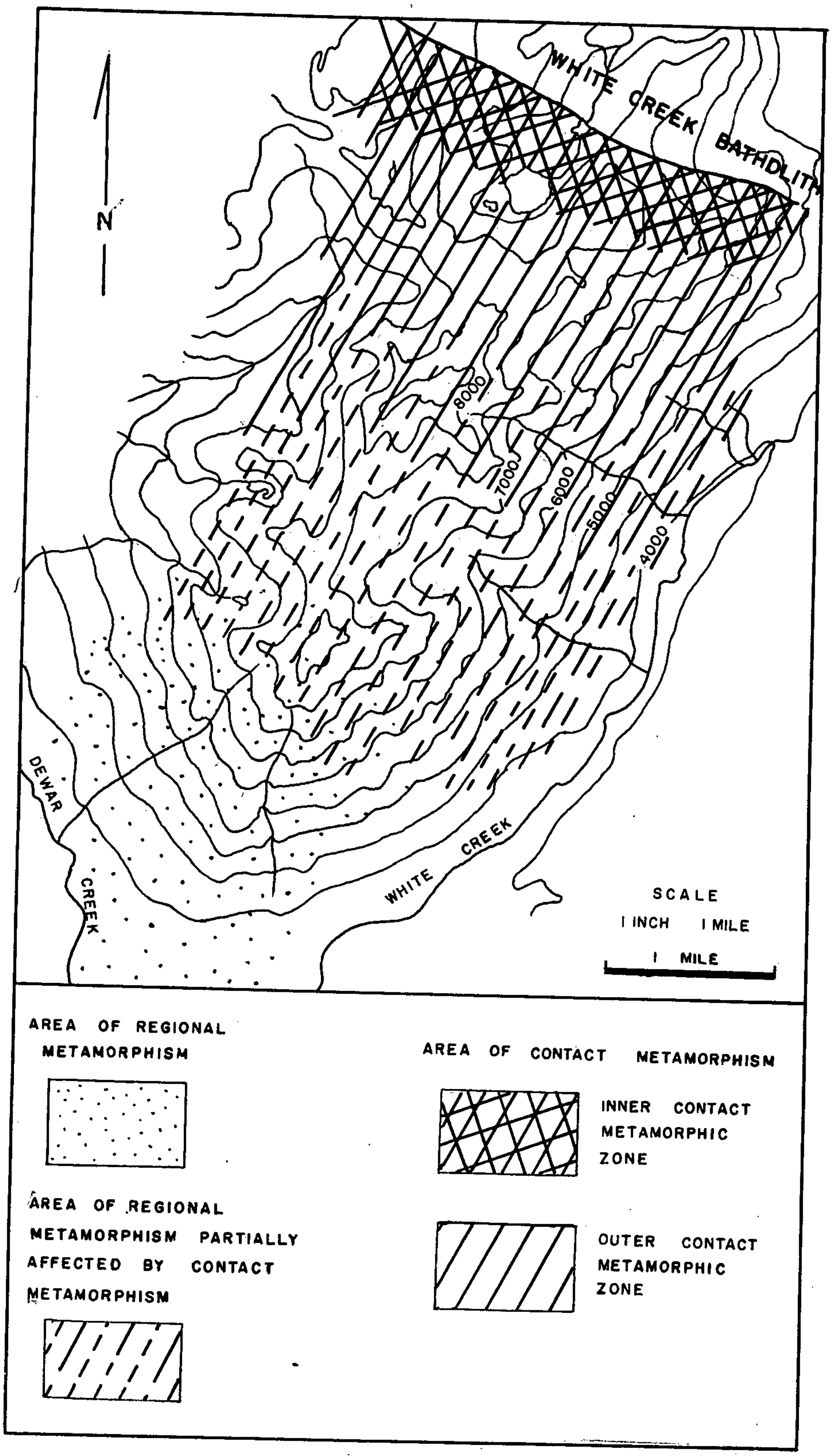
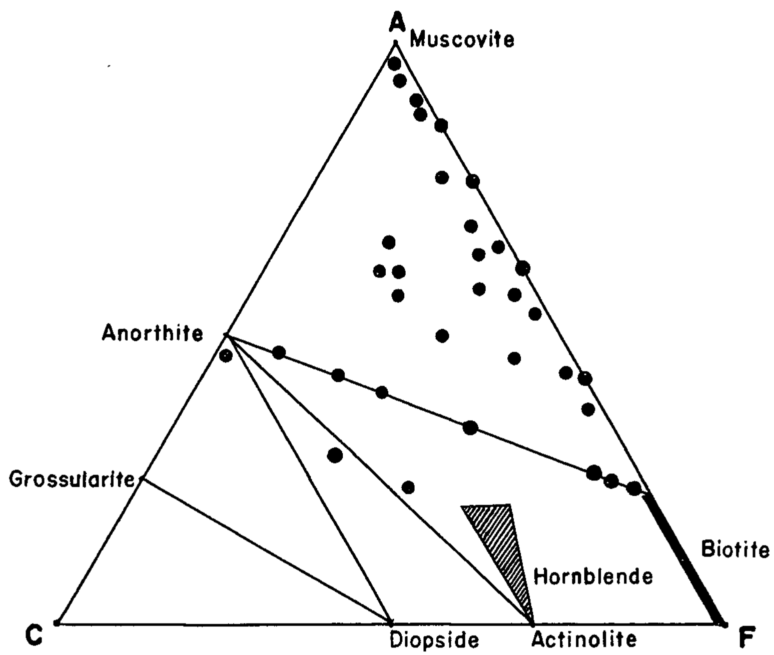
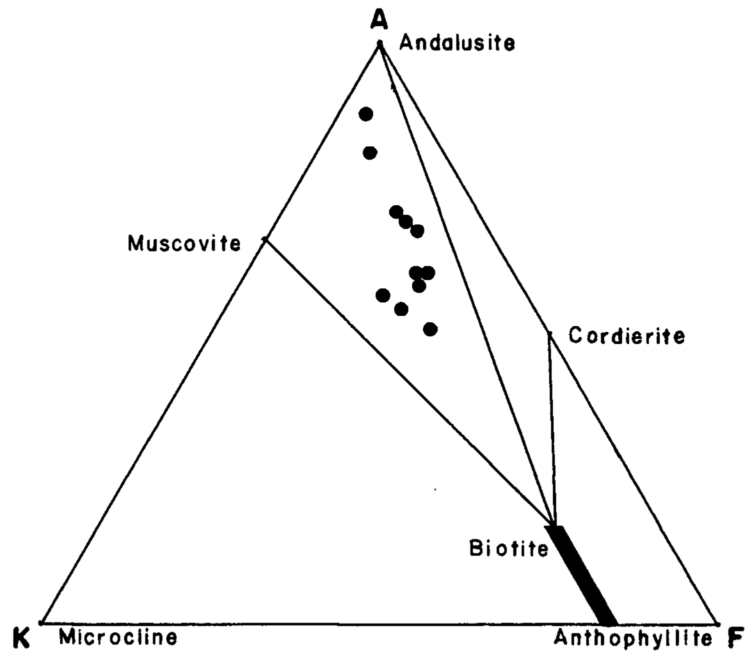


Figure 13. Sketch map showing areas of regional and contact metamorphism.



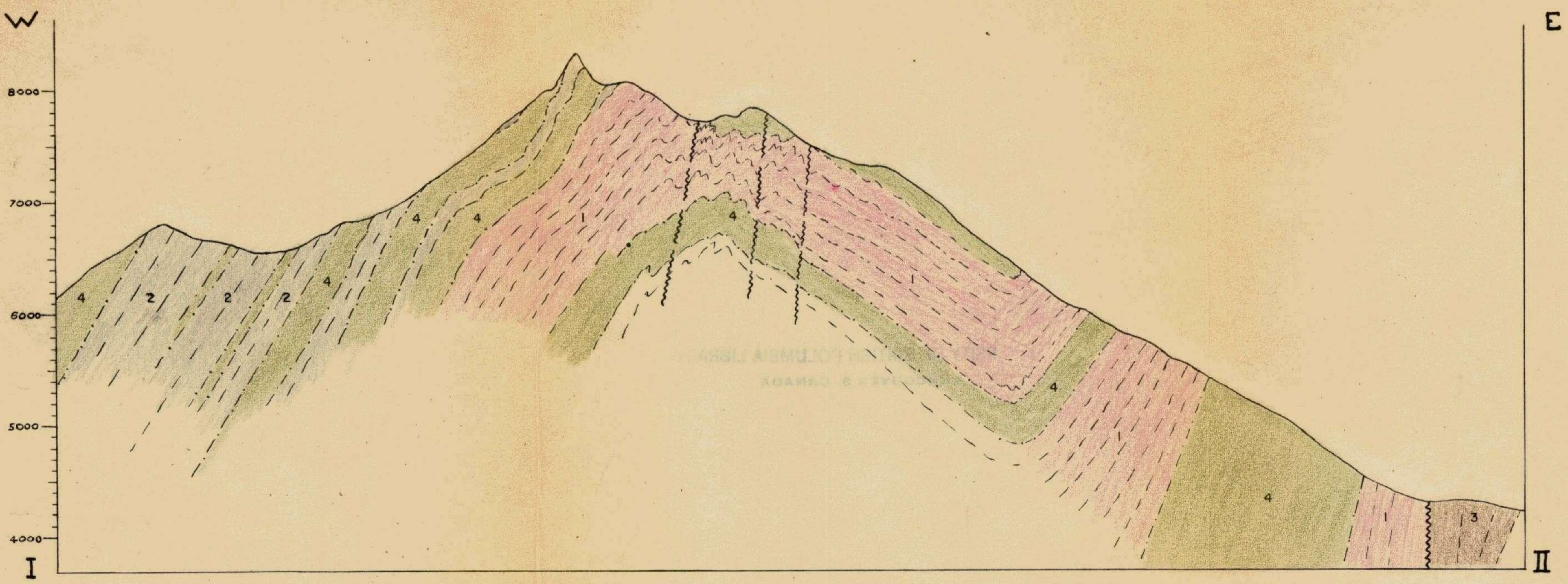
Hornblende Hornfels Facies. ACF Diagram for Rocks with Excess SiO_2 and K_2O

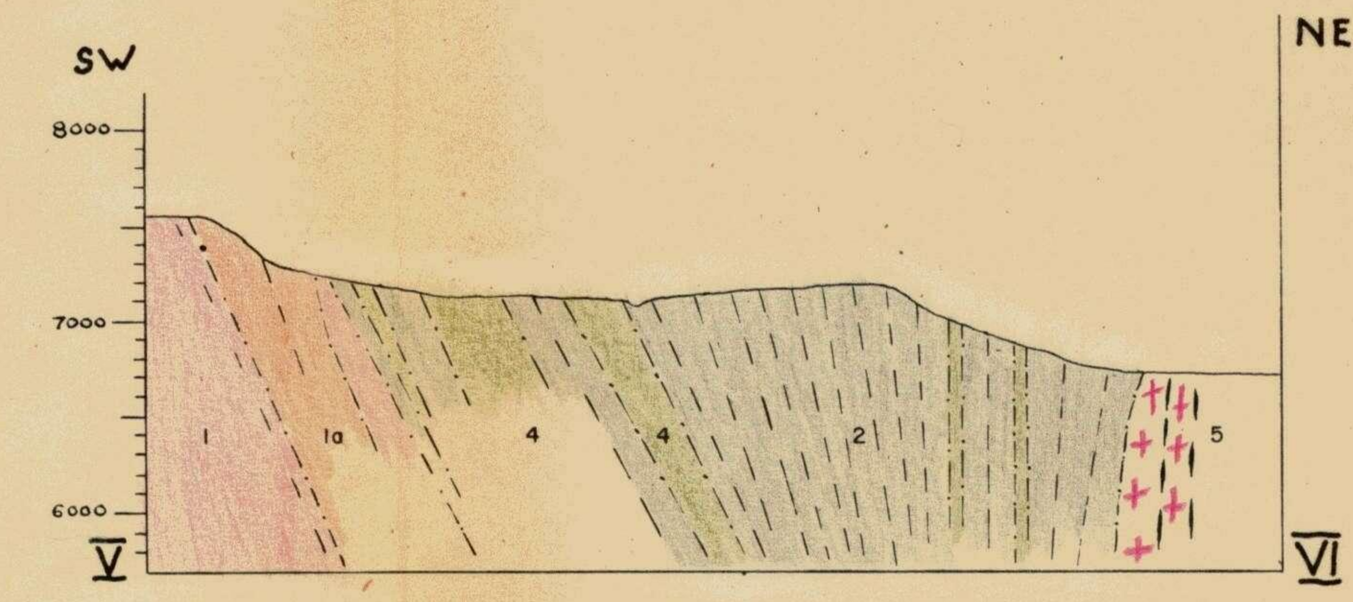


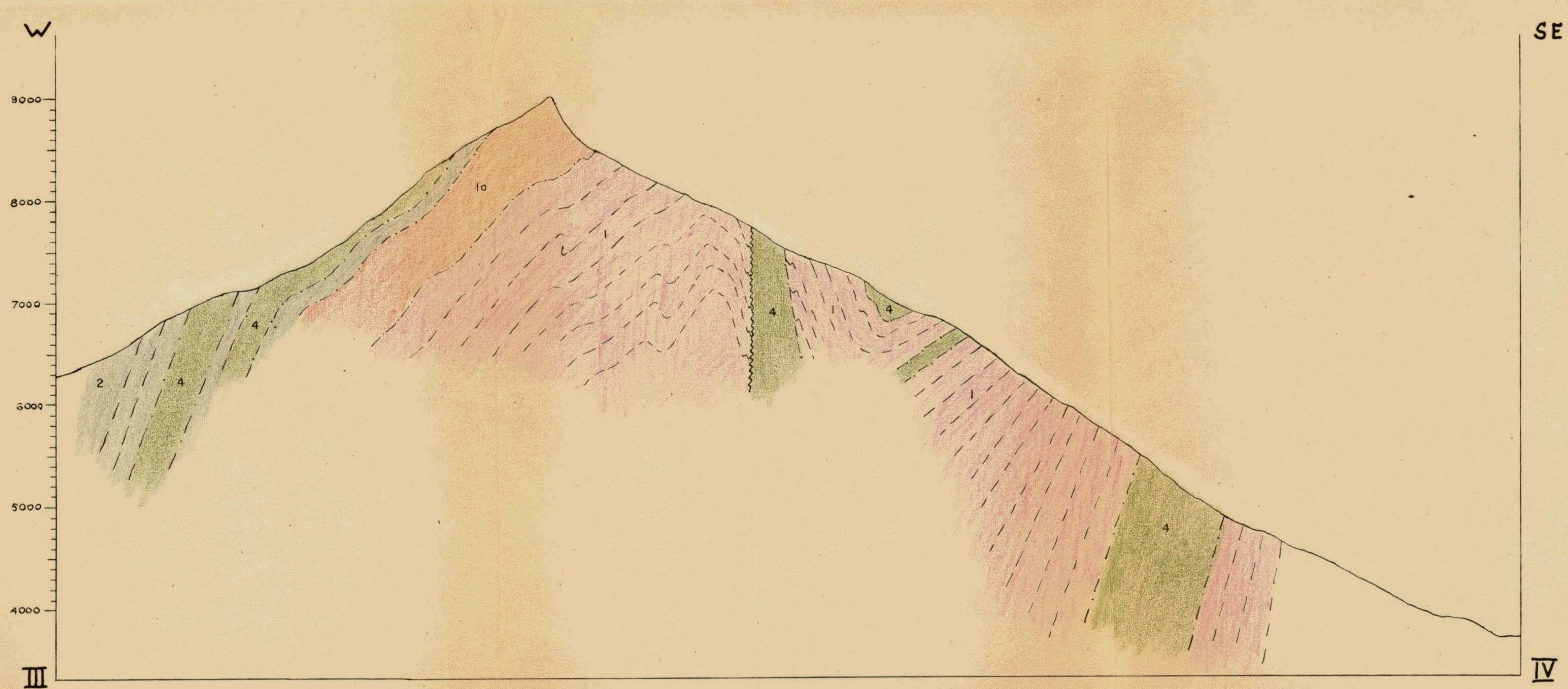
Hornblende Hornfels Facies. AKF Diagram for Rocks with Excess SiO_2 and Al_2O

Figure 19. Mineral assemblages of contact metamorphic rocks disregarding the changes produced by retrogressive metamorphism. Circles represent various rocks from the inner and outer contact metamorphic zones. (Diagrams after Fyfe, Turner and Verhoogen,1958).


LEGEND
MESOZOIC AND/OR CENOZOIC
WHITE CREEK BATHOLITH
5
Biotite granodiorite
PROTEROZOIC OR LATER
MOYIE INTRUSIVES
4
Meta-quartz gabbro
meta-diorite, meta-quartz diorite
PROTEROZOIC
LOWER PURCELL
CRESTON FORMATION
3
Green grey weathering quartzites, argillites and argillaceous quartzites
ALDRIDGE FORMATION
2
Middle Division grey weathering quartzites, argillites and argillaceous quartzites
1a 1
Lower Division 1a. Grey-rusty weathering breccia-conglomerates
1. Grey weathering quartzites, grey-rusty weathering argillites and argillaceous quartzites
BEDDING (inclined, vertical)
FOLIATION (inclined, vertical)
PLANES OF ALIGNED INCLUSIONS IN GRANODIORITE
ANTICLINAL AXIS (defined, assumed)
SYNCLINAL AXIS (defined, assumed)
FAULT (defined, assumed)
GEOLOGICAL CONTACT (defined, assumed)
AUTCROP AREAS
CONTOURS (interval 250 feet)
5000
DIORITE LAKE BASIN
DIORITE LAKE
WEST BASIN
TENT BASIN
ORANGE
DEWAR CREEK
WHITE CREEK
N
GEOLOGICAL MAP
OF
VULCAN RIDGE
DEWAR CREEK MAP AREA
BRITISH COLUMBIA
SCALE 1 INCH 1000 FEET
0
1000
2000
3000
4000
5000
6000







VERTICAL CROSS-SECTIONS of VULCAN RIDGE

- 5 White Creek batholith
- 4 Moyie Intrusives
- 3 Creston Formation
- 2 Middle Aldridge
- 1a | 1 Lower Aldridge 1a: breccia-conglomerates; 1. argillites, quartzites, and argillaceous quartzites
- bedding
- fault
- geological contacts

scale: 1 in = 1000 ft.