CONTACT PHENOMENA OF THE CENTRAL VANCOUVER ISLAND INTRUSION

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ABSTRACT

CONTACT PHENOMENA OF THE CENTRAL VANCOUVER ISLAND INTRUSION

By

Norman Edward Haimila

A petrological, mineralogical and trace element study of the eastern contact zone of the Central Vancouver Island Intrusion was conducted in the vicinities of Great Central Lake, Buttle Lake and the Elk River road in Central Vancouver Island, British Columbia. The purpose of the study was to detect differences within the batholith as it intruded the various lithologies represented in the stratigraphic section, to delineate mineralogical and elemental trends within portions of the batholith and to investigate the mode of emplacement of a typical batholith.

The Central Vancouver Island Intrusion was emplaced within a composite stratigraphic section of over 35,000 feet of varying lithologies. Approximately 14,000 feet of Paleozoic section is represented by the Sicker Group. The Sicker Group is composed of the Youbou Formation, the middle (clastic) part of the Sicker Group, the Buttle Lake Formation and possibly the "Henshaw" Formation. The Youbou Formation consists of over 8,000 feet of pyroclastics, greywacke, cherty tuff, andesitic tuff and flows, argillites, and volcanic breccia and agglomerate. The middle (clastic) part of the Sicker Group consists of up to 2,000 feet of shale and greywacke.

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The Buttle Lake Formation consists of up to 1,500 feet of limestone with minor clastic units at the base. The "Henshaw Formation" is composed of ash, tuff and conglomerate ranging in thickness from 0 to 900 feet.

The Mesozoic section cut by the intrusion is represented by over 21,000 feet of Vancouver Group rocks. The Vancouver Group is made up of the Karmutsen Formation, the Quatsino Formation and the Bonanza Subgroup. The Karmutsen Formation consists of approximately 18,000 feet of pillow lava, pillow breccia, aquagene tuff, amygdoloidal flows and minor argillite and limestone. The Quatsino Formation is 100 to 2,000 feet of light grey to black limestone. The Bonanza Subgroup consists of over 1,750 feet of tuffaceous argillite and massive andesitic flows.

The Central Vancouver Island Intrusion is a granodioritic to quartz dioritic intrusion which was emplaced within the Paleozoic and Mesozoic section approximately 166 m.y. before the present. The intrusion was emplaced along North-South Paleozoic fold axes and along Northwest-Southeast Mesozoic structural trends. Faulting in the area of the intrusion is dominated by apparent lateral separations.

The areas along the contact zone were variously sampled by combinations of random, linear and grid techniques and analyzed using standard petrological methods. Approximately 300 samples were analyzed for mineral content by X-ray using a modified Alexander and Klug internal standard technique. Sixty-five samples were analyzed by X-ray fluorescence and compared against external standards for the intermediate weight trace elements. The margin of the intrusion exhibits all variations of contacts from gradational to sharp and from xenolithic to sheared.

Over 180 thin sections were studied and the petrography of most of the units on the intrusion are included. Appropriate chemical analyses are reported for comparison purposes. The petrological, mineralogical and trace element distributions and trends indicate that the batholith is a zoned intrusion with a quartz rich belt extending from one half mile to two and a half miles from the contact zone. The quartz-rich zone is important to the mode of emplacement and the assimilation processes active at the contact zone. The Central Vancouver Island Intrusion was emplaced as a highly viscous fluid "front" enclosing a mass composed of solidified crystals and highly viscous interstitial fluid. Much of the material in the batholith was derived from the assimilated country rock.

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By

Norman Edward Haimila

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INTRODUCTION

General Statement

The nature of intrusive rocks and the mechanisms involved in their emplacement have been the subjects of classical controversies in geology. The arguments of the "granite problem" have been presented by each generation of geologists for the last one hundred to one hundred and fifty years. The many aspects of this problem have enlarged to such an extent that the natural limits of investigation are beyond the practical capabilities of a single study. It is, therefore, not the presumption of the writer to attempt to solve the total problem or dispel all the questions which have been posed. It is the investigator's task to study, interpret, and report the relevant conditions found in a typical intrusive batholith.

The Central Vancouver Island Intrusion is a typical batholith. It is a granodioritic to quartz dioritic intrusion situated in a geologic province which contains the largest batholiths on earth. These large batholithic complexes are the Coast Range Batholith, the Omineca Batholith, the Idaho Batholith, the Boulder Batholith, and the Sierra Nevada Batholith. The Central Vancouver Island Intrusion qualifies as a typical batholithic intrusion because of its

mineralogical affinities, its structural similarities, and its proximity to the Coast Range Batholith. Surface exposures of the two bodies are separated by less than forty miles and may actually connect in the subsurface.

Outcrops of rocks in southwestern British Columbia around the Coast Range Batholith usually do not reveal a long geologic history. Central Vancouver, however, contains exposures representative of as much section as can usually be found in this geological province. The stratigraphic column in contact with the Central Vancouver Island Intrusion is represented, with some breaks, by units ranging from Pennsylvanian or earlier through Early or Middle Jurassic. Although the bulk of the rocks in the stratigraphic column have volcanic affinities, basic intrusive rocks are found in moderate abundance and several clastic and carbonate units occur throughout the section. Within a relatively small area the Central Vancouver Island Intrusion cuts a composite stratigraphic section representative of approximately 35,000 feet of variable rock types.

Field observations within the Central Vancouver Island Intrusion indicated that the intrusion remained relatively rich in quartz in spite of its proximity to great thicknesses of basic volcanic rocks. Evidence of assimilation of the country rocks is apparent at numerous locations yet visible evidence of compositional changes within the intrusion are minimal.

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In order to reconcile field observations by the writer and other investigators the study of the batholith was carried out with the following general objectives:

1. to detect differences within the batholith as it intruded the various lithologies represented in the stratigraphic section
2. to delineate trends within the batholith
3. to investigate the mode of emplacement of the batholith

The more specific objectives within the general objectives were:

1. to investigate the variations in quantity and type of the feldspars within the Central Vancouver Island Intrusion
2. to investigate the abundance and mode of occurrence of the quartz within the intrusion
3. to investigate trace element distribution in portions of the intrusion and anomalous concentrations of metallic elements which are usually sought for economic development.

Previous Geological Investigations in Central Vancouver Island

The initial geological work done in the Central Vancouver Island area was related to individual and mining company investigations for minerals following the opening of Strathcona Park to prospecting in 1917.

Dolmage (1921) first published on the existence of the Central Vancouver Island Intrusion in his mapping of the West Coast of Vancouver Island in 1920. He mapped some of the intermediate intrusives along the coast and mentioned a light grey diorite in the Elk River.

H. C. Gunning carried out a reconnaissance geological investigation of the Buttle Lake area in the summer of 1930 (Gunning 1931). His study of rock distribution and mineral deposits extended from the east coast of Vancouver Island up to and including the eastern boundary of the Central Vancouver Island Intrusion between Latitudes 49^{o} 30' North and 50^{o} North.

T. H. E. Sargent extended the study of the intrusive body southward with a mapping and mineralogical study of an irregularly shaped area within the Latitudes of 49^{o} 21' North and 49^{o} 30' North and Longitudes 125^{o} 30' West and 125^{o} 50' West. The field work was carried out in 1939 and 1940 and resulted in two publications and a thesis (Sargent 1940, 1941, 1942).

Interest in the Central Vancouver area was rekindled with renewed mining activity in the Buttle Lake area in 1961 and the use of the area by the Department of Geology of the University of California at Los Angeles as a research area for students and staff. The mapping program of the Geological Survey of Canada coincided with this activity. During 1960 and 1965, various studies were being conducted simultaneously.

D. J. T. Carson of the Canadian Geological Survey was conducting a regional metallogenic study of plutons and metallic deposits of Vancouver Island (Carson 1968).

R. C. Surdam was carrying out a mapping and a research project for his doctoral dissertation at the University of California at Los Angeles (Surdam 1967 and Surdam, Suzuki and Carlisle 1963).

J. E. Muller of the Canadian Geological Survey was mapping Central Vancouver Island area at a scale of four miles to the inch (Muller 1964, 1965, Muller and Carson 1968, 1969).

R. W. Yole worked within the area conducting paleontological and stratigraphic research for his doctoral dissertation at the University of British Columbia (Yole 1963, 1965, 1969).

The writer worked with W. G. Jeffery on the mineral evaluation and mapping program during 1963 and 1964 and independently carried out additional research within the area in 1965 (Jeffery 1963, 1964, 1965, 1967).

Location and Access

The area of investigation of this study was confined to the eastern margin of the Central Vancouver Island Intrusion with the exception of one complete traverse across an arm of the batholith. The area of investigation is illustrated on Figure 1 in relation to its geographical position and its relation to the intrusive bodies on Vancouver Island. The area from which data were obtained lies in the most deeply

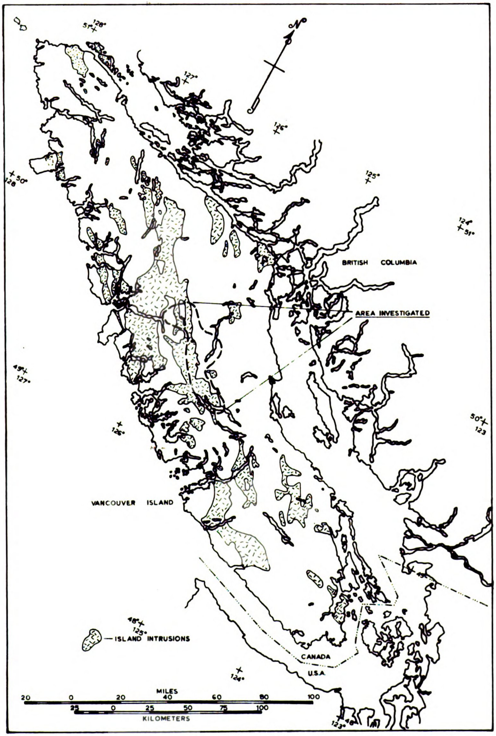

Figure 1 Location Map

incised areas of Vancouver Island. The large lakes situated in the main valleys have shoreline elevations between sea level and 800 feet above mean sea level while the peaks of the nearby mountains rise to over 7,000 feet. Plateau areas are found above 4,000 feet.

Access into the area was primarily limited to automobile or truck roads to the shores of the large lakes or heads of inlets and thence by small boat to the various locations along their shores. From the shores of the lakes, most travel was restricted to foot travel. Foot trails were lacking over most of the area and routes were governed by topography, drainage and the thick underbrush. Access to the shores of some of the lakes could also be gained by the air charter of float planes based in Campbell River, British Columbia. Helicopters also based in Campbell River gave complete access to all portions of the area. However, because of the expense involved, helicopter travel was limited to strategic locations only.

Because of the rugged terrain and the relative inaccessibility of many portions of the area, the total length of the contact zone between the Central Vancouver Island Intrusion and the eastern country rocks was not walked out.

The data were collected from ten areas within the batholith and along its eastern margin. The locations of these areas of concerted effort are illustrated on the Geological Map on Figure 2 and Plate I (Muller 1968, Jeffery 1963, 1964). The most extensive collection of data and sample material was from th

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from the western end of Great Central Lake (Latitude 49° 22' North, Longitude 125° 17' West). Two small areas of investigation extend this belt approximately eight miles further to the west past McBride Lake to the west of Leader Lake (Latitude 49° 25' North, Longitude 125° 36' West). A gap in the coverage exists between Leader Lake and the southern portion of Sargent's study area (Latitudes 49° 26' North to 49° 28' North and Longitudes 125° 35' West to 126° 36' West) (Sargent 1942). From the Bedwell Lake area (Latitude 49° 28' North, Longitude 125° 35' West) to north of Myra Creek (Latitude 49° 35' North, Longitude 125° 39' West) there is almost continuous coverage of the contact zone with additional coverage extending in a belt three miles wide along the contact within the batholith. From north of Myra Creek to south of Burman Lake (Latitude 49° 37' North, Longitude 125° 43' West) observations were confined almost totally to the country rock side of the contact. A precipitous topography controlled the location of observations.

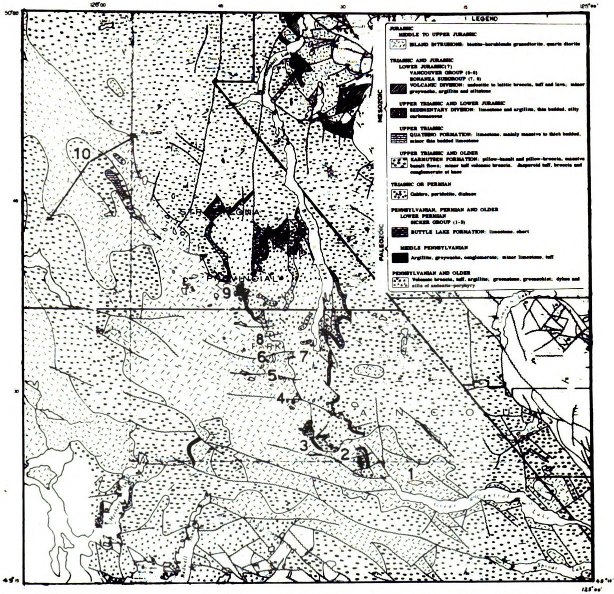
North of Burman Lake detailed examinations were made. There the intrusive contact cut through a varied stratigraphy in a very short distance.

From west of Burman Lake (Latitude 49° 38' North, Longitude 125° 46' West) to the Elk River road (Latitude 49° 54' North, Longitude 125° 51' West) no observations or sample collecting were carried out.

From the eastern intrusive contact on the Elk River road to the western intrusive contact (Latitude 49° 43'

Figure 2 Areas of Concentrated Studies and Geological Map

1. Great Central Lake Area
2. McBride Lake - Halo Hill Area
3. Leader Lake Area
4. Bedwell Lake Area
5. Thelwood Lake Area
6. Tennant Lake Area
7. Mount Myra Area
8. Myra Creek Area
9. Burman Lake Area
10. Elk River Road



GEOLOGICAL MAP OF THE CENTRAL VANCOUVER ISLAND AREA

Geological boundary (approximate)

Bedding (inclined, vertical, overturned)

Schistosity, foliation (inclined)

Schistosity, foliation and minor fold axes (inclined, vertical, arrow indicates plunge)

Lineation (axes of minor folds)

Fault (approximate); linear feature

AFTER MULLER (1968) JEFFERY (1963, 1964)

Scale

North, Longitude 126° 07' West, a continuous section was run. Samples were obtained wherever possible in the valley which cut perpendicular across the intrusive body. The sample interval averaged 2,700 feet; however, some samples were collected at closer intervals and one interval exceeded 9,000 feet.

General Geology

Stratigraphy and Lithology

The stratigraphy of the Central Vancouver Island can best be characterized as an upper Paleozoic and lower Mesozoic volcanic-sedimentary sequence in which sedimentary rocks of a non-volcanic origin play a minor role. A carbonate interval occurs below the mid-point of the composite stratigraphic section and more carbonate units occur in the upper one quarter of the section. A diagrammatic composite stratigraphic section of the interval cut by the Central Vancouver Island Intrusion is presented in Figure 3. The upper section of the column comprising approximately 3,000 feet of flows, tuffaceous argillite and carbonaceous limestone was not encountered in the study area but did occur farther north.

The base of the section is not exposed and it is possible that to the south outside the study area, units representative of lower stratigraphic intervals are exposed.

Sicker Group

Rocks of the Sicker Group are the oldest units in the Central Vancouver area. The term "Sicker Series" was introduced by Clapp (1912) for a sequence of schistose metamorphosed sedimentary and volcanic rocks variously intruded with acid and basic porphyrites. Clapp erroneously placed the "Sicker Series" as overlying the Vancouver volcanics within the Vancouver Group. Gunning (1931) followed a suggestion quoted from an earlier work by Dawson (1886) and took the Sicker type rocks out of the Vancouver Group and restricted the Vancouver Group to the volcanics higher in the section. The relationship of a limestone overlying the Sicker type volcanics was established by Gunning and was confirmed by Sargent (1942) in the Bedwell River area.

The term Sicker Group was established by Fyles (1955) in the Cowichan Lake area in southeastern Vancouver Island. The term "series" was dropped because the group was a rock unit without time significance. Fyles thought the dominant limestone lenses in his unit belonged to the uppermost formation of the Sicker Group. Although Fyles described the group in detail he separated the group according to lithologic types and refrained from naming any of the formations since the stratigraphic succession was difficult to ascertain in the Cowichan Lake area. Two sections were given from near the east and west ends of Cowichan Lake, the greatest distance that recognizable markers allowed correlation. Table I is the Stratigraphic Sequence within the Sicker Group presented by Fyles.

Yole (1963) subdivided the Sicker Group into two units and informally designated them "Formations A and B". The designations "A" and "B" were later replaced by the informal terms "Lower Division" and "Upper Division" with the "Upper Division" being further sub-divided into two formations. Yole (1969) formally proposed that the lower formation of the "Upper Division" be called the Buttle Lake Formation following Gunning's earlier suggestion. Yole assigned an early Permian (Wolfcampian-Leonardian) age to the Buttle Lake Formation. The name, Youbou Formation, was formally proposed for the "Lower Division" at the same time. The proposed type section for the Youbou Formation was Fyles' West Fork Shaw Creek section shown in Table I. The upper formation of the "Upper Division" which was described as a dark fine-grained argillite and mudstone remained unnamed. The relationship of this unnamed formation to the rest of the Sicker Group is in question and will be discussed later.

Jeffery (1967) using Yole's earlier informal sub-divisions recognized a three-fold sub-division in the Sicker Group without considering the unnamed formation at the top. Jeffery sub-divided the "Lower Division" (Youbou) into a volcanic unit in the order of 8,000 feet thick overlain by a sedimentary unit that, if not faulted, may attain 1,300 feet in thickness. The Buttle Lake Formation is related as being 1,120 feet and rests on the "Lower Division". Jeffery followed Yole's example and included ten feet of greywacke sandstone at the base of the Buttle Lake Formation.

Muller (Muller and Carson 1968) recognized on a regional scale the same sub-divisions that Jeffery had in the Buttle Lake area. Muller published prior to Yole formally proposing

STRATIGRAPHIC SEQUENCE WITHIN THE SICKER GROUP

Meade Creek (Composite Section)		West Fork of Shaw Creek	
Approximate Thickness (Feet)	Rock Type	Approximate Thickness (Feet)	Rock Type
	Top not exposed.		Top not exposed.
2,000	Grey to black feldspathic tuffs and argillaceous sediments, minor breccias.	200-300	Purplish volcanic breccia.
		1,300	Green tuffaceous greywackes.
		250	Amygdaloidal basalt.
		1,000	Thin and thick beds of tuffaceous greywacke.
		800	Black feldspathic and argillaceous tuffs, thin limestone lenses.
600	Thin-bedded cherty tuffs, minor feldspathic tuffs and tuffaceous greywackes.	600	Thin-bedded cherty tuffs.
1,500-2,000(?)	Green volcanics (massive sediments, breccias and flows).	4,500	Massive green clastic sediments and breccias.
500	Thin-bedded cherty and tuffaceous greywackes.		
3,000-4,000	Mainly massive green volcanics.		
	Base unknown.		Base unknown.

Fyles (1955)

Table I Fyles' Stratigraphy of the Lower Sicker Group "Youbou Formation"

the "Youbou Formation". Muller refers to the sub-divisions as the "Lower (volcanic) part of the Sicker Group" and the "Middle (clastic) part of the Sicker Group". The diagrammatic composite stratigraphic section in Figure 3 follows the interpretations of Jeffery and Muller for the Sicker Group and possibly explains the relationship proposed by Yole for his and Fyles' work.

The base of the Sicker Group in the Central Vancouver Island area, as it is in the Cowichan Lake area, is unknown. The lowest exposure of the Youbou formation investigated in the study area probably occurs in Price Creek south of Buttle Lake (Latitude 49^{o} 31' North, Longitude 125^{o} 32.5' West). This location is south of an easterly trending fault which appears to have a vertical separation of approximately 1,000 feet. The apparent upthrown stratigraphic section is on the south side. The rocks dip to the east and from this point southeastward the combination of stream gradient rise and the dip causes this stratigraphic section to disappear rapidly into the subsurface.

The rocks at this lowest section are cherty tuffs. They are distinguished from other cherty tuffs in the area by being banded in light creamy greens and dark purples. Alternating bands of green and purple may repeat once to several times per foot. Within the alternations, laminations of lighter to darker colors occur on spacings of less than an inch. The rocks appear to be composed of graded beds but they are so fine-grained that this cannot be determined with a hand

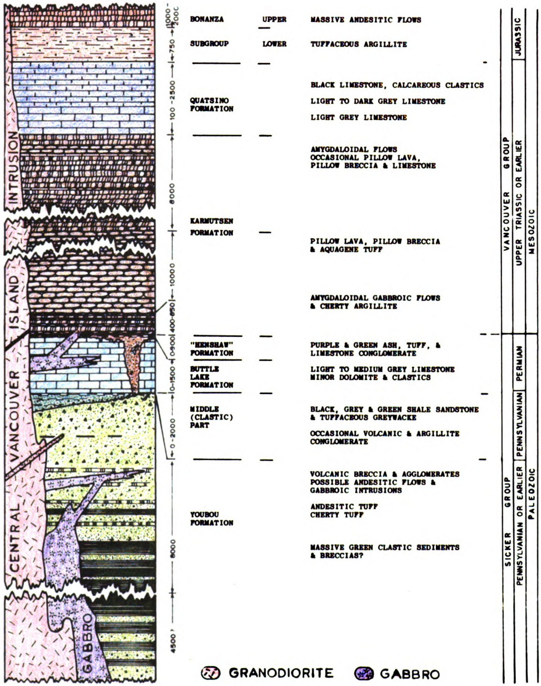


Figure 3 Diagrammatic Composite Stratigraphic Section

lens in the field and in most instances it is difficult to determine in a thin section under a microscope. These rocks resemble chert beds but weather like feldspar being softer and at times porcelainous to unctious in appearance.

Above these purple and light green cherty tuffs, the lower Sicker Group grades into additional cherty tuffs in which the purple color becomes less distinct and the number of beds which exhibit this color also diminishes. By putting together several smaller sections it appears that the very fine-grained cream, green and purple cherty tuffs make up several hundred feet of stratigraphic section. Upward, the cherty tuffs become interbedded with intervals of massive coarser tuffs containing tuffaceous fragments. Some of the massive bedded tuffs exhibit graded bedding of sedimentary aspect while others show no bedding characteristics and resemble massive greenstones or andesitic flows. The cherty tuffs and the fine-grained graded-bedded tuffs decrease in number upward and within a thousand feet become almost totally absent.

In some of the ill-sorted beds composed of tuffaceous matrix with clasts of tuffaceous material containing lapilli fragments, there are additional curled clasts of the cherty tuffs and fine-grained laminated graded-bedded tuffs. Some of the tuffaceous bed of sedimentary aspect may resemble tuffaceous greywacke.

The tuffaceous beds coarsen upward in an oscillatory manner. Rounded lapilli and agglomerate fragments up to four

inches in diameter become plentiful.

No black feldspathic argillaceous tuffs or thin limestone lenses were found in the interval between the laminated cherty tuff and the tuffaceous greywacke to massive greenstone beds. However, gabbro intrusive bodies of irregular shape and sills occur within the coarser tuffaceous sediments. About 1,500 feet above the thin-bedded cherty tuffs, there is a 1,000 foot thick basaltic to gabbroic sill. This sill may be observed on the west side of Buttle Lake just north of Myra Creek (Latitude 49° 35' North, Longitude 125° 35' West) between 2,500 feet and 3,500 feet above sea level.

The coarse tuffaceous beds continue above the sill. Tuffaceous greywacke which should lie above the sill contains crinoid ossicles in the vicinity of the Buttle Lake narrows (Latitude 49° 37.5' North, Longitude 125° 32' West). Occasional jasperoid lenses are found in the upper portions of the coarse tuffaceous beds and massive andesitic beds. These beds grade into more agglomeratic beds and coarse volcanic breccia with fragments more than one foot in diameter become common. The volcanic breccia and agglomerates continue upward to the base of the Middle (clastic) unit of the Sicker Group. At one location in the Phillips Creek Watershed (Latitude 49° 39.4' North, Longitude 125° 38.5' West) in addition to the large agglomeratic fragments, there appear to be volcanic bombs over one foot long. Both the agglomerate and bombs are contained in a purplish to brown tuffaceous matrix.

The presence of purplish breccia and the bombs may indicate subareal or near subareal conditions during the final depositional cycle of the lower volcanic unit of the Sicker Group (Youbou Formation).

At the type section of the Buttle Lake Formation, the lower contact rests on a gently undulating surface. Directly below the clastic interval of the Buttle Lake Formation, breccia fragments are truncated by this undulating surface. This may indicate an unconformity in this area.

The aforementioned stratigraphic section with the exception of the lacking black feldspathic, argillaceous tuffs and thin limestone lenses is very similar to the upper portion of the type Youbou section. If these sections do correlate, then approximately 4,500 feet of massive green clastic sediments and breccia may be buried below the Central Vancouver Island area. These pyroclastic units have been included at the base of the stratigraphic section in Figure 3.

In the vicinity of the type section of the Buttle Lake Formation (Latitude 49^{o} 41.5' North, Longitude 125^{o} 39.4' West) measured by Yole (Yole 1969) there are additional clastic sediments below the ten foot thick sandstone unit which has been included in the Buttle Lake Formation. The sediments below the Buttle Lake Formation are of highly variable thicknesses over short distances because they fill undulations in the lower (volcanic) part of the Sicker Group (Youbou Formation). Thicknesses of these overlying clastics are in the order of thirty feet to fifty feet near the type section of the Buttle Lake Formation. At this location, they are composed of black, grey, and green shales, greenish-grey fine sandstones and tuffaceous greywacke. Some of the beds exhibit graded bedding. At the head of the west fork of Wolf River on the slopes of El Piveto Mountain (Latitude 49° 42.7' North, Longitude 125° 46' West) sediments like those mentioned above, but including conglomerates with clasts of volcanic rocks and black argillite approximately four inches in diameter, occur in a similar stratigraphic position - above the Youbou Formation and below the Buttle Lake Formation. They attain a thickness of approximately 500 feet. This outcrop contains a few small faults of unknown movement making an exact measurement of the thickness difficult.

Between the Youbou and Buttle Lake Formations on the slopes of Marble Peak (Latitude 49° 42' North, Longitude 125° 35.6' West) Jeffery (1967) indicated that if faulting had not displaced the outcrops approximately 1,300 feet of similar clastics were present.

Muller (Muller and Carson 1968) found similar clastic rocks at this position at a number of locations on Vancouver Island and on adjacent islands. Paleontological dating by C. A. Ross and E. W. Bamber (in Muller and Carson 1968) puts the age of this sedimentary sequence at middle Pennsylvanian, probably early Desmonian. Muller is of the opinion that, although the thickness of this clastic sequence is variable, it probably does not exceed 2,000 feet.

Since there are places where the limestone of the Buttle Lake Formation rests directly on the undulating surface of the Youbou Formation and there are other locations where up to 2,000 feet of shale, argillite, sandstone, greywacke, conglomerate and minor tuff intervene, the middle (clastic) part of the Sicker Group is illustrated as a wedge-shaped unit between the Youbou Formation and the Buttle Lake Formation on Figure 3.

The middle (clastic) unit is shown as having a locally unconformable lower contact. The sharp upper contact may be unconformable also. Muller (Muller and Carson 1968) interprets the clastic unit as a sub-wavebase deposit which may preclude the likelihood of the unit being a shallow transgressive onlapping sequence preceding the carbonate deposition of the Buttle Lake Formation.

The Buttle Lake Formation of the Sicker Group, as mentioned earlier, consists of 1,120 feet of medium-grained, light grey limestone containing less than one hundred feet of dolomitic limestone near the middle of the section. Light to dark grey nodules, lenses, and irregular bands of chert, replace portions of the limestone and dolomitic limestone beds in zones throughout the section. The type section of the Buttle Lake Formation (Yole 1968) is given as 1,050 feet.

The Formation contains fossil rich beds at various intervals throughout the section. The fossils are represented by fenestrate and ramose bryozoans, solitary corals, spiriferid and productid brachiopods and crinoid ossicles. The

dolomitic zone is probably the most fossiliferous interval in the section becoming a coquina at various locations. This section often weathers as slightly darker grey than the rest of the section making it recognizable from a distance.

In the Central Vancouver Island area the Buttle Lake Formation is usually intruded by a gabbro sill in the order of 400 feet thick. This sill rises slowly from very near the base of the Buttle Lake Formation toward the northeast. It is interpreted that the sill broke through the sedimentary cover in certain areas. The sill is related to the Karmutsen volcanics and will be discussed later.

The top of the Buttle Lake Formation in the Central Vancouver Island area is believed to be erosional. Some features characteristic of karst topography have been observed near the type section and elsewhere. On a plateau (Latitude 49^{o} 42' North, Longitude 125^{o} 38' West) lapies are present. These solution features are infilled by basic igneous material of the first volcanic episode related to the Karmutsen Formation. Similar solution features are exposed on the eastern shores of Buttle Lake (Latitude 49^{o} 40' North, Longitude 125^{o} 32.2' West). The Buttle Lake Formation varies in thickness from 1,530 feet on Eastern Vancouver Island to less than 100 feet or zero in other areas. This variability may be due in part to the erosion of the upper surface prior to Triassic deposition.

Elsewhere on the eastern side of Buttle Lake though not confined to that area, there occur outcrops of ill-sorted, mixed volcanic and sedimentary rocks in stratigraphic positions above the Buttle Lake Formation. In general, these rocks consist of predominantly purple to brick red volcanic material in which are scattered clasts and boulders of crinoidal limestone up to ten feet thick in diameter. In addition to this dominant lithology, there occur in this sequence, cobbles of andesite, andesitic tuff and limestone in a purple ashy matrix, limestone breccias, and purple to greyish-green glassy volcanic ash pumice and tuff. Jeffery (Jeffery 1967) proposed that this unit be called the "Henshaw Formation" because the greatest thickness and most varied lithology is found in Henshaw Creek (Latitude 49^{o} 36' North, Longitude 125^{o} 32' West). To date, the proposed name, "Henshaw Formation" has appeared only in manuscript form within the British Columbia Department of Mines and Petroleum Resources and therefore is enclosed within quotation marks throughout this work. The "Henshaw Formation" grades into finer grained red reworked volcanic siltstones and mudstones upwards and westward from Henshaw Creek.

Muller (Muller 1968) mapped this series of exposures as belonging to the middle (clastic) unit of the Sicker Group. The "Henshaw Formation" may locally truncate reduced thicknesses of the Buttle Lake Formation and directly overlie the lower (volcanic) part of the Sicker Group (Youbou Formation) leading to alternate interpretations. Since no fossils have been found in the "Henshaw Formation", one must rely on

lithologic correlations. Nowhere else in the Buttle Lake area is there a lithology as distinct as that in the "Henshaw Formation". The included limestone clasts and boulders are indistinguishable from the Buttle Lake Formation. At numerous locations around Buttle Lake, brick red, purple and greenish-grey ashy beds are found directly on the Buttle Lake Formation. Approximately three quarters of a mile south of the type section of the Buttle Lake Formation (Latitude 49° 41' North, Longitude 125° 40' West) brick red volcanic siltstones are found below the sill of flow that is assumed to be the first volcanic event in the Karmutsen Formation. One half mile to one mile north of this exposure, the same beds are found above the continuation of this flow or sill. Fragments of purple ashy cherts and argillaceous tuffs are included in the top of the basic intrusion which exhibits a blocky texture with numerous vesicles and crude columnar joints. Above the brick red volcanic siltstone and purple ashy cherts and argillaceous tuffs in an apparent conformable relationship are black and white banded argillaceous cherts which are usually included in the Karmutsen sequence.

The "Henshaw Formation" is diagrammatically illustrated in Figure 3 to represent a formation which overlies the Buttle Lake Formation in a disconformable relationship possibly cutting completely through it in places to rest directly on the middle and/or lower parts of the Sicker Group with unconformable contacts also. The sill that intrudes the Buttle Lake Formation is discordant in places cutting up through the

overlying portion of the Buttle Lake Formation, the "Henshaw Formation" and the lowest sedimentary unit of the Karmutsen Formation. After cutting through the lowest Karmutsen unit, the "sill" becomes a flow.

The age of the "Henshaw Formation" is unknown, but is probably representative of part of the Permian between Leonardian and the Triassic. The thickness of this formation may vary between zero and 900 feet.

The Vancouver Group

The volcanics and sediments that overlie the "Henshaw Formation" were named the "Karmutsen Volcanics" by Gunning (1932) in North Central Vancouver Island. Surdam (1967) recognized eighteen units within the volcanics and referred to the total section between the Buttle Lake Formation and the overlying Quatsino Formation as the "Karmutsen Group". The units within the volcanics were described according to their lithologies but were not formally named.

Muller (Muller and Carson 1968) refers to this sequence as the Karmutsen Formation within the Vancouver Group without elevating the Vancouver Group to Super Group status. In this study, the name Karmutsen Formation is used. Central Vancouver Island area both Surdam (1967) and Muller (1968) estimate that the Karmutsen Formation is approximately 18,000 to 19,000 feet thick.

The base of the Karmutsen Formation which appears to conformably overlie the "Henshaw Formation" is composed of up to 160 feet of black, grey and white laminated argillite.

In thin sections, they resemble the cherty tuffs in the Youbou Formation but on the surface they are quite different in color, weathering, and jointing characteristics. The rocks joint vertically on a very close spacing across the black, grey, and white laminations to yield chips that look like striped dominoes.

The argillite is overlain by a flow of amygdaloidal and vesicular gabbro to basalt which has been described earlier as also being the sill within the Buttle Lake Formation. This gabbroic flow may attain thicknesses of 450 feet west of Buttle Lake.

The interrelationships of the sill that intrudes the Buttle Lake Formation and then discordantly cuts up section through the "Henshaw Formation" and the lower argillite sequence of the Karmutsen Formation to become the first flow in the Karmutsen Formation are shown on Figure 4. The upper portion of the figure is diagrammatic but is representative of the area extending from Mount McBride (Latitude 49^{o} 43' North, Longitude 125^{o} 39' West) southwest and thence south to the south end of Limestone Ridge (a name given to the southwest shoulder of Mount McBride) (Latitude 49^{o} 40.5' North, Longitude 125^{o} 40' West).

The figure is also representative of the stratigraphic relations below the Buttle Lake Formation. The outcrop relations as they now appear have been complicated by cross-cutting vertical faults but can readily be seen on the face of Mount McBride when viewed from the southeast. The lower

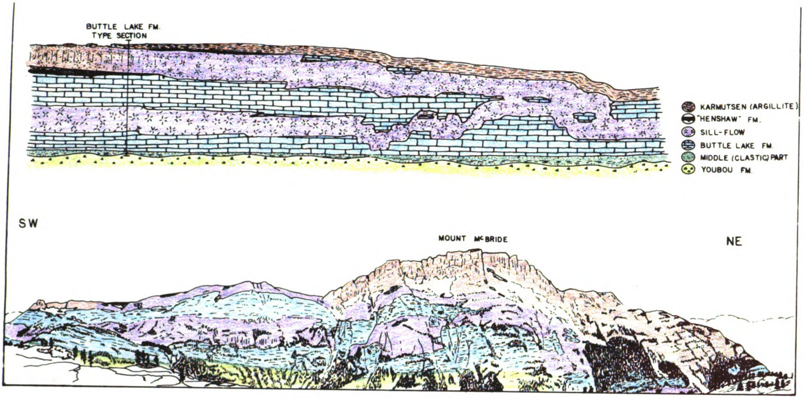


Figure 4 Interrelationships of the Gabbroic Intrusion-Extrusion and the Buttle Lake Formation, the "Henshaw Formation" and Karmutsen Formation

half of the diagram is a sketch of the area as it now appears.

More black and grey argillites occur above the first gabbroic to amygdaloidal flow. In this instance, they are only a few tens of feet thick. They are succeeded by another amygdaloidal flow fifty to 100 feet thick which in turn is overlain by approximately ten more feet of argillite. Occasionally, one more set of flow and argillite is deposited in this sequence before a change in depositional mode occurs.

Following the deposition of the cyclic argillite and flow sequence is a great thickness of pillow lavas. In the areas where the Central Vancouver Island Intrusion cuts the Karmutsen Formation, only pillow lavas were observed above the basal flows and argillite. It has been reported by Carlisle (1963), Surdam (1967), and Muller (Muller and Carson 1968) that the pillows break into pillow breccias and aquagene tuffs to the east and the fragmental rocks dominate the sequence. The pillow lavas in the Central Vancouver Island area are approximately 10,000 feet thick.

Above the pillow lavas of the Karmutsen Formation, occurs the second most abundant mode of deposition for the volcanic rocks. Relatively thin amygdaloidal volcanic flows ten to twenty feet thick accumulated in this interval to a total thickness of approximately 5,000 feet before the next depositional cycle was added to the formation.

Approximately 100 feet of pillow lavas, pillow breccia and limestone intervene above the amygdaloidal flows below and the next sequence of amygdaloidal flows above. Above the mixed volcanic-sedimentary interval the amygdaloidal flows accumulated an additional 2,000 feet in relatively thin flows.

It was approximately at this stratigraphic position that the traverse across an arm of the Central Vancouver Island Intrusion was carried out. The Karmutsen Formation was encountered as the eastern and western bordering country rocks and was also found in a roof pendant within the intrusion.

Above the previous 2,000 foot thick sequence of amygdaloidal flow is another limestone unit which varies from zero to 100 feet thick. The limestone is followed by 100 to 400 feet of pillow lavas and pillow breccia.

The succession is capped by approximately an additional 300 feet of amygdaloidal flows. The Karmutsen Formation is represented on Figure 3 in an interrupted manner since it is so thick.

The last amygdaloidal flow of the Karmutsen Formation is directly overlain by the Quatsino Formation. The relationships of the Karmutsen and the Quatsino were not investigated by the writer but Surdam (1967) reports that the limestone of the Quatsino Formation rests on an unweathered upper chilled margin of an amygdaloidal flow. The Quatsino Formation (Muller 1971) may have 100 to 2,500 feet of massively thick bedded light grey limestone overlain by 600 feet to 1,200 feet of light grey to black, thick-to-medium bedded limestone overlain by 600 feet to 1,200 feet of limestone black fissile limestone, calcareous siltstone, calcareous greywacke and argillite. The top of the formation may contain another light grey thick-to-medium bedded limestone.

The Quatsino Formation was not investigated in any detail in the Central Vancouver Island area but it occurred in the roof pendant which was traversed along the Elk River road. The formation did not come in contact with the Central Vancouver Island at this location. The intrusion cuts the Quatsino Formation at other locations on Vancouver Island. The Quatsino is represented diagrammatically on Figure 3 as a limestone grading upward into a mixed impure limey assemblage. This is the top of the Triassic section.

Bonanza Subgroup

Gunning (1932) introduced the name Bonanza Group for the volcanic and sedimentary volcanic rocks in Northwest Vancouver Island. However, since it is part of the Vancouver Group, Muller (Muller and Carson 1968) suggests it be called the Bonanza Subgroup. Surdam (1967) placed 750 feet of tuffaceous argillite at the base of the Bonanza Subgroup. Suzuki (in Surdam 1967) indicated a lower Jurassic age for these sediments. Volcanic rocks of the Bonanza Volcanic Division conformably overlie the tuffaceous argillite. The thickness of these volcanic units is thought to be in the order of 1,000 to 2,000 feet. The age of the units may be Early to Middle Jurassic. The writer did not observe the Bonanza Subgroup anywhere in the Central Vancouver Island area but this unit was included on Figure 3 because it was the last unit that was deposited before the emplacement of the Central Vancouver Island Intrusion. According to Muller (Muller and Carson 1968) the granodiorite invaded the Bonanza volcanic rocks, but in places contact is gradational. In addition, more acidic dikes usually thought to be associated with the Bonanza volcanics cut some Jurassic Island Intrusions.

The Central Vancouver Island Intrusion

Eastwood (1968) proposed that the term "Island Intrusions" be used for the intrusions on Vancouver Island to differentiate them from those found on the mainland of British Columbia. The Central Vancouver Island Intrusion is the term used by the writer for that "Island Intrusion" that occurs in the central portion of Vancouver Island. This intrusion is of an intermediate composition ranging from a granodiorite to a quartz diorite. It is a coarse-grained, grey to pinkish grey or greenish-grey rock with its most pronounced character being the abundance of large quartz segregations in most areas. The intrusion is primarily composed of zoned plagioclase and quartz with minor potash feldspar and accessory minerals mainly restricted to hornblende and some biotite. Much of the hornblende has altered to chlorite while the plagioclase is saussuritized. The saussurite outlines variations within the plagioclase allowing the presence of zoning and twinning to be determined in the larger grains in the field.

The Central Vancouver Island Intrusion cuts all the formations in the stratigraphic column apparently with equal ease. Contact relations within any one unit were just as varied as within any other unit.

The Jurassic date based on field relationship is substantiated by isotopic age determinations. Two samples collected by Muller (Muller and Carson 1968) gave 162 ± 9 m.y. and 166 ± 8 m.y. (Wanless et al 1967). Two other determinations outside the Central Vancouver Island area gave dates of 167 ± 10 m.y. (Wanless et al 1965) and 160 ± 8 m.y. (Wanless et al 1968) for other granodioritic intrusions which appear related to the intrusive episode.

Structural Geology

The Central Vancouver Island area in the vicinity of Buttle Lake is a regionally scaled north-trending, breached anticline which has been complicated by a number of episodes of faulting and the emplacement of the Central Vancouver Island Intrusion. The anticline has been eroded to expose the stratigraphy that has been discussed in the preceding section. The axial culmination of the anticline appears to be located at the southern end of Buttle Lake (Latitude 49° 33' North, Longitude 125° 34' West). However, the general impression within the Youbou Formation of the Sicker Group is that the stratigraphic section continues to be truncated at deeper levels to the south.

Muller (Muller and Carson 1968) has suggested that the arches in the Lower Sicker Group were the depositional sites of the Buttle Lake Formation whereas the Middle (clastic) part of the Sicker Group was deposited in basins adjacent to these arches. If this is the case, the Middle (clastic) part of the Sicker Group need not be a turbidite sequence since most dips within the Sicker Group associated with the arches are gentle.

Within the Central Vancouver Island area, most folds seen were broad and open. The exception to this condition is where shear folding has taken place adjacent to faults and the intrusive contacts. The beds within the Sicker Group that can be traced, generally dip to the north, northwest, northeast, east or west. The sills within the Sicker Group conform to this generalization.

The axis of the anticline following the deposition of the Buttle Lake Formation appears to have shifted slightly from a position generally coinciding with Buttle Lake to a position east of Buttle Lake since the Buttle Lake Formation is more deeply eroded in that area.

Southeast trending faults may have been initiated at this time since the "Henshaw Formation" appears to occur along these southeast trends. Faults oriented in a northwest-southeast orientation terminate against other faults, especially northerly trending faults.

The depositional trends within the Mesozoic section and folds developed therein have a more northwesterly alignment than the underlying Paleozoic section. The Karmutsen Formation arches in a broad fold plunging to the northwest.

The Lower Mesozoic and older rocks are cut by a number of large vertical to near vertical northerly trending faults. These faults do not seem to carry through the Central Vancouver Island Intrusion but zones of joints continue on trend in some locations. Of all the slickenslides observed on the northerly trending faults none were found to plunge steeper than 20^{o} from horizontal indicating that at least the later movement was of a strike-slip nature.

Outcrop trends may be explained rather simply by invoking right-lateral movement on the northerly trending faults. If the conglomerate facies of the "Henshaw Formation" can be used as a marker, approximately eight miles of right-lateral movement may be indicated across Buttle Lake between Marble Peak (Latitude 49^{o} 42' North, Longitude 125^{o} 35.5' West) and Henshaw Creek (Latitude 49^{o} 36' North, Longitude 125^{o} 32' West). The overall outcrop pattern of the area also exhibits an equivalent amount of right-lateral separation across Buttle Lake.

Following the emplacement of the Central Vancouver Island Intrusion, another set of faults developed in the Central Vancouver Island area. The granodiorite is cut and its margins are apparently offset by a series of faults with a dominant orientation trending approximately North 77^{o} West and to a minor degree North 80^{o} East. There is apparent left-lateral separation of the intrusive contact zone across these faults. In addition, there appears to be a tilting of the blocks between pairs of these easterly trending faults. The blocks seem to tilt to the north increasing the dip of the strata in that direction. This tends to produce faulted features which resemble half-grabens, the south side of the fault having an apparent downthrown relationship. The left-lateral separations and the south side apparently being downthrown may be the result of strike-slip or oblique faulting transecting arches and shifting the axes in such a manner to give this outcrop pattern. The left-lateral strike-slip with some dip slip component is favored because the less steep western margins of the intrusion seem to have a greater separation across the faults than the steeper dipping eastern margin. Within the granodioritic intrusion and in the surrounding country rocks a pronounced northeast-southwest nearly vertical joint system is developed.

The Central Vancouver Island Intrusion has intruded the axial and western portions of Vancouver Island along a trend which is approximately North 30° West. This is the linear trend of the eastern margin from Great Central Lake (Latitude 49° 25' North, Longitude 125° 10' West) to Nimpkish Lake in Northern Vancouver Island (Latitude 50° 25' North, Longitude 127° 5' West). Along the eastern margin of the Central Vancouver Island Intrusion this trend is modified by the tendency of the granodiorite to have intruded to higher stratigraphic positions and also higher elevations along synclinal axes within the Sicker Group. By the same token, anticlinal axes are intruded to lower stratigraphic positions and lower elevations. Since the Sicker Group is aligned with northerly plunging fold axes the Central Vancouver Island Intrusion developed cupolas and arms into the batholith along the trends of the synclinal axes and roof pendants and septa along the anticlinal axes. To the north and also to the west of the area investigated, the northerly is the dominant trend of the Central Vancouver Island Intrusion. The overall trend of the Central Vancouver Island Intrusion crops out as a large "X" tilted to an overturned position to the northwest (Refer to Figure 1). It is not known whether the conditions mentioned above apply to the other arms of the intrusion.

The interpretation of intrusions invading into the axes of synclines is in general agreement with the conditions that occur elsewhere along the Insular Belt of British Columbia (Sutherland Brown 1966).

METHODS OF INVESTIGATION

Field Investigation

The three month field seasons during the summers of 1963 and 1964 were spent mapping and sampling in the Central Vancouver Island area. A little less than one half of the time was spent within and along the contacts of the Central Vancouver Island Intrusion during this period. The remainder of the time was spent mapping the distribution and structural relationships of the country rocks within the area. As was mentioned in the Introduction, the major previous work carried out within the area was done by Gunning (1931). He produced a map of the Central and East Central portion of Vancouver Island on a scale of one inch to eight miles. This map delineated three map units, two within the central portion and one more on the east central portion. These units were the Intrusive, the country rock, and the overlying Upper Cretaceous sediments.

Since there were no other maps available at the beginning of the mineral evaluation project, one of the tasks assigned to Dr. W. G. Jeffery was to establish a stratigraphic succession and map the area in addition to running a geochemical survey to aid in evaluating the mineral potential of the area. During the summer of 1963, emphasis was placed on working out the relationships within the Sicker Group using the limestone at the top as a marker. Because of the remoteness of the intrusion, a minor amount of field work was done in the intrusion except around the Myra Creek (Latitude 49° 34' North, Longitude 125° 37.4' West) and Mount Myra (Latitude 49° 32.6' North, Longitude 125° 36' West) where most of the mineral exploitation activity was taking place. Additional investigations were carried out southwest of the areas just mentioned in the Tennant Lake area (Latitude 49° 33' North, Longitude 125° 38.4' West). Samples and observations were taken on a random basis as changes occurred in the granodiorite. Changes which prompted special note were: (1) compositional changes (2) textural changes (3) changes in xenolith abundance (4) fracturing and faulting orientations (5) intrusion of dikes.

Jeffery produced a preliminary geological map of the Buttle Lake area as a result of the field work carried out in 1963.

During the 1964 season the boundaries of the area of investigation were extended to the east, west and south. Dr. Jeffery concentrated on the mineralogical and economic aspects of the area in addition to the general mapping of the area. In the course of the natural disposition of duties it befell the writer to concentrate on the intrusive bodies in the area besides other general mapping duties.

In the course of the 1964 field season, the western end of Great Central Lake (Latitude 47° 23' North, Longitude 125°

25' West) was investigated and sampled on a random basis. During the same period, the McBride Lake, Halo Hill area (Latitude 49° 25' North, Longitude 125° 28' West) was traversed and sampled on a random basis. The Bedwell Lake area (Latitude 49° 31' North, Longitude 125° 35.5' West) was investigated in a similar manner to the previous areas.

The Myra Creek area was reinvestigated and the contact area was roughly plane tabled. Samples were chosen from selected points from within the plane-tabled area. The Burman Lake area (Latitude 49° 38.5' North, Longitude 125° 45' West) was investigated in a combination of ways. The contact area where the intrusion cuts the Sicker Group, the gabbroic sill within and above the Buttle Lake Formation, the Buttle Lake Formation and the lower portion of the Karmutsen Formation was roughly plane-tabled and selectively sampled. The areas more distant were investigated and sampled on a more random basis.

Preliminary petrological studies of the samples collected in 1963 and 1964 indicated that more concentrated sampling was necessary to round out the study, so during 1965 the sampling technique was modified. In addition to random sampling, a grid sampling program was planned.

Prior to the initiation of the grid sampling in 1965, the areas of random sampling were filled in. The area around Mount Myra was reinvestigated and selected features were sampled. The area around Leader Lake, south of Mount Nine Peaks (Latitude 49° 25' North, Longitude 125° 33' West) was visited and observations of the contact relations were made.

The linear traverse across the Central Vancouver Island Intrusions was initiated in 1965 to investigate variations that might occur across from the batholith to complement those observations made along the eastern margin of the intrusion. The only readily accessible area in which a linear traverse might be undertaken was the Elk River road. This road was a private logging road which was useable to a limited extent during weekends when logging operations were curtailed. The plan was to collect samples at an optimum one half mile interval within the intrusion. The traverse ran from the eastern margin of Central Vancouver Island Intrusion (Latitude 49° 50.1' North, Longitude 125° 50' West) eleven and one half miles southwest along the road to the western margin of the intrusion in the vicinity of Latitude 49° 43' North and Longitude 126° 06' West. This traverse has been designated Number 10 on Figure 2. Since the road followed the valley floor through this mountainous terrain, outcrops did not occur as regularly as might have been expected and sampling distances varied from the planned one half mile interval.

From the country rock exactly fourteen miles west-southwest of the corner where the Elk River road leaves the North-South portion of Campbell Lake and turns west following the western arm of Campbell Lake, the first sample was taken. Succeeding samples were taken at the following intervals: 1, 1.1, 1.1, 0.6, 0.9, 0.4, 0.2, 1.0, 0.9, 0.6, 1.8, 0.5, 0.5, and 0.5 miles.

The grid sample area chosen for this study was situated at the western end of Great Central Lake. This area was chosen for the following reasons:

1. The area was near the roof of the intrusion providing a number of contact zones.
2. The area had moderate relief for Central Vancouver Island. This relief was only 2,000 feet instead of the usual 4,000 to 5,000 feet in other areas.
3. The intrusion cut the Sicker Group as well as the Karmutsen Formation in the area.
4. The granodioritic intrusion was moderately accessible within the area.

The grid that was developed for the western end of Great Central Lake was established on a trial and error basis. The goal was to develop the smallest spacing that would span the natural topographic features of the area and not leave gaps at inaccessible points. The "best fit" that resulted produced a minimum natural spacing of 4,100 feet or 1.25 kilometers.

The orientation of Great Central Lake controlled the orientation of the grid once the minimum spacing was established. The columns of the grid were oriented nine degrees east of north and the rows were set up perpendicular to the northerly columns. The columns were given number designations with "1" being the most westerly column and "10" the most easterly. The rows were given letter designations, with the southern most row being designated "A" and the northern most row being designated "H".

Fifty-six locations on the grid were visited and fifty-one were sampled. Five locations were found to have outcrops of country rock or no outcrop. Of the remaining grid locations, three locations were situated within Great Central Lake, one location was relatively inaccessible and the rest were with questionable certainty outside the outcrop boundaries of the intrusion. The locations sampled in the gridded area resulted in a pattern of coverage indicated in Figure 5.

At each grid location within the granodioritic intrusion, the orientation and relative frequency of the fractures were recorded and optimumly five hand specimens were collected. Field observations had indicated that the coarse-grained nature of the intrusion, the tendency for the minerals to clump together, and the variations within the intrusion caused by the assimilation of xenoliths made it mandatory to assure representative samples from each location. The plan for sample collecting called for one specimen to be collected from each grid center and four more specimens to be collected around the grid center on a fifty foot radius. In most instances, the goal of five specimens from each location was attained.

The specimens from the areas which were sampled randomly and those from areas which were sampled selectively either for specific features or to fulfill the requirements of the grid layout, were set for laboratory investigation.

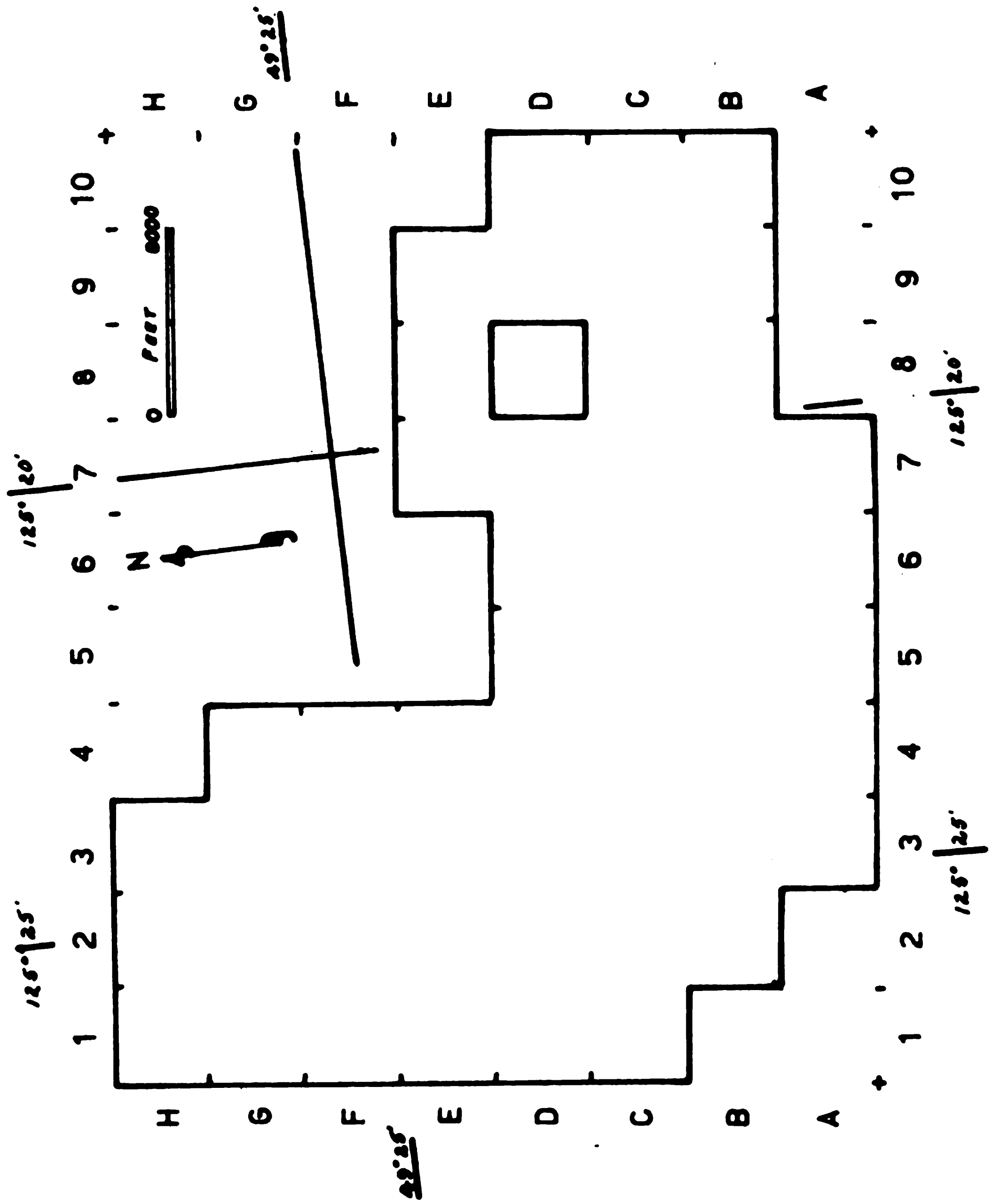


Figure 5 Layout of the Grid-Sampled Area at the Western End of Great Central Lake

Laboratory Investigations

The specimens collected in the course of the field investigations were prepared in a number of ways for subsequent study. At least 180 specimens from throughout the area were cut and thin sections were prepared for petrological studies. Included in this number was one thin section from each grid center from the grid samples area around the western end of Great Central Lake and one thin section from each specimen location along the linear traverse through the arm of the intrusion along the Elk River road. Most of the thin sections were made on standard one inch by two inch glass slides, but a number showing special features were prepared on two inch by four inch slides.

The slides were acceptable for qualitative work, illustrating textures, examining grain boundary conditions, checking the mineral constituents of the rock and checking for the progression of alteration. The slides were not adequate for quantitative work. Mineral segregations in excess of one centimeter across or 0.4 inch allowed only two to six such segregations to be noted across the width of a slide.

The grid sampled area and the linear traverse was designed to alleviate this problem in a specific area. In the grid-sampled area each of the five specimens, if five were available, was slated for X-ray and X-ray fluorescence analysis. In preparation for these analyses, each rock specimen was trimmed to remove any weathered surfaces. The specimen was trimmed on a granite slab using a one pound hammer. Care was taken not to contaminate the specimens. The three-quarters to one-half pound specimens (approximately 175 grams to 225 grams) were reduced to approximately three ounces (approximately eighty grams) of pebble-sized fragments (Wentworth scale). These fragmented specimens were stored in glass containers with enamel lined rubber-gasketed, metal lids. The pebble-sized fragments were subsequently ground in a hand-driven, laboratory mill (Straub Serial F4, Curtin No. 6224) with a dry grinding worm feed and fine, cast iron grinding plates.

The pebble-sized fragments were ground to very fine to coarse-grained sand-sized (Wentworth scale) material in the mill. The mill was vacuum cleaned after grinding each sample and after the grinding of all five samples from a grid location, the mill was completely disassembled and cleaned by brushing and vacuum cleaning.

Approximately two ounces (fifty-six grams) of sand-sized material resulted from this stage of sample preparation. Again this material was stored in glass containers in the same manner as the previous stage. The material was mixed and approximately five grams were withdrawn from the ground material. This five gram sample from each original 175 gram to 225 gram specimen was ground in a porcelain mortar and pestle (Coors U. S. A. No. 622-3 and No. 62215). The mortar and pestle were cleaned after each grinding. The resulting powder was in the range of very fine silt-to-clay-sized particles.

The very-finely ground material was stored in paper laboratory envelopes until such time as the capsules were prepared for the X-ray and X-ray fluorescence analysis.

One sample from each grid location was split in half for "spiking". The samples were "spiked" in the following manner. That portion of the sample that was chosen for "spiking" was weighed on a laboratory scale accurate to at least three decimal places (in grams) and the fourth decimal could be estimated. To this weighed sample, approximately ten percent by weight of the weight of the combined quantities was added in the form of NaCl. Most of the samples were "spiked" with nine to eleven percent NaCl but one sample was "spiked" with a quantity as low as 4.83 percent by weight and another as high as 22.38 percent by weight. The "spiking" was done to provide additional control for peak height intensities and aid in the determination of minerals. The spiked samples were not used in the X-ray fluorescence studies.

The samples from the linear traverse across the intrusion were not "spiked". One sample from each locality was prepared in a similar manner to those that were taken from the grid-sampled area except no NaCl was added to any of the capsules. The capsules were prepared in the following manner. The capsule was filled and packed with micro-granular cellulose, sold under the trade name of Avicel. The sample was mixed and a thin layer of sample or "spiked" sample was spread over the whole surface of the Avicel in the capsule. The capsule was mounted in a forming piston and approximately two tons of pressure were applied by a hydraulic press. Two successive cycles were applied to each capsule and its contained sample. The capsule was compressed from a height of five-sixteenths of an inch to approximately one-eighth of an inch while the diameter was kept constant. Both the X-ray machines and X-ray fluorescence unit were designed to accept the resulting capsules.

Two different machines were used during the course of the X-ray analyses. The bulk of the analyses were run on a fully automated modified General Electric X-ray machine while additional samples were run on a Rigaku Denki X-ray machine which was partially automated.

The General Electric machine was a standard model, except the goniometer had been exchanged with a Rigaku Denki goniometer so the automated equipment could be attached. Fifty to eighty samples could be run without interruption. The General Electric base and copper targeted X-ray tube were supplied through a General Electric power supply. The goniometer had been modified to accept the General Electric detector which was linked to a General Electric strip chart recorder.

The second X-ray machine was a Rigaku Denki X-ray supplied with power through a Rigaku Geigerflex power supply which also supplied power to the X-ray fluorescence unit. The detector and strip chart recorder were also manufactured by Rigaku Denki. This second machine was not fully automated at the time the samples were run.

The X-rayed samples were scanned at 2^{o} per minute for $2\theta^{o}$ from 2^{o} to 60^{o}. The copper tube was excited at forty kilovolts and twenty-five milliamperes. The recorder was set in the manner in which whole rock analyses were usually run on this machine. The range on the recorder panel was set at 500 counts per second, the time constant was set at 1.0, the scale was linear over a range of ninety-two units and the rate meter was set within the range of nineteen to twenty.

Approximately 320 records were obtained from X-rayed samples and standards. A novaculite standard was placed at the beginning and end of each automated run to ensure that the machine maintained its alignment and to check that the combination of power and detected signal remained relatively constant over the length of the run. If the run contained numerous samples, additional novaculite standards were arbitrarily inserted into the body of the run. Novaculite standards were also used at the beginning and end of the partially automated runs on the Rigaku Denki machine.

The X-ray fluorescence analyses were run on one sample from each grid location in the Great Central Lake area and from one sample from each location point on the linear traverse across the Central Vancouver Island Intrusion along the Elk River road. From the gridded area, one sample from each location was chosen on the basis of an average composition as determined by the X-ray analysis or field notation. Where a capsule had been damaged in the X-ray analysis, the next nearest sample was chosen from that location. From the linear traverse across the intrusion only one run was X-rayed and the same sample was subjected to X-ray fluorescence analysis.

The X-ray fluorescence analyses did not utilize any internal standard or dilution techniques. The determinations were made by direct comparisons from plots of known standards which were analyzed separately in sequence with the unknowns from the intrusion. For this purpose, standards known as G-2, GSP-1 and W-1 were run in addition to a blank Avicel capsule.

The X-ray fluorescence analyses were run on a Rigaku Denki unit (Serial No. 120037) which was coupled to a Rigaku Denki X-ray as was mentioned earlier. The power supply was the Rigaku Denki Geigerflex unit and the strip chart recorder was a Rigaku Denki unit also. The tube in the X-ray fluorescence unit was a chromium targeted tube. The tube was excited at forty kilovolts and twenty-five milliamperes. The detector was a scintillation counter. The control panel was set up in the following manner. The gain was set at thirty-two, the mode in R. M. (rate meter), the base line was set at ten, the channel width was 700, the count was by integration and the time constant was set at one. For all runs, the multiplier was set at twenty times. However, when a peak intensity ran off the chart that peak was re-run with the multiplier set at forty times. This effectively cut the recorder peak height in half on the strip chart. All samples were analyzed in a vacuum of approximately two to four millimeters of mercury pressure. The samples were scanned from 10^{o} to 56^{o}. The sample began to fluoresce at 10^{o} with a chromium tube but did not reach maximum fluorescence until the vicinity of 15^{o} depending on the matrix. Because of this high threshold K peaks could not be detected, with certainty, for elements with atomic numbers greater than forty-seven (silver). Peaks from elements beyond silver to those elements with atomic numbers up to fifty-seven (barium) might be detected if they were present in large enough quantities.

X-ray fluorescence analyses were performed on approximately sixty-five samples. Four standards were run and approximately eight samples were duplicated with elevated base lines. The eight analyses with the elevated base lines were used only for comparison.

Reduction of Data

The petrological data were accumulated by standard petrological techniques. The identification of minerals in thin sections was based on their optical properties under varying conditions as described in Petrographic Mineralogy (Wahlstrom 1955). The properties determined during the examination of the thin sections were as follows: extinction angles, index of refraction, birefringence, cleavage, habit, twinning, zoning, grain size, color, optic orientation, optic angle, optic sign, and interference colors. A number of different petrographic microscopes was used in the course of the study.

Photomicrographs were taken of approximately 124 of the thin sections. Approximately forty percent of the photomicrographs were in color and the rest were in black and white. The photomicrographs were arranged spatially so trends might be observed and comprehended with relative ease.

Visual estimates were made of the relative abundance of the component minerals but mineral counts employing techniques similar to those developed by Chayes (Chayes 1949, 1956) and others were not used because the size of the grains relative to the area of the thin section slides would not permit large counts to be taken. Field observations indicated that the scale of homogeneity was greater than the size of most hand specimens that could readily be collected.

The quantitative determinations of mineral abundance were performed on the specimens from the grid sampled area by X-ray analyses. The grid sampled area was assumed to be representative of the Central Vancouver Island Intrusion. The semi-quantitative determinations of mineral abundance from specimens obtained along the linear traverse across the intrusion were also performed by X-ray analyses.

The minerals identified in the petrological study were verified on the X-ray records using the Inorganic Index to the Powder Defraction File, ASTM Publication P. D. 1S-171 (Smith 1967 Ed.) and Calculated X-ray Powder Patterns For Silicate Minerals (Borg and Smith 1969). A sample of the form of X-ray record with the identified peaks is shown in Figure 6. This pattern is from within the granodioritic intrusion on the west side of the large roof pendant, 5.3 miles west-southwest of the first specimen on this traverse. There are no NaCl peaks on the record since no internal standards were added to specimens from the linear traverse.

The analyses of the grid sampled area were planned to have been performed in the manner described by Alexander and Klug (1948) utilizing the NaCl "spike" as an internal standard. The standards were prepared on a volumetric basis to give at least six points over a large spread of volumetric percentages. From these volumetric percentages, it was anticipated that ratios of X-ray peak intensities might be calculated for each mineral present in the samples. The volumetric standards proved unsatisfactory since packing could not be controlled closely enough. Weight percentages were substituted for the volumetric percentages.

Ideally, according to the Alexander and Klug internal standard technique, as also described by Azaroff and Buerger (1958), a number of different proportions should be mixed and run for each matrix. With a minimum of 250 samples in the grid-sampled area, this technique might conceivably run to over 1,000 records with approximately six minerals per record. To by-pass this great bulk of records, the internal standard was interpolated against average compositions from the whole area to establish general peak intensity trends. From these studies it was found that the peak intensity ratios

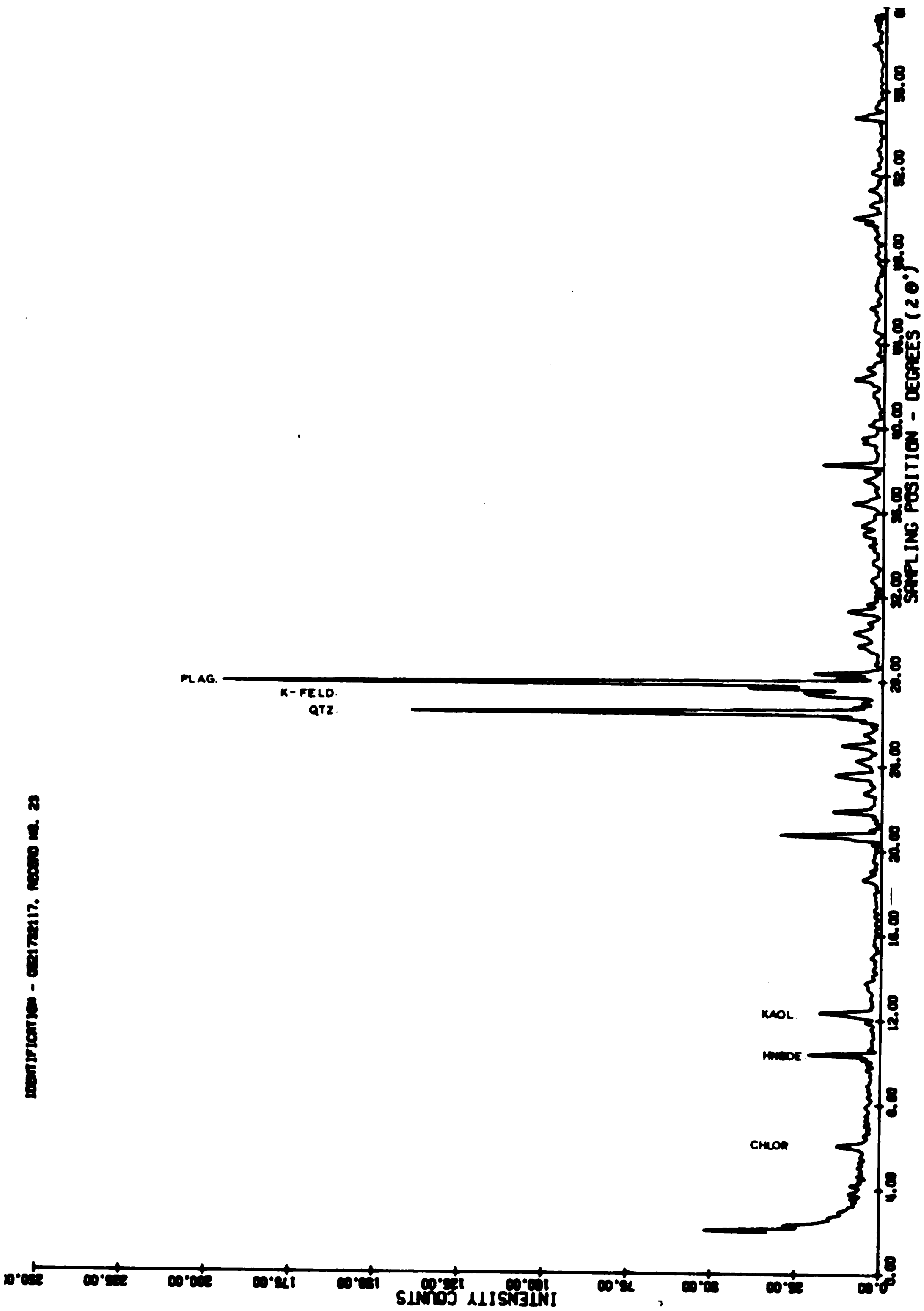


Figure 6 Sample X-ray Record with Mineral Peaks Identified

varied linearly for the major peaks of the different mineral. The linear ratios of intensity changes used in this study were approximately as follows:

$$\frac{I(NaCl)}{I(Quartz)} = 2.0, \quad \frac{I(NaCl)}{I(Plagioclase)} = 2.66, \quad \frac{I(NaCl)}{I(Hornblende)} = 2.0$$

$$\frac{I(NaCl)}{I(K\text{-}feldspar)} = 2.1\text{-}2.6?, \quad \frac{I(NaCl)}{I(Chlorite)} = 2.3?, \quad \frac{I(NaCl)}{I(Kaolinite)} = 1.33?$$

The K-feldspar, chlorite, and kaolinite were somewhat erratic in their distribution and their abundances were relatively low in most of the samples causing some uncertainty in their ratios.

Duplicate runs were made on some samples to verify unusual records and occasionally a sample which had become jammed in the sample changer inadvertantly resulted in multiple records from a single sample. In one such instance of a multiple run, when six repetitions occurred, the absolute peak intensities of one mineral within the sample varied by eleven percent above and below the mean value. When peak intensity ratios relative to other peaks on the record were calculated, the spread of variation between records was reduced to within eight percent of the mean value. These values indicate the best precision that might be expected from these X-ray determinations and it is probable that the precision is less than this example.

To increase the precision all the internal standard peak heights were plotted against their weight percent within the samples. The best straight line was fitted through the points by trial and error and was tested by an approximate least squares method. The best-fit indicated that for ten percent by weight of NaCl, the chart recorded twenty-three units as shown on Figure 7. This linear relationship was used to compare ratios of peak intensities and to adjust records which, for some reason, had anomalously high or low peak intensities for all minerals. The linear traverse across the Central Vancouver Island Intrusion was X-rayed without internal standards. The records were reproduced from magnetic tape and plotted by computer. The proportions of minerals in these samples were determined by measuring the absolute peak intensities and adjusting the values according to the ratios used in the grid-sampled area.

The X-ray fluorescence analyses were run without the benefit of internal standards. The identification of the elemental peaks was accomplished by comparing the peak position with the positions compiled by Powers (1960) for the appropriate analyzing crystal. A lithium fluoride analyzing crystal was used throughout the analyses.

The quantitative determinations were performed by comparing the peak intensities of the various elements within the samples with the peak intensities from standards which were run in sequence with the unknown samples. The background was removed by subtracting the straight line continuation of the background from the peak intensity under study. A straight line plot of the peak intensities against quantity of the element contained, was plotted for each element investigated. The values used for elements in U. S. Geological

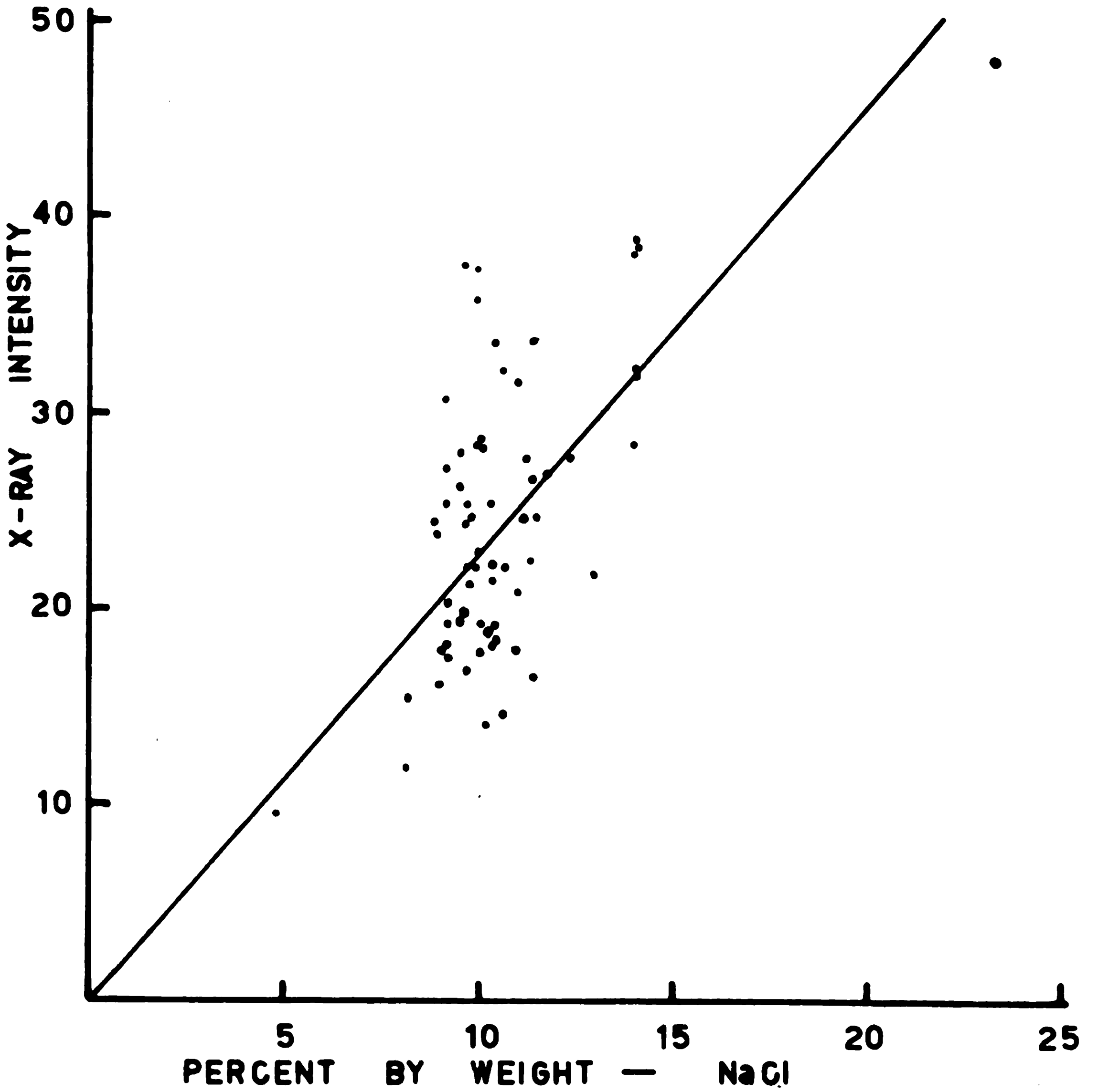


Figure 7 Peak Intensities vs Percent by Weight for the Internal Standard NaCl

Survey standard W-1 were those suggested by Fleischer (1968) in his compilation. The values used for elements in U. S. Geological Survey standards G-2 (split 75, position 27) and GSP-1 (split 41, position 7) were the average values compiled by Flanagan (1968).

The blank standard of "Avicel" indicated that the X-ray fluorescence tube contained impurities of undetermined amounts within it. These impurities within the range scanned were as follows: silver, paladium, molybdenum, lanthanum, tungsten and copper. The peaks from these elements remained relatively unaffected when other samples were analyzed. Within the standards, expecially W-1, when higher quantities of an element indicated as an impurity were encountered, the peak intensities were reduced rather than increased. This indicates that matrix and absorption effects of the denser sample dominated over excitation of the element in the standard. The samples are assumed not to have had appreciable quantities (estimated at greater than 200 ppm) of the elements which also occurred as impurities in the chromium tube.

The master plots for the peak intensities relative to the quantity of a particular element in the standards are found combined on Figure 8. Zirconium, Strontium, Rubidium and Iron related to percent Fe_2O_3 were the only trace elements detected in the X-ray fluorescence study between $10^\circ 2\theta$ and $55^\circ 2\theta$.

Iron was present in such great abundance that half scale readings had to be taken on approximately thirty percent of

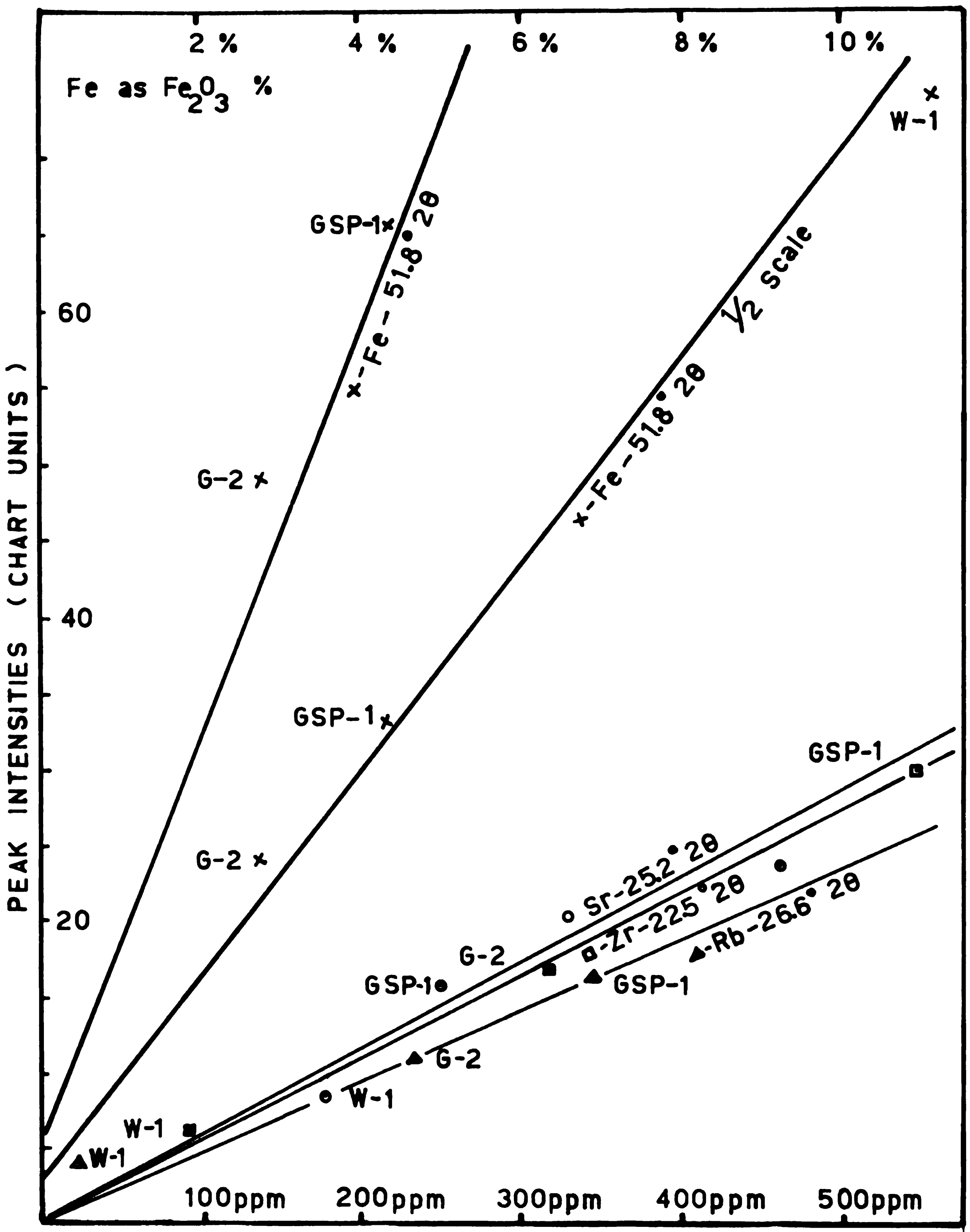


Figure 8 Master Plot of Elements in U. S. Geological Survey Standards

the records. Both scales are represented on Figure 8.

The X-ray fluorescence unit as it was operated for this study was probably capable of detecting 50 ppm of an element utilizing $K\alpha$ peaks and was less sensitive to $K\beta$ and L series peaks. It is inferred from this that the following elements were present in amounts less than 50 ppm:

Rhodium, Ruthenium, Technetium, Niobium, Yttrium, Krypton, Bromine, Selenium, Arsenic, Germanium, Gallium, Zinc, Nickel and Cobalt.

OBSERVATIONS

Physical Contact Relationships

Burman Lake Area

In the area one quarter of a mile north of the north shore of Burman Lake, the Central Vancouver Island Intrusion cuts through approximately 4,500 feet of stratigraphic section representative of the upper part of Sicker Group and the lower part of the Vancouver Group. The strata in this locality strike approximately North 20^{o} East and dip 30^{o} Northwest. The intrusion cuts there approximately at right angles to the strike with a near vertical contact zone. Figure 9 illustrates the contact relationships in a very small area relative to the contact relations along the whole zone. The contact is remarkable for the fact that there are very few reentrants either in the country rock or within the granite. The country rock is composed of six quite different lithologies of varying chemical composition and different mechanical properties. The andesitic tuff, breccia, and agglomerate of the Youbou Formation are at the base of this section. A thin sequence of the middle (clastic) part of the Sicker Group may possibly be present though it was not seen. The limestone of the Buttle Lake Formation occurs above the andesites. It is split into a number of layers by the intrusion of a gabbroic silt. Above the Buttle Lake Formation is a thin section of green and slightly purplish sediments which may represent the "Henshaw Formation" grading upward into the lower siliceous sediments of the Karmutsen Formation. The gabbroic to amygdaloidal flows intercalated with the siliceous to cherty argillites are overlain by the great thickness of pillow lavas making up the bulk of the Karmutsen Formation.

As is illustrated in Figure 9, two large xenoliths of limestone are caught against the granodiorite at the eastern end of the outcrop map. It is not known whether the gabbro intrusion moved them into this position or if they were dragged down into this position by the granodiorite. It seems more likely that they were moved by the gabbro and the granodiorite intrusion fortuitously stopped at this location. The limestone xenoliths are very coarsely recrystallized (one half inch crystals) and are very friable. There appeared to be almost no silica alteration. Tremolite or wollastonite were questionably identified in one hand specimen. Because of its friable nature specimens were difficult to obtain.

In contact with the gabbroic intrusion, there is a zone of more dioritic material which appears to be incorporated into the granodiorite. Dacitic dikes intrude the gabbroic sills in these locations. The mixed dioritic zone next to to gabbroic sills and flows also occur, further west directly north of the mid-point of Burman Lake along the contact. This mixed zone of dioritic rock is surrounded by "quartz-eye"

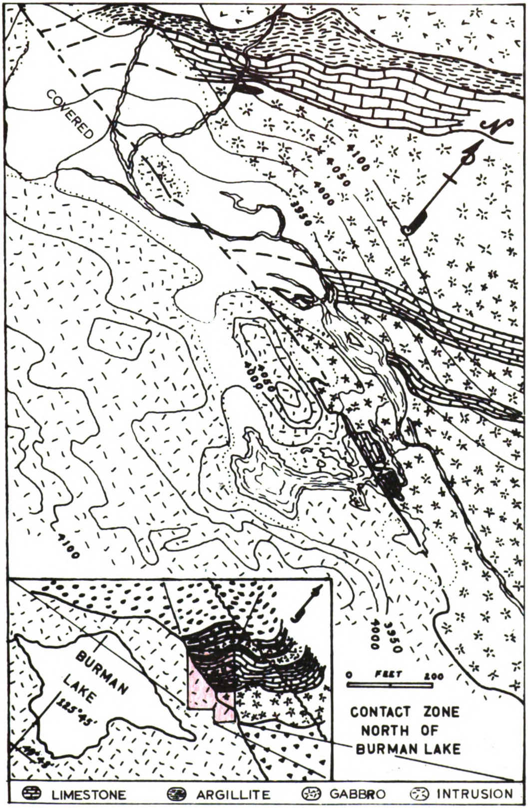


Figure 9 Contact Zone North of Burman Lake

granodiorite.

At the east end of Burman Lake, the granodiorite becomes rich in dioritic xenoliths while the ground-mass becomes rich in quartz segregations.

At the west end of Burman Lake north of the outlet, the contact between the granodiorite and the pillow lava trends North 72° East dipping 85° Northwest. At this one small locality the contact may be sharp over one inch or gradational over ten feet.

The rocks to the north of the contact between the Karmutsen Formation and the Central Vancouver Island Intrusion for distances up to or exceeding one mile are cut by dikes of dacite porphyry, granodiorite and felsitic material. The gabbroic sills and flows exhibit the same character.

The contact between the country rock and the granodiorite becomes highly faulted to the southeast. Along this belt, the granodiorite is in contact with the upper part of the Youbou Formation and the overlying Buttle Lake Formations with its included sills. The slight metamorphism of the contact zone may have indurated the country rocks slightly since the zone of contact stands like a wall to form a ridge between the area of Sicker Group Outcrops and the Central Vancouver Island Intrusion. A few small dikes of quartz dioritic composition intrude the Youbou Formation to the east for distances of less than a mile. Within the granodioritic intrusion on the north shoulder of Mount Burman, there is a grey weathering dike of unknown composition which trends northeast to southwest across the intrusion at moderate dips. This dike may represent an auto-intrusion or a later period of intrusive activity.

Myra Creek Area

Northwest of Myra Creek, the Central Vancouver Island Intrusion is in contact with the Youbou Formation and the Buttle Lake Formation and its intruded sill. Approximately one and a half miles north of the creek at Latitude 49° 35' North and Longitude 125° 39' West, the exposures reveal slightly deeper stratigraphic levels of the Youbou Formation. At this point the granodiorite comes in contact with a gabbroic sill. Subparalleling this sill is a small amount of dioritic rock which invades the country rock for slightly over one half mile. Outcrops are poor and the exact nature of the contact is in doubt.

At first appearance, the contact along the north side of Myra Creek looked to be fault controlled but on closer examination, it is seen that the contact is quite sharp and granodiorite occurs on both sides of a zone of fractures. Plate II illustrates the general setting of the contact in Myra Creek. The light grey rocks in the foreground are granodiorite. There seems to be a natural break in the rocks where they become dark green just below the weathered tree with the geologist on it. However, on closer inspection, lighter granodioritic rocks may be seen above the undulating fracture zone.

Plate III is a closer view of this exposure. The natural

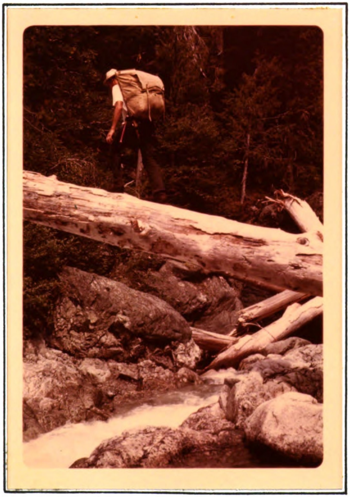


Plate II General setting of the contact between the Central Vancouver Island Intrusion and Sicker Group rocks in Myra Creek break mentioned earlier is directly above and parallel to the lower margin of the illustration. The hammer in this illustration is still within granodioritic material while the contact runs obliquely from the upper left corner to the lower end of the log in the background. The rock above this contact is a massive greenstone which within a few tens of feet may be recognized as an andesitic tuff. The contact at this point strikes North 40° West and dips 40° to the Northeast. In places the dip becomes as low as 15° to the Northeast and to the south the contact becomes North-South.

Plate IV is a closer view of the same outcrop. The photograph was taken from the point where the log is in Plate III looking at the other side of the outcrop shown in Plate III. The weathered branches in the foreground of Plate IV are approximately two to three inches in diameter. The contact can be seen as it emerges from the water obliquely up to the left where it is obscured by the shadow of the overhang. The contact is very sharp over distances of fractions of an inch. There appears to be a slight concentration of platey minerals along the contact.

Small apophyses begin to develop along the contact in the vicinity of Myra Creek. These apophyses are subparallel to the contact and parallel to a weak foliation in the country rock.

Plate V shows a very small apophysis in the greenstone. A small, apparently detached epiphesis of granodiorite can be seen just beyond the end of the apophysis.

Plate III Contact between greenstone and granodiorite above the fracture zone

Plate IV Sharp contact between greenstone and granodiorite

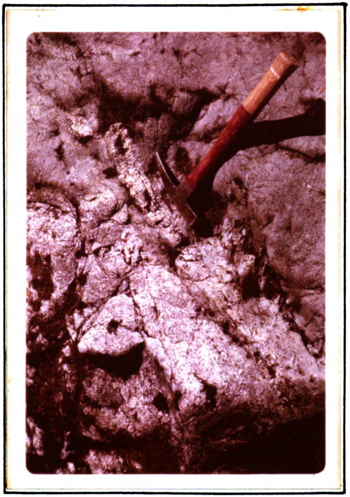


Plate V Small Apophysis of Granodiorite in Greenstone

Approximately 100 feet to the east of the contact is a vertical North-South striking dike of dioritic to gabbroic composition. Three-quarters of a mile south, a similar dike is found on strike within the granodiorite and two more are found on strike an additional mile to the south.

Mount Myra Area

On the north slopes of Mount Myra, between 4,500 feet and 5,500 feet above mean sea level, the granodiorite extends eastward into the Youbou Formation. The north and south boundaries of this protrusion appear to be fault bounded. In addition, the country rock is invaded by a number of generally East-West trending dacitic dikes. A few of these dikes penetrate to the eastern slopes of Mount Myra. The area resembles a series of large and small apophyses extending the Central Vancouver Island Intrusion eastward toward an isolated stock at the head of Henshaw Creek east of Buttle Lake (Latitude 49° 32' North, Longitude 125° 28' West). A small outcrop of dark red monzonite was found on the east side of the valley one half mile south of the south end of Buttle Lake.

South of this protrusion of granodiorite on the western slopes of Mount Myra, the contact between the Central Vancouver Island Intrusion and the Youbou Formation becomes highly sheared with the country rock taking on the appearance of a migmatite. Veins of "acidic" material are injected into the greenstone in a number of orientations. The greenstone appears to contain xenoliths of more crystalline acidic material near the contact. Apophyses of fine-grained foliated granodiorite are injected into the sheared greenstones and septa of the greenstone are isolated within the granodiorite.

Plate VI illustrates the above conditions. Just to the right of the geologist is a mottled pseudo-xenolithic zone within the greenstone. These are thought to be sheared zones of injected and partially replaced tuff. The intensive veining is visible in the sheared greenstone to the right and behind the geologist. Shear planes are visible behind the geologist as near vertical surfaces extending directly away from the viewer. Apophyses of granodiorite and septa of greenstone are visible to the left of the geologist.

On close examination the Youbou Formation was found to be shear folded into isoclinal altitudes near the contact. Minor gabbroic sills were boudinaged into the isoclinal folds and the matrix was changed into a sheared porphyroblastic texture. The porphyroblasts appeared to be pyroxene or a mineral pseudomorphic after pyroxene. The isoclinal fold axes were North-South and nearly vertical with the axial line almost horizontal. The isoclinal folds died out rapidly to the east and within one half a mile the country rock was again recognizable as an andesitic tuff with nearly horizontal bedding planes.

The eastern peak of Mount Myra contained a thin layered sequence of black argillite and limey beds. It is not known where these rocks fit into the stratigraphic section. They

Plate VI Sheared Contact Between Granodiorite and Isoclinally folded Greenstone on Mount Myra may be part of the middle (clastic) part of the Sicker Group or they may be from middle of the Youbou Formation as set out in Table I.

Tennant Lake Area

On the western ridge of Mount Myra extending to the head of Tennant Lake is a complex of dioritic to granodioritic aspect which has been cut by a few younger dikes of diorite, and feldspar porphyry of andesitic composition.

The composition of the Central Vancouver Island Intrusion at some places varied in composition on opposite sides of the dikes. In one instance, the composition varied from a quartz diorite on the west to a quartz rhyolite porphyry on the east.

The main character of the intrusion in the Tennant Lake area is the great abundance of xenoliths in the zone between Tennant Lake and the Mount Myra contact. In some areas, xenoliths comprise seventy percent of the outcrop. As one proceeds away from the contact, the xenoliths become less numerous and more obscure until at the last stages of recognition, there are slight concentrations of mafic minerals within the granodiorite. Exceptionally large xenoliths may be found a great distance from the margin. One six foot by one foot xenolith was found two miles from the eastern contact.

Field observations indicate that the abundance of quartz increases toward the margins of the intrusion and the size of the quartz segregations increases toward xenolithic zones.

Plate VII illustrates the concentration of xenoliths within the granodiorite at some localities. The geologist

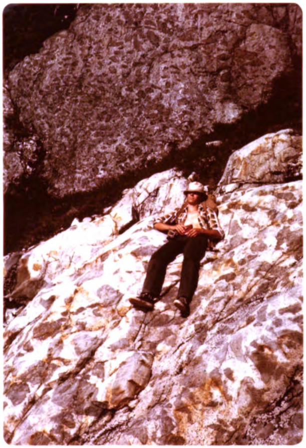


Plate VII Concentration of Dioritic Xenoliths in Granodiorite Southeast of Tennant Lake is reclining on a freshly exposed surface while a weathered surface may be noted in the background. The xenoliths in this one outcrop vary in their degree of assimilation but are primarily of dioritic composition. Some of the xenoliths seem to be physically separated from adjacent xenoliths by the parallel injection of quartz rich granodioritic material while others seem to be rotated out of their fitting positions. There appears to be a crude sub-horizontal alignment to the xenoliths on the weathered surface and the concentration of the xenoliths tends to vary in bands also.

Thelwood Lake Area

The Thelwood Lake area in the valley south of Tennant Lake is characterized by a xenolithic granodiorite in which the xenoliths have been assimilated to such a degree that they appear ghost-like in the ground mass. Near the eastern end of Thelwood Lake the injection of quartz rich granodiorite has broken out large xenolithic blocks over five feet across. The quartz rich granodiorite may be only one inch wide between the adjacent blocks and composed of over fifty percent quartz in large segregations while the blocks show very little evidence of assimilation. Eastward, the country rock is predominantly an altered tuff which has taken on the appearance of a diorite.

The increase in quartz content around xenoliths and near the contact zone is also visible to a lesser degree around individual xenoliths within the granodiorite. Plate VIII illustrates the increase of leucocratic material around a

Plate VIII A Halo of Leucocratic Material Around A Dark Xenolith small xenolith on a fresh exposure. The halo extends around the inclusion for distances that may exceed an inch. This xenolith is much better defined than most xenoliths in the Thelwood Lake Area.

The dikes which cut through the Myra Creek and Tennant Lake areas continue southward past Thelwood Lake.

The Bedwell Lake Area

The Central Vancouver Island Intrusion is characterized by a slightly more basic composition in the area around Bedwell Lake. Most of the features described in the other areas may be found in the Bedwell area. Migmatized zones similar to Mount Myra may be found to the northeast of Bedwell Lake. A series of satellite stocks line up in a direction toward the large stock at the head of Henshaw Creek. A series of acidic dikes cut the country rock between Bedwell Lake and the Henshaw Creek Stock. Some of these are found on the ridge between Price and Thelwood Creeks.

The proportion of xenoliths increases in the quartz diorite to granodiorite south of Bedwell Lake. They seem to be more concentrated along a line following Latitude 49^{o} 29' North from Longitude 124^{o} 34' West to 124^{o} 37' West.

McBride Lake - Great Central Lake Area

The southern end of the study area is dominated by a structural grain which aligns in an Easterly to Westerly direction. Where contacts are found in this orientation, the zone of contact is usually more gradational than those that align North-South. An example of this phenomena is seen at the south end of Halo Hill (Latitude 49° 24' North, Longitude 125° 27.5' West). Here the andesitic rocks of the Sicker Group are turned into a greenstone with porphyroblasts of chlorite and hornblende which appears to be pseudomorphous after a pyroxene.

On the north shore of Great Central Lake within the grid sampled area there are outcrops which appear to be parts of septa aligned in an East-West direction within the granodiorite.

The contacts with the country rocks in the roof of the intrusion are also gradational where seen in the grid sampled area. The exception to this usual gradational contact is the sharp contact where the granodiorite intrudes the limestone of the Buttle Lake Formation.

Throughout all the areas investigated where the Central Vancouver Island Intrusion is in contact with gabbroic or basaltic rocks, the contact phase of the intrusion is usually dioritic with some reintrusion of granodioritic material. Where andesitic material appears to have been stoped, the interstices are filled with quartz rich granodioritic phase and the andesite appears to have been altered to a diorite. The quartz segregations may attain one inch diameter under these conditions. As the contact zone is approached from within the intrusion, there appears to be a zone which is richer in quartz than the bulk of the granodiorite.

The East-West contacts and the roof of the intrusion tend to have more gradational contact zones than the North-South portions or those areas in which limestone is the country rock.

Petrography of the Country Rocks

Youbou Formation of the Sicker Group

The base of the Sicker Group as described by Fyles (1955) and formally named the Youbou Formation by Yole (1969) is composed of breccias and massive sediments. Fyles described this sequence which was not seen by the writer as being composed of breccias and tuffaceous greywacke. The crystal and rock fragments range from a tenth of a millimeter to approximately a foot across. The fragments are imbedded in a matrix of siliceous, calcareous or argillaceous material altered to epidote biotite and hornblende. The rock fragments in the breccia are clastic and cherty sediments in addition to porphyritic basalt. The crystals which were found in the tuffaceous greywackes are primarily broken crystals of amphibole and less commonly pyroxene.

The thin bedded cherty tuffs make up the lowest units in the Central Vancouver Island area. In thin section they are composed of minute subangular to stellate grains of approximately ten micron diameters. The birefringence of these grains are low first order greys. If they were equal to the thickness of the slide in particle size they might appear to have a higher birefringence. These small grains appear to be quartz and plagioclase. However, there is no evidence of twinning in the fine-grained groundmass. Secondary chlorite is interspersed throughout fine-grained matrix. Most of the chlorite is in the same size range as the quartzo-feldspathic groundmass but segregations up to 200 microns do occur. Fine green acicular crystals up to fifty microns long and five to ten microns wide are found throughout the groundmass. They are pleochroic in light and darker green and have extinction angles of approximately fifteen degrees. Because of their minute size which makes identification difficult, they are only tentatively identified as hornblende but may also be epidote. Epidote is seen elsewhere in the thin bedded cherty tuffs, usually in larger grains. Some bands contain equant angular opaque grains which appear to be magnetite.

Some bands of the cherty tuff contain individual isolated crystals of plagioclase of andesine composition. In addition, rounded blebs were found within the finely laminated andesitic tuffs. The blebs were composed of angular mosaics of chlorite. In crossed-polarized light these chlorites have anomalous bronzy-brown birefringence and are thought to be prochlorite. Minute quartz veinlets cut these thin bedded to laminated cherty tuffs. Calcite occasionally occurs as veinlets and it is possible that prehnite is also present.

Clapp (1917) reported on a chemical analysis of a typical cherty tuff from the San Juan River in southern Vancouver Island. The tuffs contained 71.22 percent silica. The minor components were reconstituted into six percent calcite, and 0.5 percent each of carbonaceous matter and pyrite. By assuming an albite-oligoclase composition ($Ab_{94}An_6$) for the plagioclase that might be present in the tuffs, Clapp determined that sixty five percent of the rock was plagioclase and twenty eight percent was quartz.

The andesitic tuffs, lapilli and breccia range from units with the groundmass similar in composition to the cherty tuffs through coarser matrices to pyroclastics composed almost completely of compacted breccia fragments with small amounts of argillaceous material between the larger fragments. All variations of breccias may be present. Tuffs with phenocrysts of plagioclase may be included in fragments without phenocrysts or, conversely, tuffs composed of microlitic plagioclase may be carried in a porphyritic matrix. The plagioclase is dominantly labradorite and is usually zoned in an oscillatory manner. The range of zoning does not appear to be very large and in spite of its oscillatory nature trends from calcic in the center to slightly more sodic toward the exterior. Both albite and pericline twinning are common. The plagioclase is found in all stages of alteration. Some are altered to sericite or replaced by calcite in zones. Some plagioclase may be highly altered in the center and be relatively fresh looking on the peripheries while in others the reverse is true. The plagioclase phenocrysts may be up to four mm long but are usually about half that size. Pyroxene may be present in small amounts, if it has not been replaced by hornblende. Hornblende is present as phenocrysts in many of the breccia fragments besides replacing the pyroxene. The hornblende is replaced in turn by the ever present chlorite. Penninite seems to be the dominant form of chlorite; however prochlorite and clinochlore are also common. The hornblende like the plagioclase may occur as four mm long crystals.

The groundmass of the tuffs and breccia may contain appreciable disseminated calcite and occasionally scattered siderite. In addition, segregations of calcite are common and large crystals which may be fragments of echinoderms are occasionally found. The quartz-feldspathic groundmass which is usually a very fine mosaic may develop patches of coarser quartz grains which are optically continuous across intervening material for up to twenty grain diameters (200 microns) or more.

Andesitic dikes and flows may also occur within the Sicker Group. Within these more massive units, partially resorbed phenocrysts of quartz, orthoclase and/or sanidine may be found and the plagioclase microlites may develop in a felted texture like a very fine basalt.

At many places, the coarse breccias near the top of the Sicker Group contain fragments which are purple to brick red in color. The color appears to be derived from finely disseminated hematite in an ashy to devitrified glassy matrix.

Dickenson (1968) and Turner and Verhoogen (1960) have compiled a number of chemical compositions from volcanic andesite suites. All of these analyses come from rocks of various ages from around the Pacific Ocean. The majority come from the western Pacific around Japan.

Table II Range of Andesite Compositions from Around the Pacific Ocean

	(Dickenson) Low-Silica Andesites	High-Silica Andesites	(Turner-Verhoogen) Basaltic to Pyroxene Andesite
SiO_2	55.3 - 55.4	55.1 - 60.6	55.83 - 67.70
Al_2O_3	17.6 - 19.3	15.7 - 19.6	16.32 - 18.01
TiO_2	0.7 - 0.8	0.6 - 1.1	0.30 - 0.84
Fe_2O_3	2.6 - 5.2	1.8 - 4.3	0.27 - 2.63
FeO	2.6 - 5.0	3.0 - 7.8	3.20 - 4.07
MgO	2.5 - 5.1	2.6 - 3.3	1.25 - 5.12
CaO	7.7 - 9.1	6.3 - 7.7	3.35 - 7.40
Na_2O	2.9 - 3.7	3.2 - 3.8	3.64 - 3.89
K_2O	1.0 - 2.0	0.5 - 2.4	1.22 - 3.22

The Buttle Lake Formation

The Buttle Lake Formation, where in contact with the Central Vancouver Island Intrusion, may be up to 1,100 feet thick. Where directly in contact with the granodiorite, it may be finely to very coarsely recrystallized calcite to dolomite. The crystals are intensely twinned and the twin laminae are kink-banded on a micro scale. Curved twin and compositional plane may be indicative of dolomite. Fractures in the limestone may be partially filled with magnetite in bead-like chains resembling pater noster lakes in glaciated terrains. Neither tremolite or wollastonite were seen in thin section but near the contact they were tentatively identified in the outcrop.

The chert nodules and lenses which may constitute forty percent of some beds appear to be diagenetic replacements of the limestone. The nodules may terminate part way through fossils. Delicate spines of productid brachiopods may be silica over half their length and calcite over the rest.

The Buttle Lake Formation is essentially $CaCO_3$ with minor amounts of SiO_2 and MgO.

The Vancouver Group

The Karmutsen Formation

The sill within the Buttle Lake Formation is considered the precursor of the volcanic activity within the Upper Triassic of Vancouver Island. As was illustrated earlier, the sill broke through its covering rocks and became the first flow in the lower argillite and flow sequence of the Karmutsen Formation. The sill and flow are composed of large crystals of pyroxene varying in composition from a magnesian pigeonite to a sub-calcic augite. These pyroxene crystals served as nucleation centers for plagioclase which developed contemporaneously. The plagioclase became subophitic in the pyroxene resulting at times in a glomeroporphyritic texture. The plagioclase ranges from a labradorite to a sodic bytownite. Zoning is common and fractured and partially resorbed crystals sometimes act as nucleating centers for later plagioclase development especially lath-like crystals of volcanic character. The plagioclase crystals exhibit albite, pericline and Baveno twins. Both plagioclase and pyroxene may develop crystals up to four mm long in the central portions of the sill. The pyroxene constitutes about twenty to thirty-five percent of the rock while the plagioclase makes up thirty-five to fifty-five percent of the minerals. The accessory minerals are chlorite six to eighteen percent in the form of penninite magnetite three to fourteen percent, leucoxene two to six percent, sericite zero to seventeen percent, quartz three percent and calcite two percent.

The argillites are very similar under the microscope to the lower cherty tuffs of the Youbou Formation except they may be slightly coarser grained due in part to what appears to be fragments of sponge spicules. The groundmass is an intimate mixture of quartz and feldspathic material. Occasionally light brown gelatinous looking particles are intermixed with the quartzo-feldspathic groundmass. Acid residues from these rocks did not yield any spores or pollen. Little or no clayey material was seen in the argillite. The generally used term for this sequence is a misnomer since there is little or no clay in the sequence. Where the sequence is in contact with the flow, the joints break vertically across the beds instead of parallel to bedding.

The pillow lavas are essentially similar to the sill which has been described except that they are much finer grained. The diabasic to micro-glomeroporphyritic texture is preserved in many instances with microlites of plagioclase extending from calcic andesine to labradorite. Zoned plagioclase is also common in the pillows and flows and hornblende replaces pyroxene as the mafic mineral in many instances. The pillows also have a glassy phase in which the plagioclase is imbedded in a dirty brown devitrified glass.

Both Surdam (1967) and Muller (1971) published chemical analyses of the Karmutsen Formation. The ranges of chemical compositions are given in the following table.

Table III Range of Chemical Compositions of the Karmutsen Volcanics

	(Surdam)		(Muller)
	Dikes	Pillows	Flows and Pillows
SiO_2	45.90 - 50.22	42.30 - 51.20	47.3 - 49.5
Al_2O_3	13.24 - 14.60	11.77 - 14.42	12.9 - 17.1
TiO_2	1.22 - 2.40	1.11 - 2.42	1.23 - 2.38
Fe_2O_3	11.06 - 14.00	9.44 - 14.00	1.5 - 5.2
FeO			7.3 - 9.1
MgO	5.44 - 8.31	5.26 - 11.00	5.4 - 7.7
CaO	10.63 - 12.32	10.29 - 11.83	9.3 - 13.1
Na_2O	1.57 - 2.16	1.48 - 2.16	1.7 - 3.5
K_2O	0.11 - 0.27	0.11 - 0.25	0.1 - 0.21

The Quatsino Formation

The Quatsino Formation was not studied petrologically. Despite the stratigraphic descriptions which indicate that the Quatsino Formation is a dark grey carbonaceous limestone chemical analyses of equivalent formations indicate that certain portions are a very pure limestone with other portions being a dolomitic limestone. Insoluble portions make up less than one percent of the limestone. Where intruded by the

Central Vancouver Island Intrusion contact metasomatic deposits of magnetite are common (Muller in Muller and Carson 1968).

The Bonanza Subgroup

The Bonanza Subgroup was not studied petrologically but chemical analyses published by Muller (1971) indicate a wide range of chemical compositions for the volcanic portion of the subgroup. The ranges are given as follows:

Table IV Range of Chemical Compositions of the Bonanza Volcanics

SiO_2	43.7 - 74.4
Al_2O_3	12.8 - 19.6
TiO_2	0.29 - 2.21
Fe_2O_3	0.3 - 7.1
FeO	1.8 - 7.9
MgO	1.4 - 9.3
CaO	0.7 - 10.9
Na_2O	2.3 - 5.4
K_2O	0.8 - 3.1

Petrography of Central Vancouver Island Intrusion

The Central Vancouver Island Intrusion is generally considered to be a granodiorite grading into a quartz diorite at some localities. The plagioclase series of minerals exceeds the potassic-feldspar minerals in abundance. Quartz is present in quantities usually greater than ten percent. The abundance of the mafics, usually hornblende determines whether the intrusion is a granodiorite or a quartz diorite. If the hornblende is below ten percent in abundance, the rock is granodiorite and if over ten percent it is a quartz diorite.

In thin section the rock textures span the field from xenomorphic-granular where no crystal outlines are developed to hypautomorphic-granular where there is a matrix of euhedral, subhedral and anhedral grains. Examples of these textures may be found on Plate X which is a photomicrographic mosaic of the grid-sampled area around Great Central Lake. The xenomorphic-granular textures may be seen at positions B3 and C1, while the hypautomorphic-granular texture is best represented in D9. Occasionally a diabasic to felted texture is developed within the xenomorphic-granular texture in E8. Rarely a granophyric to myrmekitic texture was developed by the quartz within granular plagioclase and mafic groundmasses (upper left corner of C1). Sutured and interpenetrating boundaries are the rule rather than the exception, (most positions) and poikilitic textures are common especially at contact zones. Optically continuous quartz in grains greater than five mm across and occasionally up to one inch across contain ophitic to subophitic plagioclase within them. The white areas in A3, B4, B6, B8, D2, D3, E1, F4, G2 and H3 are examples of the optically continuous quartz. The poikilitic textures may be present on a number of scales. The quartz just mentioned may be one scale and the contact zone seive textures may be a smaller scale.

The plagioclase exhibits a number of habits within the intrusion. Equant to elongate rectangular grains exhibiting a number of kinds of twinning are usually found at some distance from the contact zone. These angular grains may be zoned, with half the grain displaying more pronounced zoning while the other half is complexly twinned in the albite and pericline mode with occasional Manebach-wedges being developed. Within the gridded area the closest examples of this phenomena are seen in position B5 and G3. Inclusions of sericite and calcite are common in the plagioclase throughout the intrusion but these plagioclase grains are clear compared to the contact zones.

Closer to the contact zones than the equant grains the plagioclase grains contain more inclusions. The inclusions of sericite and occasionally calcite form in zones which seem to mark relict grain outlines. Resorption outlines are common and overgrowths of more sodic plagioclase can be seen. Fractured zoned crystals some of which also show resorption, act as nucleating centers for renewed crystal growth. Occasionally two fractured crystals of differing zoned extinctions may be rejoined in offset positions and overgrowths of plagioclase redeveloped. Examples of these features may be seen on Plate IX also in positions A3, A4, A5, C3, D1, E7, F1, F3 and H2.

Even closer to the contacts, probably within a thousand feet, the plagioclase becomes less distinct both in outline and composition. The individual grain contains such a high percentage of finely disseminated sericite and/or calcite that the birefringence of the whole grain is overcast by second and third order colors. Twinning and zoning are seen through the inclusions. The closest example in the grid-sampled area is illustrated in position A7. In this position, interpenetrating twinned grains are seen in the center of the photomicrograph.

Where the intrusion is in contact with basic igneous material, there is usually an intermediate stage of fine-grained quartz diorite between the coarse granodiorite or quartz diorite and the basalt or gabbro. In this instance, fine microlitic plagioclase develops into coarse-grained albite twinned and zoned plagioclase. The plagioclase has a poikilitic texture with hornblende, chlorite and occasionally quartz included. There seems to be a slight tendency for the {010} plane of the plagioclase to orient sub-parallel to the contact.

The plagioclase determined by extinction angles on twin planes and in zone crystals ranges in composition from oligoclase to andesine ($An_{15}Ab_{85}$ to $An_{42}Ab_{58}$). Occasionally in a gradational zone, the composition goes as high as the calcic end of andesine ($An_{50}Ab_{50}$).

The quartz exhibits all degrees of strain phenomena within the intrusion. The most common form of strained quartz is that which exhibits undulatory extinction. Even the optically continuous infusion of quartz blebs often exhibits minor undulatory extinction phenomena. In addition to the undulatory extinction quartz, Boehm laminae are occasionally seen. Needle quartz can be found in some large strained grains and peripheral crush quartz is also present. In a few instances the large segregations of quartz, commonly called quartz eyes in the outcrop areas, are recrystallized into mosaic quartz with sutured boundaries.

Evidence in the thin sections suggests that the quartz is the most mobile mineral in the granodiorite, quartz diorite or the country rocks. The first mineral to be seen in the country rock on the contact zone in a fresh inclusion-free form is quartz. The hornblende alters easily but does not seem to migrate in its form as an amphibole.

Some highly strained quartz has the appearance of a weakly grid-twinned microcline. Minerals which have all the optical properties of quartz but are biaxial positive are also found. It is not known whether the straining was intense enough to cause this anomalous behavior or whether other ions were included in the strain distorted lattice. According to phase diagrams (Morey 1964) Na_2O and K_2O may be present in quartz at elevated temperatures in amounts varying from approximately nine percent to twenty-one percent.

The hornblende in some of the diorite and the country rock occurs as acicular euhedral to subhedral crystals up to four mm long and .5 mm wide. In the other diorite, the hornblende is 0.5 mm long by 0.1 mm wide. Most of the grains are green, but a brown variety may be seen on rare occasions. Both varieties are pleochroic in the shades of green and brown respectively.

In the granodiorite and quartz diorite, the hornblende is anhedral and pleochroic in greens and occasionally browns. The irregular shaped hornblende fills interstices between other crystals (the upper right corner of D9). If the interstices are large, individual subhedral crystals may form. Hornblende is not usually seen right at the contact of the intrusion with the country rock.

The chlorite is ubiquitous throughout all the rocks in the area. It occurs as colorless to light green interstitial material in varying amounts. The anomalous blues of penninite are easily distinguished in the thin sections. Clinochlore with a low birefringence and prochlorite with a bronzy-brown birefringence are also identifiable in lesser abundance.

Very rarely skeletal grains of pyroxene are encountered where the intrusion is in contact with basic rocks like gabbro or the Karmutsen volcanics. Magnetite is scattered throughout the intrusion as opaque grains. Its abundance increases near contacts with basic rocks. Sericite and calcite are common as inclusions within the plagioclase and in the interstitial groundmass. The sericite may be accompanied by clay minerals wherever alteration has occurred. Biotite and also muscovite are quite uncommon in the Central Vancouver Island Intrusion. Remnants or islands of mica may rarely be found in the center of chlorite accumulations.

A chemical analysis of a sample from location D2 in the grid-sampled area was performed by the Chemical Laboratory, British Columbia Department of Mines and Petroleum Resources, for the writer. The analysis as reported and the calculated normative minerals are as follows.

Table V Chemical Analysis and Normative Minerals of the Central Vancouver Island Intrusion at Great Central Lake

Oxides	Percent	Normative Minerals	Percent
SiO_2	61.72	Quartz	12.72
Al_2O_3	16.03	Orthoclase	5.56
Fe_2O_3	1.09	Albite	39.82
FeO	4.31	Anorthite	19.74
P_2O_5	0.13	Diopside	5.52
CaO	5.56	Hypersthene	13.20
MgO	3.24	Magnetite	1.62
TiO_2	0.63	Ilmenite	1.22
SO_3	0.008	Apatite	0.34
MnO	0.09	Calcite	0.20
Na_2O	4.72		99.94
K_2O	0.90	Plagioclase = $An_{33}Ab_{67}$	
H_2O	+ 0.01		
	- 1.46		
CO_3	0.11		
	100.008		

The intrusion does not contain appreciable pyroxene but does contain hornblende. If the pyroxenes were replaced by hornblende, more quartz would be available for normative quartz. This might increase the normative quartz to about 15.7 percent. If some sodium and potassium were included, the quartz percent might even be higher.

Chemical analyses from other intrusions on Vancouver Island have been reported by Clapp (1913) and Stevens (1950). These analyses are given on the following table.

Table VI Chemical Analyses from other Granodiorites, Quartz Diorites on Vancouver Island

		(Stevens - Zabellos)					(Clapp - Saanich)
		Granodiorite		Quartz Diorite			Granodiorite
		(1)	(2)	1	2	3	I
SiO_2		71.80	71.64	65.10	67.5	65.12	62.64
Al_2O_3		15.33	14.46	14.91	15.51	16.18	17.75
Fe_2O_3		0.61	0.84	0.79	0.40	0.33	1.64
FeO		2.84	2.30	4.09	2.70	2.19	3.44
MgO		1.06	0.22	2.42	2.42	0.71	2.53
CaO		1.44	2.04	5.14	3.16	3.99	4.44
Na_2O		3.25	2.97	3.64	3.62	0.15	3.52
K_2O		2.38	2.16	1.01	2.20	4.94	2.14
H_2O	-	0.05	0.13	0.06	0.18	0.26	1.65
	+	0.62	2.11	1.14	1.20	2.14	
TiO_2		0.46	0.42	0.58	0.52	0.50	0.60
P_2O_5		0.13	0.14	0.19	0.11	0.14	0.25
MnO		0.06	0.06	0.09	0.05	0.07	0.14
B_2O		0.10	0.10	.07			
		100.13	99.59	99.23	99.63	96.72	100.75

The Saanich Granodiorite (Clapp 1913) had a normative and modal composition as follows.

Table VII Normative and Modal Composition of the Saanich Granodiorite

	Norm		Mode
Quartz	19.74		24
Orthoclase	12.23		10
Albite	29.87	Andesine	44
Anorthite	20.29	$Ab_{65}An_{35}$	
Corundum	2.35	Biotite	9
Hypersthene	10.52	Hornblende	10
Magnetite	2.32		1.5
Ilmenite	1.22	Titanite	0.4
Apatite	0.62		0.6

Textural trends and mineral variations may be seen on Plate X also. This plate shows the variations that occur along the linear traverse across the intrusion on the Elk River road. In addition to the photomicrographic mosaic and mineral values, the trace elements are presented. The interpretation of these trends will be discussed in the following section.

MINERALOGICAL AND ELEMENTAL DISTRIBUTIONS AND TRENDS

Elk River Road

The samples obtained from the traverse along the Elk River road were scanned by X-ray and analyzed for plagioclase, quartz, potassic-feldspar (K-feldspar), chlorite, hornblende, kaolinite, calcite and montmorillonite. In addition pyroxene was determined as a representative quantity for one country rock sample each end of the traverse.

The absolute peak intensities for the eight minerals were pro-rated according to the ratio of peak height obtained from analyzing the records from the grid sampled area. Since all minerals in the grid sampled area were compared with the internal standard NaCl, a series of ratios between the minerals was established by holding the NaCl constant. These same ratios were applied in the absence of the NaCl. After the ratios of the eight minerals were obtained, they were normalized to a total of 100 percent. The pyroxene was excluded from this normalization and was added as an approximate representative value later. If it had been included, the percentages of the eight minerals would have to be reduced proportionately. The distribution and trends of the minerals and elements are presented on Plate X.

One of the most diagnostic trends is the abundance and distribution of quartz in the intrusion and in the country rocks. At the eastern end of the traverse (0 miles), the quartz constitutes about fifteen percent of the rock. Within a mile this value increases to more than forty-four percent. The point of actual contact between the country rock is not precisely known within this interval so the forty-four percent may not be the highest value present. Toward the center of the intrusion the values trough a little to forty-one percent. The quartz rises to a maximum before reaching the boundary of the central roof pendant, attaining a value of over fifty percent. Within the pendant the quartz drops to lows of 0 to 3.5 percent except where a quartz porphyry was encountered at location 4.7 miles. Quartz reached a value of forty-nine percent in the porphyry.

In the intrusion on the western margin of the roof pendant, the abundance of quartz jumps to thirty percent and continues at nearly that value for over a mile with the quartz diorite phase of the intrusion. At location 7.8 miles, the intrusion becomes a granodiorite with fifty-one percent quartz. Beyond this point the quartz values trough again to a minimum of thirty-one percent before peaking again at the western boundary of the intrusion with a quartz value of forty-four percent. The country rocks yield values of 3.5 to 7.5 percent quartz at the western end of the traverse.

With the possible exception of the eastern margin the the hornblende values peak at the contacts between granodiorite, country rock, and/or quartz diorite phase. These peaks of seventeen to forty percent occur at locations, 3.8 miles, 5.1 miles, 6.3 miles and 10.6 miles. A peak may exist to the east of the first sample location. Since there seems to be an inverse relation in this area between the quartz and the hornblende, the quartz would have to be a minimum before hornblende increases. The quartz is an intermediate value leaving open the possibility that the hornblende may increase within a mile to the east of the first sample (location 0 miles).

The K-feldspar abundance shows a good correlation with the outcrop of the intrusion in the first half of the intrusion but west of the roof pendant, the positive correlation is not as readily apparent. The K-feldspar reaches a maximum of sixteen percent on the western side of the roof pendant and drops in abundance in three steps and two plateaus to five percent in the western country rock.

The calcite and chlorite do not have distributions that are readily correlatable with any lithological or textural change. These minerals vary from 0 to 12 percent but occur in quantities of approximately four to six percent through most of the intrusion.

The kaolinite and montmorillonite are roughly proportional to the distribution of the feldspars and are present in quantities varying from 0 to eleven percent but occur mostly within the range of two to four percent.

The trace element distributions are not definitive in making boundaries or correlating with mineral distribution.

The absolute quantities of strontium, zirconium, and rubidium tend to be higher in the intrusion than in the country rock, but their distributions are erratic.

The abundance of elemental iron (expressed as percent Fe_2O_3) is very diagnostic in delineating the intrusion and the country rock but does not outline the quartz porphyry within the roof pendant very well. The country rocks, in this case the Karmutsen Formation, contains thirteen to fifteen percent iron near the contact. The first location (0.0 miles) on the eastern margin does not seem to show normal country rock iron abundance. Probably a sample further east would have been more representative.

Within the granodiorite and quartz diorite the quantity of Fe_2O_3 varies from 2.5 to seven percent and in the quartz porphyry there is just under twelve percent Fe_2O_3.

Great Central Lake Area

Fracture Distribution and Trends

In the grid sampled area around the western end of Great Central Lake, the mineralogical and elemental distributions and trends were related to the spatial and vertical distribution of the grid points. In addition, the fracture distributions and trends were noted to determine if they influenced the other variables under consideration.

From the regional geologic map illustrated on Plate I, the large faults are found to be oriented in North 15° West and North 75° West. Other fault directions are found to be less dominant. Within the grid sampled area, joints and shear zones were found to occupy a number of other orientations. The fractures, whether joints or shear zones are illustrated on Plate XI. The joints are represented as planes on lower hemisphere stereographic projections for each grid point. Within the stereographic projections, the frequency of a particular orientation is graded according to an arbitrary normalized scale of one to ten. Each integer is equivalent to ten percent of the fractures at the grid-center represented. If the intensity of fractures were low, a nominal low frequency of one or two was given to each joint set.

The easterly to westerly directions are readily seen throughout the area but the northerly to southerly preferred orientation is diffused over a broader range by a number of separate fracture orientations. Horizontal and sub-horizontal planar jointing is apparent in the southern and southeastern portion of the gridded area. In spite of the relatively pervasive fracture orientations and apparent lateral separations on the regional map the trends of minerals and elements did not indicate large offsets.

Mineral Distributions and Trends

The distribution and trends of quartz in the Great Central Lake area are shown on Plate XII. In general the high quartz values form an undulating surface tilted to the south and a little southeast. Superimposed on this tilted surface are concentrations and deficiencies of quartz aligned North-South to North 30° West - South 30° East.

The highest quartz concentrations are found approximately 1,000 to 2,000 feet from the contacts or projections of the roof above the intrusion. Examples of this are seen at locations G2 and G3 where the highest quartz values in the area are found. The contact with the roof is found as a gradational contact at approximately 3,400 feet on Mount Bueby. The contact is tilted to the west and is found at 2,700 feet on the slopes above Drinkwater Creek. Locations G2 and G3 are found at 1,750 feet and 2,075 feet above mean sea level respectively. Locations C1, E2 and E3 are similarly situated 1,000 to 2,000 feet below the roof of the intrusion which is projected to 2,500 to 3,000 feet above mean sea level.

The abundance of quartz varies from 10.6 percent at location E4 to 46.4 percent at location G3. Location E4 is in the gradational contact zone where the intrusion is in contact with the Karmutsen Formation which caps Mount Bueby.

In the Great Central Lake area the hornblende exhibits the inverse relationship that was noted along the Elk River road. The contour lines of hornblende content correspond closely to those of quartz except the values are lower and trend in the reverse direction. The hornblende varies from 2.7 percent at location H2 in the vicinity of the quartz maxima to 19.4 percent at position B6 where it is thought that a septum of country rock is contained in the intrusion. Contact metamorphism may be responsible for this high amount of hornblende within the septum at this location, since the usual amount of hornblende from the contact zone ranges from twelve to fifteen percent.

The usual range of hornblende abundance within the intrusion is six to ten percent. This range makes the bulk of the intrusion a granodiorite with some areas of quartz diorite composition occurring near the eastern contact zone and along the valley of Drinkwater Creek.

The feldspar distribution and trends are illustrated on Plate XIII. The plagioclase isocon lines delineate planar surfaces with slightly curved eastern margins where the contact dips more steeply. The isocon surfaces dip at low angles to the south. These isocon surfaces indicate lower concentrations with depth, or conversely, increased concentrations upward toward the roof of the intrusion and the Karmutsen Formation. The isocon surfaces are revealed by the intersection of the topography with the various surfaces.

An exception to the planar configuration occurs where the quartz concentrations are exceptionally high in the vicinity of locations G2, G3 and G4. There the plagioclase has values around forty-two to forty-five percent while over the rest of the area the plagioclase ranges from twenty-one to sixty-five percent. The anomalous values appear to be displaced approximately 1,000 to 1,500 feet upward from their projected isocon surfaces if they were truly planar.

The K-feldspar isocon surfaces undulate along North-South and North 70° West - South 70° East axes with high values occurring at locations E3, H2 and E9. The K-feldspar varies from 4.6 percent at location D5 to 13.0 percent at location E3. In some parts of the area, there is a hint of proportionality between the quartz abundance and the K-feldspar abundance but in most instances there is not a readily apparent relationship between the abundance of K-feldspar and the other minerals in the intrusion.

In Plate XIV, the distributions and trends of chlorite and kaolinite are set out. The quantities of chlorite in the intrusion are roughly proportional to and equivalent to the hornblende in the intrusion with the exception of a strong East—West minimum trend parallel to row "D". The range of chlorite values in the gridded area are from 5.1 percent to 11.2 percent. The quantity of chlorite generally increases upward toward the roof of the intrusion where the Karmutsen Formation is present.

The kaolinite distribution also is roughly proportional to the hornblende and chlorite distribution except that the highest values occur toward the northwest and southwest where the intrusion is in close proximity to the Youbou Formation of the Sicker Group. The values for kaolinite range from 3.7 percent at location D3 to 14.1 percent at location H1. The kaolinite does not seem to be directly related to the distribution of either plagioclase or K-feldspar as might be thought.

<u>Elemental Distributions and Trends</u>

The distributions and trends of iron and rubidium are shown on Plate XV. The distribution of elemental iron is represented as percent of Fe_2O_3 throughout the study. The abundance of iron is an excellent indicator of the proximity of country rock especially where the intrusion is in contact with the Karmutsen Formation. The granodiorite is characterized by Fe_2O_3 percentages in the order of four percent to six percent while the Karmutsen Formation contains twelve percent to fourteen percent Fe_2O_3. In general, andesites fall between these two ranges with contained iron on the order of eight percent. The distribution corresponds quite closely with the distribution of hornblende. The high value of 12.6 percent Fe_2O_3 at location B6 correlates with the 19.4 percent hornblende at the same location. The values for Fe_2O_3 in the grid—sampled area range from 3.2 percent at D3 and H3 to 12.6 percent at B6 as was just mentioned. The Fe_2O_3 isocons generally trend Northeast-Southwest.

The rubidium distribution and trends are inversely proportional to the iron trends over most of the area. Where the iron has its lowest percentages the rubidium is in its greatest concentrations. At location G3 where 3.2 percent of iron is contained, 140 ppm of rubidium is present. At location B6 where the iron is at its highest concentration (12.6 percent) the rubidium is present in concentrations of seventy-six ppm. The lowest concentrations of rubidium actually occur at locations B7, D7 and E7 where sixty-five ppm of rubidium are contained. The rubidium values range over the area from sixty-five ppm to 140 ppm.

The strontium and zirconium distributions and trends are presented on Plate XVI. The strontium highs and lows are oriented roughly in a Northeast-Southwest direction like the rubidium and iron but there is no direct or inverse proportionality with either of them. The greatest strontium concentrations are in the southeast portion of the grid-sampled area at location B8 where 495 ppm are contained in the intrusion. The lowest concentration is at location C5 with 195 ppm while secondary lows occur at locations D3 and H2. The areas of high and low concentrations of zirconium are elongate approximately at right angles to the strontium trends. Low concentrations of 135 ppm and 137 ppm occur at locations C5 and B6 respectively. The southeast portion of the grid sampled area has relatively high concentration of zirconium with the highest value of 255 ppm at location B8. Additional highs of 245 ppm, and 225 ppm occur at F4 and G4 respectively and 230 ppm occurs at E3.

CONCLUSIONS

In general the Central Vancouver Island is a zoned intrusion. From the petrological and mineralogical studies, it was found that the composition of the intrusion varies with distance from the contact. In addition, it was found that the country rock was also zoned near the intrusion.

In the environment in which the Central Vancouver Island Intrusion is found, it was discovered that there is a hornblende rich aureole surrounding the intrusion. This hornblende-rich band is approximately one half a mile wide but varies from place to place. The hornblende rich zone is equivalent to the basic hornblende-hornfels facies of Turner and Verhoogen (1960). It meets the criteria of a rock with excess SiO_2 and either excess or deficient K_2O. In most cases it is deficient in K_2O. The rocks in the hornblende rich zone have a mineral assemblage equivalent to the equilibrium field of plagioclase (calcic) - hornblende - anthophyllite and rarely equivalent to the equilibrium field of plagioclase (calcic) - hornblende - biotite. In both instances, quartz is in excess of the amount necessary to form the equilibrium minerals and may be present as liquid-like blebs in the interstices. The minerals are very fine-grained but increase in size as the contact with the granodiorite is approached.

At the contact, the hornblende was degraded to chlorite in most instances and the plagioclase took a dramatic jump in grain size. The composition of the plagioclase is essentially the same as the country rock with older crystals from the country rock having formed the nucleus of the growing crystals. The crystals were zoned as the available components of the plagioclase were mobilized around the developing relict grains. The quartz concentrated into large masses around the plagioclase and the chlorite was squeezed into the available interstices as crystallization occurred. The plagioclase occasionally contained, in a poikilitic texture, hornblende which had not been converted to chlorite. Convolute zoning was also common as inclusions were pushed from the crystallizing plagioclase.

The abundance of quartz in excess of the possible normative quartz in the intrusion is probably indicative of a medium with a great quantity of other constituents contained therein. There appeared to be a relative migration of the quartz from the country rock into the granodiorite. If the intrusive contact were relatively stationary, then there was an actual migration of a quartz-bearing medium. If the intrusive contact were advancing then the quartz-bearing medium maintained a relatively constant position in reference to the contact forming a "concentration-front" which advanced toward the country rock as it was being assimilated.

Within the quartz rich zone the plagioclase was able to adjust to the physical-chemical conditions and the number of inclusions within the plagioclase became fewer. More sodic plagioclase was accreted to the margins of the zoned crystals and hornblende began to reform in the interstices. It is interpreted that the quartz-rich zone which may be a belt with indefinite boundaries up to two miles wide was at the time of intrusion a highly viscous fluid in which appreciable movement or flowage took place. The plagioclase constituted crystals within this fluid which were subjected to shearing, fracturing and rehealing as they aggregated in masses and retarded flow.

Within the granodiorite behind the quartz "concentration-front", the plagioclase, hornblende and the trapped quartz-rich fluid stabilized into an intrusive body with a normal granodioritic composition. The plagioclase which had begun its transformation into a more sodic plagioclase in the quartz-rich zone with the exclusion of impurities and the consolidation of zones continued to homogenize through diffusion processes and possibly by lattice adjustments through twinning.

It is interpreted that the Central Vancouver Island Intrusion was formed through the mobilization of parts of the andesitic suite of rocks which make up the Sicker Group since their compositions were relatively similar. The composition was modified to some degree as the intrusion invaded the overlying Vancouver Group. The intrusion does not appear to have been completely molten at any one time but was composed of a crystal phase and a highly viscous fluid phase.

The quartz diorite phase of the intrusion appears to have been one stage of the assimilation process as quartz was leached from the country rock before complete assimilation took place.

The batholith was not affected to any great degree by the various lithologies through which it passed. Minor changes were seen in the hornblende abundances in the intrusion. Where more basic rocks were intersected, the quantity of hornblende increased over limited exposures. The greatest change between the country rocks and the intrusion is the variation in iron content. The iron does not appear to have been assimilated. The excess iron from the Karmutsen Formation may have been driven upward into the Quatsino Formation where many contact metasomatic magnetite deposits are found.

The most striking trend within the batholith is the quartz "concentration-front" which is usually found within a half mile of the contact and extends in a belt up to two miles wide around the margins of the batholith.

The batholith seems to have intruded as a combination of a highly viscous quartz-rich fluid in which constituents of the country rock were transported and transformed into a crystal-rich mass which solidified behind the quartz "concentration-front". The plagioclase feldspars within the Central Vancouver Island Intrusion have an average composition of andesine ($An_{35}Ab_{65}$) but vary from oligoclase ($An_{12}AB_{88}$) to labradorite ($An_{55}Ab_{45}$) in zoned crystals whose composition is controlled by the composition of the country rock which was assimilated. The K-feldspar where it occurred was usually present in perthites.

The trace element study was not diagnostic in delineating any major trends within the batholith with the exception of iron which was present in quantities of up to sixteen percent (Fe_2O_3). Strontium, rubidium and zirconium were detected and correlated for all the samples analyzed but the elements of usual economic importance such as copper, lead, zinc, gold, silver and molybdenum were not detected in anomalous quantities anywhere in the grid-sampled area at the western end of Great Central Lake or along the linear traverse on the Elk River road.

The X-ray analysis technique employed in this study was appropriate for delineating trends and relative abundances of minerals. However, the X-ray analysis technique was lacking in the precision necessary to perform a detailed quantitative analysis of individual minerals in a matrix which varied in composition.

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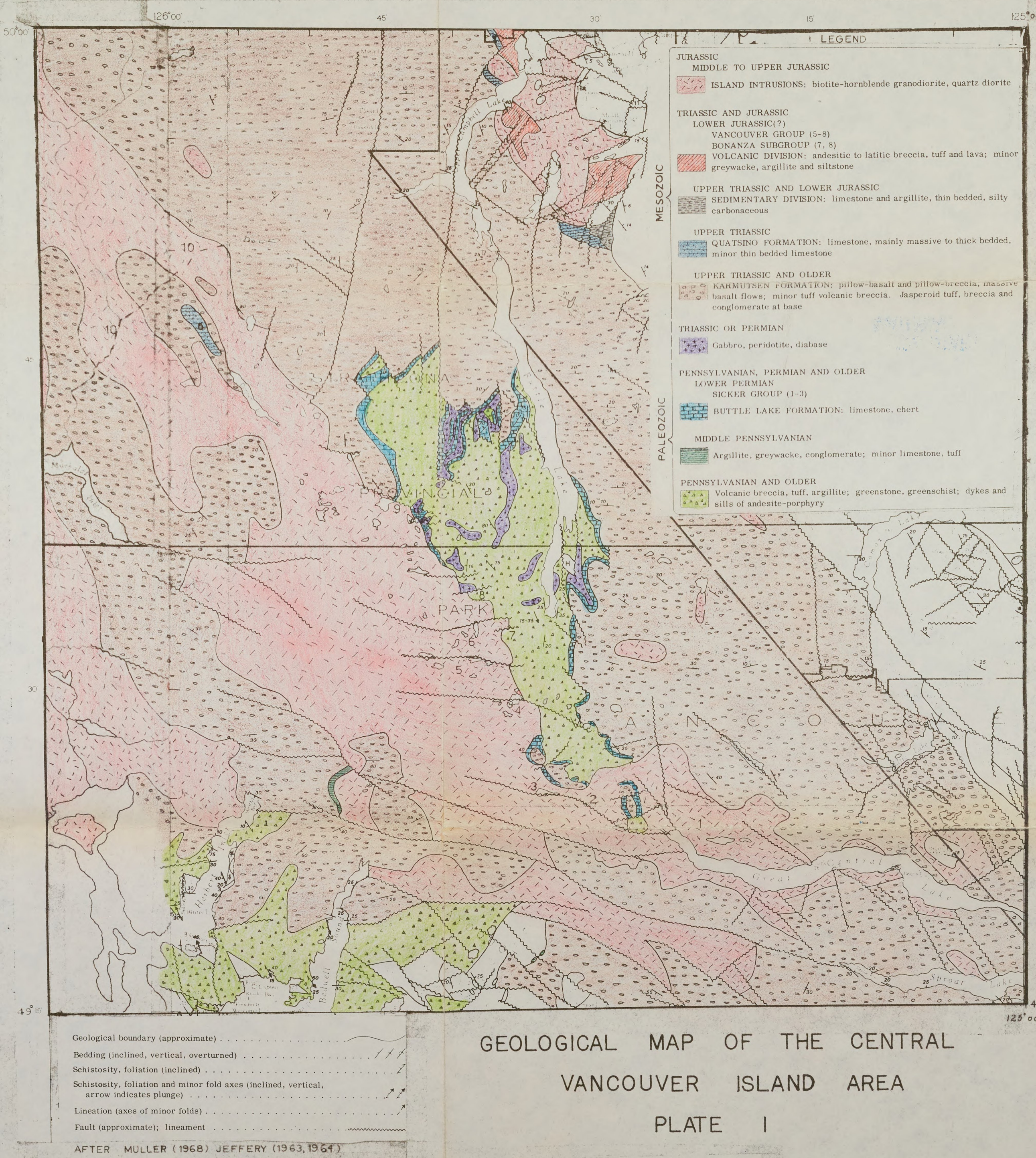
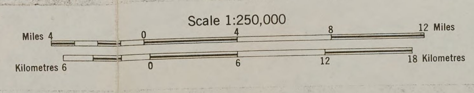
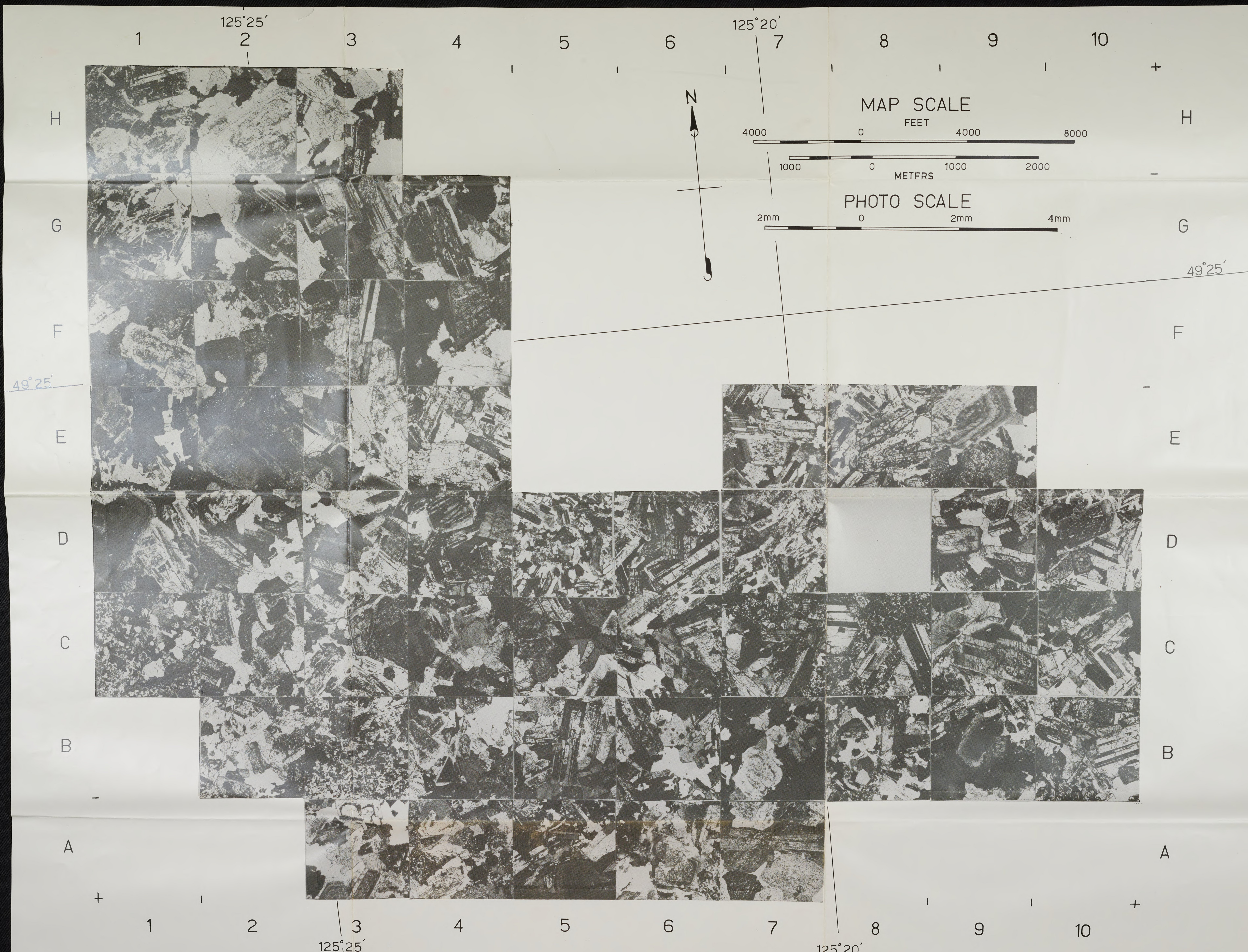


AFTER MULLER (1968) JEFFERY (1963, 1964)

GEOLOGICAL MAP OF THE CENTRAL VANCOUVER ISLAND AREA

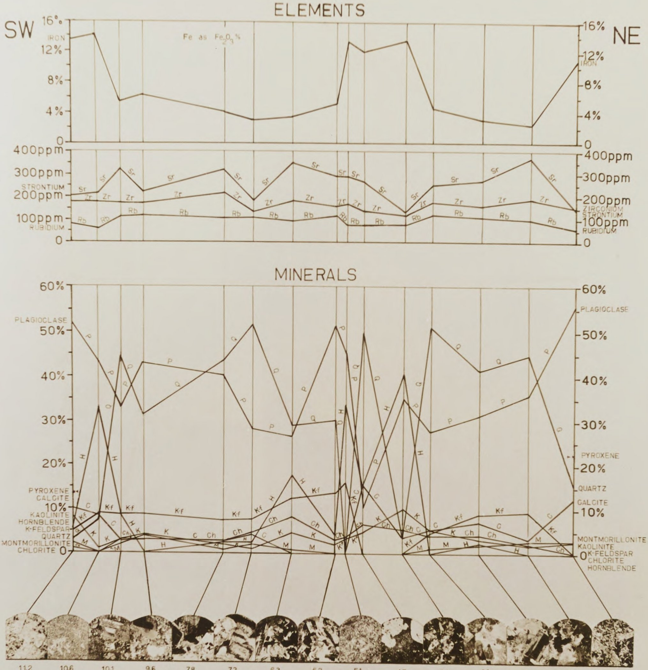
PLATE I





PHOTOMICROGRAPHIC MOSAIC
OF THE
CENTRAL VANCOUVER ISLAND INTRUSION
AT
GREAT CENTRAL LAKE

PLATE IX



ELEMENT AND MINERAL
DISTRIBUTION AND TRENDS
ELK RIVER ROAD B.C.

PLATE X