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SURFACE GEOLOGY AT THE GRANDUC MINE

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SURFACE GEOLOGY AT THE GRANDUC MINE

by

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ABSTRACT

The Granduc Mine is near the British Columbia-Alaska boundary in rugged mountainous country about 36 miles northwest of Stewart B.C. The writer participated in detailed surface mapping in the vicinity of the mine during the field season of 1959. Rock specimens were collected in the field and examined microscopically in the laboratory. The results of the latter investigation form the greater part of this thesis.

The oldest rocks in the area are north trending, steeply dipping and isoclinally folded metavolcanic and metasedimentary rocks that are believed to be correlative with the Hazelton group. These consist of a basal andesite complex which is overlain by a large thickness of metasedimentary rocks. The Hazelton group rocks have been regionally metamorphosed and synkinematically intruded by small subconcordant bodies of foliated diorite and hornblende granodiorite. The metasediments are believed to have formed from greywackes, marls and sandstones that have been progressively metamorphosed to form schists that can be classified in the quartz-albite-epidote-biotite subfacies of the greenschist facies. Almost identical mineral assemblages are found in the altered dioritic and metavolcanic rocks, and it is concluded that these initially high temperature assemblages have

retrogressed during regional metamorphism to attain or approach equilibrium in the same metamorphic facies. At a late stage in the metamorphism strong differential movement was localized in a quartz-rich member of the metasedimentary rocks in a zone near the contact with metavolcanic rocks. All rocks in this zone have undergone retrogressive metamorphism, and have attained equilibrium in the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. Drag folds show that this dislocation metamorphism was related to the formation of an anticlinal structure that lies to the east of the map area. Some of the major structural ore controls appear to have formed at this time.

The strongly-developed isoclinal folding was later flexed during or following intrusion of the Coast Range batholith. Ore bearing solutions are believed to have been derived from batholithic emanations and these were channeled along crumpled and brecciated zones that formed during the earlier period of regional metamorphism.

Two mineralized zones are present and these are essentially conformable with the metasediments and consist chiefly of chalcopyrite, pyrrhotite and sphalerite. Mineralization has replaced the host rock along favourable lithologic horizons, but appears most heavily concentrated in brecciated zones. The deposit is classified as Mesothermal Replacement.

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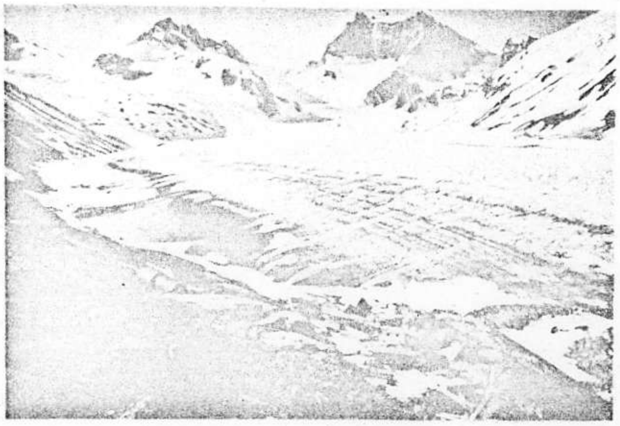

Frontispiece

South Fork of Leduc Glacier looking to the southeast. 3250 portal of the Granduc Mine in foreground.

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CHAPTER I - INTRODUCTION

LOCATION AND ACCESS

The Granduc Mine is near the British Columbia-Alaska boundary in rugged mountainous country about 36 miles northwest of Stewart B.C., at latitude 56°13'N and longitude 130° 22'W (Figure 1). Stewart B.C., at the head of the Portland Canal, is the supply base for the area. Northland Navigation steamships maintain a schedule between Vancouver and Stewart. Pacific Western Airlines and Omenica Airways are available for charter flights in the area.

Access to the mine from Stewart is somewhat difficult because of the rugged, mountainous terrain, and the presence of extensive snow and ice fields over much of the route. In the winter months, "snow-cats" can negotiate the difficult terrain from Stewart to the mine over the snow-covered glaciers. Access by foot travel is possible in the summer months, but the journey is difficult, dangerous and time-consuming.

Airplanes are used for transport of personnel and all but the heaviest of equipment, which is brought in by "snow-cat". Granduc Mines Ltd. has built a hangar and supply depot at the air-strip at Stewart. A dirt landing strip has been built on the west side of Granduc Mountain for summer use, and in winter snow-covered glaciers form satisfactory landing-strips.

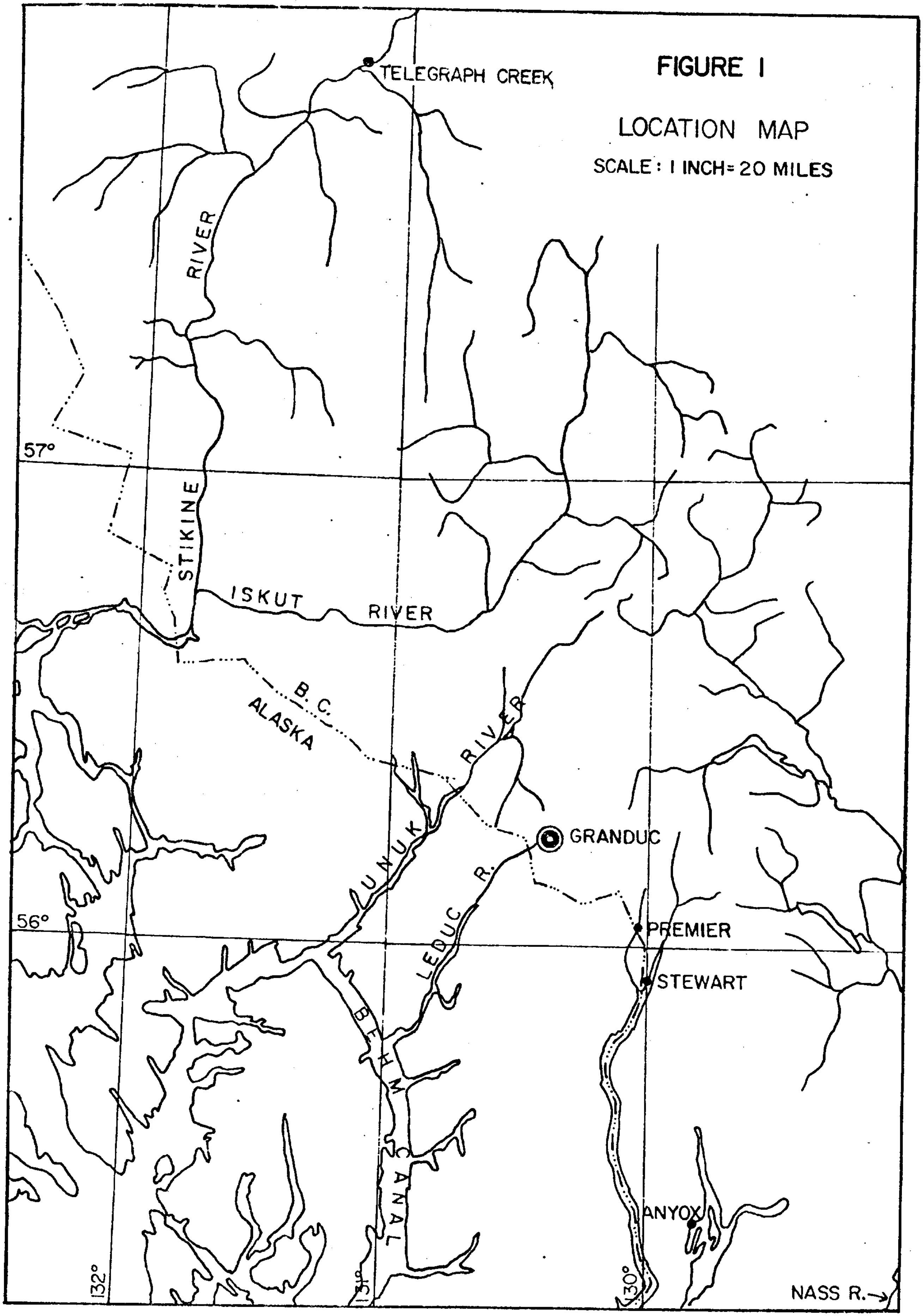


FIGURE I

LOCATION MAP

SCALE: 1 INCH=20 MILES

HISTORY OF THE PROPERTY

The first official reference to the Granduc showings is found in the 1931 B.C.Minister of Mines Report. Wendell Dawson and the late W. Fromholz are reported to have ascended the Leduc River in 1931 and located three claims that appear to have covered at least a part of the present Granduc property. The claims lapsed, and it was not until 1948 that the showings were "rediscovered" by E. Kvale. E. Kvale and T.McQuillan located claims on these showings in 1951. Additional claims were located in 1952.

Granby Mining Smelting and Power Co.Ltd. examined the showings in 1952, and formed a new company, Granduc Mines Ltd. Later, Newmont Mining Corp. Ltd., entered into an agreement with Granby, whereby they would aid in financing the development of the mine.

PREVIOUS WORK IN THE AREA

The region drained by the Unuk River remains one of the major unmapped areas on the eastern flank of the Coast Range Mountains. Regional mapping has been done in the areas to the south, west, and north. Most of this work has been carried out by the Geological Survey of Canada, and the United States Geological Survey.

A small scale sketch map of the area appeared in the 1935 B.C. Minister of Mines Report, while a sketch map of the area immediately surrounding the mine appeared in the 1953 B.C. Minister of Mines Report. In 1955, W.R.Bacon mapped 148 square miles in the Granduc Area on a scale of 1 inch = 1 mile. As yet only a preliminary map of this work has been released by the B.C.Department of Mines.

PURPOSE OF THE THESIS

The author participated in the mapping of a 40 square mile area in the vicinity of the Granduc Mine during the field season of 1959. Most of this area was mapped on a scale of 1 inch = 800 feet, but a smaller portion near the mine was mapped on scales of 1 inch = 100 feet, and 1 inch = 200 feet.

Because of relatively high grade metamorphism, complex structure, and the lack of complete regional mapping, it is difficult to correlate the stratified rocks of the Granduc area with those mapped to the north and south. It is hoped that the present study will help in understanding the petrogenesis of the Granduc rocks, their correlations, and the genesis and ore controls of the mineral deposit.

The laboratory study is based on 461 specimens from which 128 thin sections, 3 polished thin sections, and 15 polished sections were prepared.

CHAPTER II - PHYSIOGRAPHY

TOPOGRAPHY

The topography is that of a youthful rugged mountainous region, which has been deeply dissected by river erosion, and both Pleistocene and modern alpine glaciation. The existing glaciers are fed by and in part consist of extensive ice and snow fields that cover as much as 60% of the Granduc area. Snow-line on the ridges is at an elevation of 4000 to 5000 feet, and valley glaciers terminate at less than 2000 feet elevation in the Leduc and Unuk Rivers. Gradients on the main valley glaciers range from 500 to 1000 feet per mile, but hanging glaciers have gradients of 2000 or more feet per mile.

Relief within the area is great, with peaks rising to 7000 or 8000 feet from valleys or glaciers 2000 to 4000 feet in elevation. Mountains less than 7000 feet elevation tend to have smooth rounded tops, bnt the higher mountains have sharp jagged peaks. Mountain slopes are steep, some averaging over 40° for thousands of feet.

The main valleys of the Leduc and the Unuk Rivers below the glaciers are broad, flat-floored and "U" shaped as a result of glaciation. As the glaciers retreated, the streams cut channels in the flat, debris filled valley floors.

DRAINAGE

The Granduc area is drained by the South Fork of the Unuk River (shown as Gracey Creek on some maps) and the Leduc River. The former flows about 12 miles due north to join the main Unuk River, which then flows 40 miles in a southwesterly direction to the head of the Behm Canal in Alaska. The Leduc River flows 36 miles in a southwesterly direction, and enters the Behm Canal about 14 miles south of the mouth of the Unuk River. Both streams cut through the core of the Coast Mountain system.

Tributary streams cascade down the steep slopes, and either disappear beneath valley glaciers, or directly enter the main stream channels almost at right angles. Seasonal variation in the flow of these streams is very large.

CLIMATE

Precipitation is heavy and except for the summer months largely in the form of snow. During the winter snow may reach a depth in excess of 20 feet in the valleys.

FLORA AND FAUNA

On mountains protruding from the snow and ice fields, vegetation is sparse, consisting almost exclusively of heather, and alpine grasses and flowers. On the slopes of the main valleys below the toes of the glaciers, timber and underbrush become increasingly abundant. Animal life in the immediate area is scant. Numerous marmots, ptarmigans and an occasional ermine were seen.

GLACIAL FEATURES

The Leduc and the Unuk Glaciers are the principle glaciers in the Granduc area. Each consists of two main forks that range in width from ½ to 1 mile, and are as much as 4 miles long. These are fed by the extensive snow and ice fields that cover much of this region.

As stated previously, the gradient of the main valley glaciers ranges from 500 to 1000 feet per mile. Steeper hanging glaciers have gradients up to 3000 feet per mile. These vary up to 1/4 mile in width, and are generally less than ½ mile long. Ice falls are common on some of the steeper glaciers. (Figure 2).

The toes of the main glaciers are 50 to 100 feet thick and drilling has shown that the ice is approximately 700 feet thick in the South Fork of the Leduc Glacier near the mine. Maps show that the toes of the main glaciers have receded at least ¼ mile since 1955 and at the mine, the elevation of the surface of the glacier has decreased 50 to 100 feet since 1953. (Figure 3).

Lateral, medial and terminal moraines are Cirques and hanging valleys in all stages of development occur

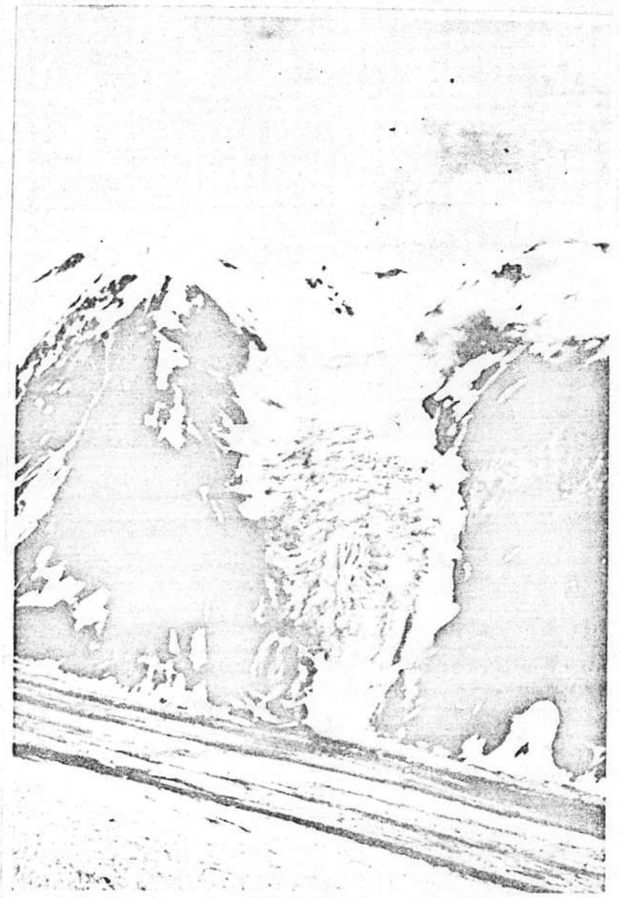


Figure 2

Steep hanging glacier with ice falls. Note the well developed cirque at the head of the glacier.

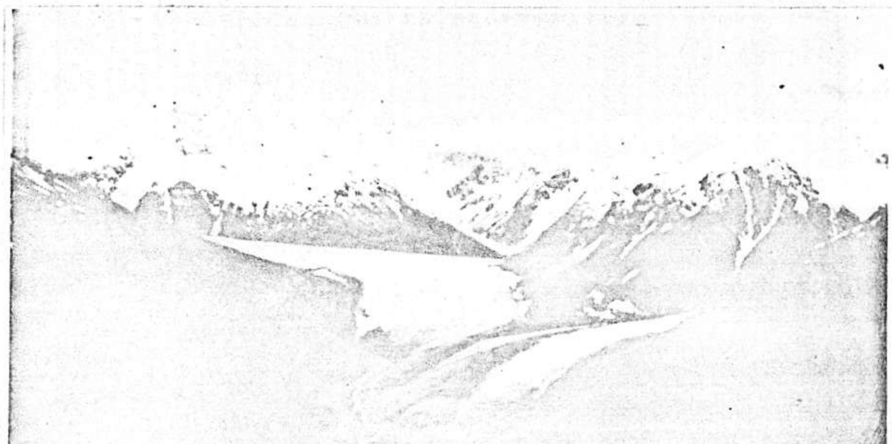


Figure 3

the Unuk Glacier looking to the southeast. Granduc in is in the background. Retreat of the glacier is by the sharply defined timberline.

along the main valleys and in the source areas of the glaciers. Roches moutonnees are fairly well-developed on some slopes, producing a terraced slope marked by subparallel rock benches.

PHYSIOGRAPHIC HISTORY

The nature of the stream gradients and the narrowness of the interstream divides, indicate that the area is approaching a stage of early maturity. Schofield and Hanson (1922, p 31) state that in the adjacent Salmon River district B.C., the Coast Range was almost peneplained during the Cretaceous, and that the present valleys were eroded during the Tertiary period. Buddington (1928, p.22) agrees that a mature topography had been developed at least locally in pre-Eocene times in southeast Alaska. He postulates a considerable uplift in post-Eocene times, possibly in the Pliocene or early Pleistocene. Buddington describes uplifted Tertiary sandstones, conglomerates, and volcanic rocks that have a dip of 8° southeast, suggesting tilting as well as uplift.

The Leduc and Unuk Rivers cut through the core of the Coast Mountain system, and it is probable that these are pre-Eocene, antecedent streams.

The Pleistocene glaciation later modified the master valleys of the Leduc and Unuk Rivers giving them their pronounced "U" shape. With ablation of the Pleistocene and Recent glaciers, these valleys have been partially filled with debris that now forms the flat valley floors.

The Pleistocene ice sheet appears to have reached a maximum elevation of 7500 feet above present sea level. Mountain and ridge tops below this elevation are scoured and have distinctively rounded tops. A few sharp jagged peaks ranging from 8000 to 8500 feet in elevation appear to be unglaciated. Recent glaciers have further modified the topography, and glacier features of many kinds can be observed in all stages of development.

The South Fork of the Unuk River may have been captured from the Leduc River. Uplift and possibly the damming effects of the ice fields may have caused the South Fork to flow in a northerly direction in post-Pleistocene times.

CHAPTER III

Regional Geology

The Granduc area lies 1½ to 5 miles north and northeast of the eastern contact of the granitic complex that forms the backbone of the Coast Mountains. The discussion of regional geology will be restricted to a belt 40 to 60 miles wide on the east flank of this complex, extending from the Nass River, north to the Stikine River (Figure 1). The Granduc area is centrally located in this belt.

Pre-batholithic rocks on the eastern flank of the Coast Mountains consist of Paleozoic and Mesozoic sedimentary and volcanic rocks that have been metamorphosed to varying degrees, and are commonly closely folded.

Paleozoic rocks occur in isolated patches in the Lower Stikine and Western Iskut River areas (Kerr 1948, p.22), apparently outcropping in eroded anticlinal structures that parallel the axis of the Coast Mountains. Pre-Mesozoic rocks have not been reported in areas mapped to the south (Hanson 1929, 1935). Paleozoic rocks in the Stikine Area are predominantly sediments, characterized by abundant limestone, with minor amounts of argillite, chert, quartzite, sandstone, tuff, and their metamorphic equivalents. Although the structure is complex, and most sections are incomplete, Kerr (1948, p.22) postulates a maximum thickness of 15,000 feet for Permian and pre-Permian rocks.

Sedimentary and volcanic rocks of Mesozoic age and their metamorphosed equivalents form the major portion of the rocks east of the Coast Range granitic complex. The sediments consist largely of greywacke, arkose, argillite, and tuffaceous rocks, with numerous thin beds of limestone, sandstone, and conglomerate. Interbedded andesitic and basaltic lavas and related pyroclastic rocks are abundant and widespread, although their distribution is irregular. Measurements of a complete stratigraphic section of Mesozoic rocks in the Stikine area is lacking, however, a minimum value of 10,000 feet is suggested by White (1959).

The granitic complex of the Coast Mountain systems includes rocks of widely variable composition that range in age from pre-Upper Jurassic to post-Lower Cretaceous. Hanson (1935) mapped granite, granodiorite, quartz diorite, and related phases as a unit in the Portland Canal area, whereas Buddington (1928) and Kerr (1948) emphasize the composite nature of the batholith. This granitic complex intrudes pre-Lower Cretaceous sedimentary and volcanic rocks, and is overlain unconformably by Tertiary volcanics and continental sediments.

The structure of the Coast Mountains is extremely complex. The Paleozoic and Mesozoic rocks occur in north to northwesterly trending folds on the flank on the granitic complex. In a few places remnants of pre-Mesozoic structure have been recognized, but for the most part, any older structures have been completely obliterated by those resulting from Mesozoic orogeny.

CHAPTER IV - GEOLOGY OF THE GRANDUC MINE AREA

INTRODUCTION

The oldest rocks in the Granduc area are a sequence of metavolcanic and metasedimentary rocks of Lower Mesozoic (?) age. These have been closely folded and intruded by Coast Range batholithic rocks and by granitic dikes and sills that are genetically related to the batholithic intrusions. The major rock-units are listed in hypothetical chronologic order in a table of formations on page 15, and their general distribution is shown on the areal map (Map 1). More detailed lithologic map units are shown on Map 2.

In the following discussion, the Metasedimentary formation has been divided into two lithologically distinctive members that will be referred to as the Mine member and the Schist member. The former is characterized by closely folded quartz-rich phyllonitic rocks, whereas the latter consists essentially of plagioclase-biotite-actinolite-epidote schists and amphibolites.

METAVOLCANIC ROCKS

Distribution

The metavolcanic rocks outcrop chiefly along the eastern side of the map area. In the southeastern corner of the map sheet (Map 1), the metasedimentary-metavolcanic contact strikes in a northeasterly direction, and disappears

TABLE OF FORMATIONS

SEDIMENTARY AND VOLCANIC ROCKS

ERA	PERIOD	GROUP	FORMATION	MEMBER	MAP UNIT
Mesozoic	Jurassic and/or Triassic	Hazelton	Metasedimentary	Schist	Plagioclase-biotite actinolite-epidote schist; amphibolite; quartz-rich schists; limestone.
				Mine	Quartz-sericite (graphite-chlorite) phyllonite; quartz-biotite-(chlorite) phyllonite; plagioclase biotite-chlorite (calcite) schist; amphibolite; limestone
			Metavolcanic		Porphyritic and non-porphyritic andesite; locally pillowed, fragmental, brecciated. Sheared equivalents

INTRUSIVE ROCKS

ERA	PERIOD	DESCRIPTION
Mesozoic (mainly or entirely)	Lower Cretaceous or Later.	Granodiorite; granodiorite, aplite, quartz diorite sills and dikes.
	Jurassic(?)	Hornblende granodiorite. Diorite and sheared equivalents.

under the snow-cap on Granduc Mountain. Mapping to the east of this contact shows an apparent thickness of volcanic rocks, that despite local complexities of structures, amounts to at least 1000 feet thick. On the northwest corner of Granduc Mountain metavolcanic rocks outcrop in the crests of erroded, north plunging anticlines. In this area, the strike of the contact is in a northwesterly direction. The western contact of a thick band of volcanic rocks cuts across the northeast corner of Mount Willibert.

Petrography

The petrographic study deals only with the extreme western portion of the volcanic sequence on the south side of Granduc Mountain. Two complete sections from unsheared porphyritic andesite to the metasedimentary contact were studied, one on the surface and the other underground. Further east, the volcanics consist of porphyritic (pyroxene and/or feldspar) and non-porphyritic flows, with minor amounts of pillowed, brecciated, and fragmental types.

In hand specimen, the unsheared porphyritic andesite consists of dark green phenocrysts of "pyroxene" averaging about 1.0 mm in diameter, set in a fine-grained (0.15 mm diameter), medium green groundmass. Generally these rocks are structureless.

In thin section, the phenocrysts are found to consist of actinolite pseudomorphous after augite. Rarely small relict patches of augite can be observed. (The pyroxene has moderate birefringence, $Z \wedge C = 36^{\circ}$, and in one instance the typical 90° cleavage was observed.) The altered phenocrysts are set in a fine-grained matrix composed of plagioclase (An_{32}), actinolite, chlorite and epidote. Many of the actinolite pseudomorphs exhibit a slight porphyroclastic texture (Figure 4). Plagioclase tends to be highly altered to sericite and epidote. Relict albite twinning was observed in the less altered areas. Locally, almost all of the plagioclase has been altered to epidote and sericite.

The average mineral composition of six porphyritic andesites as estimated from thin sections is as follows:

Actinolite	47%
Plagioclase (An_{32})	26%
Epidote	9%
Biotite	6%
Sericite	5%
Chlorite	5%
Carbonate	2%
Sphene, Apatite	1%
Quartz	1%
Opaques	1%

Chlorite and biotite appear to be replacing actinolite marginally and along crystallographic boundaries. Sphene, apatite and iron ore(?) are present as accessories.

A relatively thin layer of brownish to brownish-green rock occurs between the unsheared porphyritic andesite and the quartz-rich phyllonites of the Mine member. This brownish rock is dense and fine-grained with a rather granular texture and a weakly developed schistosity. An excellent cleavage and irregular colour banding parallels this schistosity. Occasionally, relatively large (up to 1.5 mm in diameter) dark green grains of amphibole, and slightly greenish anhedral grains of feldspar were observed. These are generally oriented parallel to the schistosity. Pyrite occurs in finely disseminated grains and also in lens-shaped concentrations that parallel the schistosity. Lithologically similar rock is found underground at the contact of the volcanics and Mine member and near the Crapper Creek fault, but here, the rocks tend to be greener in colour and somewhat more fine-grained.

In thin-section, these rocks consist chiefly of porphyroclasts of actinolite and plagioclase (An_{32}) up to 1.0 mm in length, which tend to be oriented parallel to the schistosity. These grains are fractured and shreaded, and progressively decrease in grain size as the contact with the sediments of the Mine member is approached. (Figure 5). The prophyroclasts or are set in a fine-grained matrix composed essentially of biotite, chlorite, and fine-grained plagioclase. The micaceous minerals in the matrix are oriented and produce the schistosity in the rock. The average mineral composition of seven of these sheared andesites is tabulated on page 20.

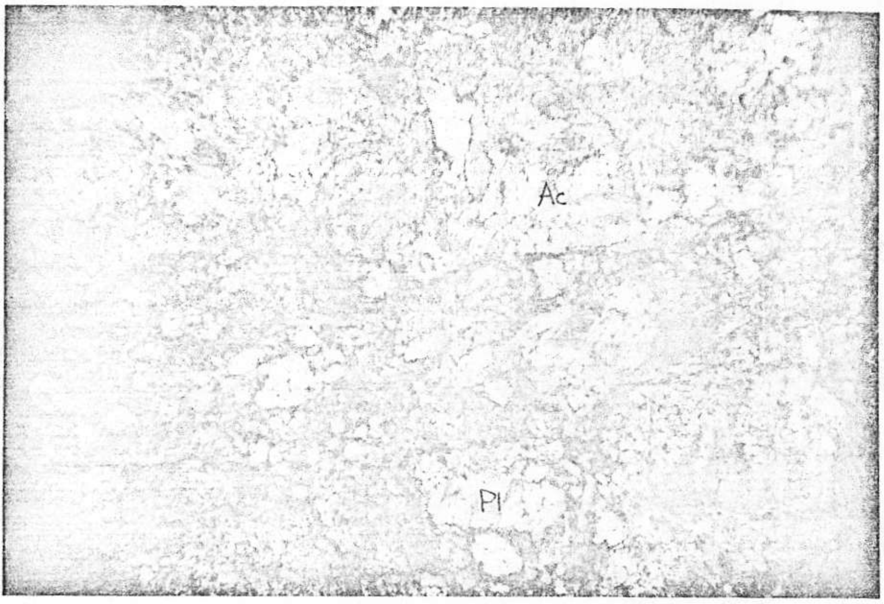


Figure 4

Photomicrograph of a typical porphyritic andesite. Many of the pseudomorphs of actinolite are porphyroclastic (X16)

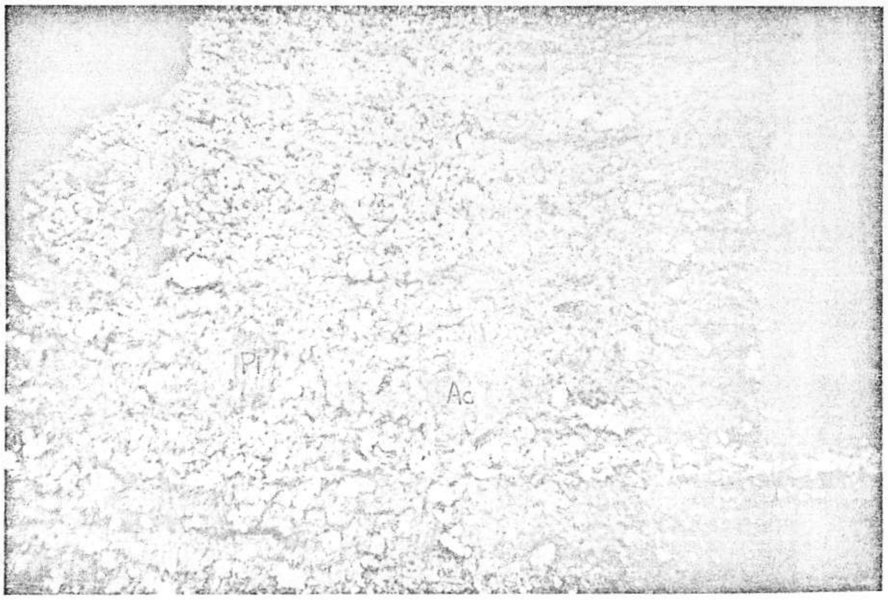


Figure 5

Photomicrograph of sheared andesite. Porphyroclasts of altered plagioclase and actinolite are set in the fine-grained schistose groundmass (X16).

Plagioclase (An_{32})	38%
Biotite	31%
Carbonate	11%
Chlorite	5%
Quartz	4%
Actinolite	3%
Epidote	3%
Sericite	2%
Opaque (pyrite)	2%
Sphene, Apatite	1%

Samples were taken underground across an intensely sheared section where the Crapper Creek fault zone cuts the volcanic rocks. The rocks in this zone consist of fine-grained green phyllonites and somewhat coarser grained chloritic schists. These rocks have a well-developed schistosity that is parallelled by lenses and layers of quartz-rich chlorite-rich and biotite rich material. Crumpling and drag folding is commonly found in the phyllonitic rocks. Finely disseminated pyrite is abundant in the less-sheared types.

In thin-section, these rocks were found to consist essentially of green biotite, chlorite, sericite, carbonate and quartz. Compositional banding is well-developed, with micaceous bands and lenses alternating with lenses rich in either quartz or carbonate. Tourmaline (var. schorlite) which is common in some of these rocks may have been introduced hydrothermally during shearing. A few relict shreds of actinolite persist in some of the less sheared specimens, but these are extensively altered to biotite and chlorite.

These rocks are generally fine-grained (0.15 mm diameter), but some quartz-rich and carbonate-rich lenses have an average grain size of up to 0.40 mm diameter. The larger size and the absence of any features indicative of straining, suggests that the material in the lenses crystallized at a late stage in the deformational history.

The average composition of five of these green phyllonites or chloritic schists is as follows

Quartz	22%
Chlorite	21%
Carbonate	19%
Biotite	19%
Sericite (Muscovite)	12%
Actinolite	2%
Schorlite	2%
Opaques (Pyrite)	2%
Epidote	1%
Sphene	1%

MINE MEMBER

Distribution

The rocks of the Mine member occur at the apparent base of the Metasedimentary formation, and overlie the metavolcanic rocks. Their stratigraphic relationships are most clearly shown on the northeast corner of Mount Willibert (Map 1), where their apparent thickness is 400 feet. On the north side of Granduc Mountain these rocks are interfolded with the metavolcanics, and outcrop in synclinal depressions. On the south side of Granduc Mountain, the apparent thickness of these beds is probably large because of close isoclinal folding. Infolding of the underlying metavolcanics and also of the overlying Schist member is suggested by the presence of bands of these rocks within the Mine member.

Petrography

The Mine member rocks are characteristically fine-grained, quartz-rich, and tightly folded. Included in the sequence is a limestone marked bed, and some irregular interbedded or interfolded bands of rocks that resemble those in the Schist member. The Mine member is divided into the following map units, each of which will be described

(i) Quartz-Sericite-(graphite-chlorite) phyllonite
(ii) Quartz-biotite-(chlorite) phyllonite
(iii) Plagioclase-biotite-chlorite-(calcite) schist
(iv) Amphibolite
(v) Limestone

Quartz-Sericite-(Graphite-Chlorite) Phyllonite

This unit is most commonly found in the lower part of the Mine Series near the contact with the underlying metavolcanics. The rocks are extremely fine-grained, the grains averaging less than 0.05 mm in diameter, and have a dull cherty appearance. Colour varies from light grey or cream to dark grey, with thin (less than ½ inch) colour-banding frequently well-developed.

In thin-section, compositional banding is a prominent feature. Layers rich in quartz alternate with layers rich in sericite (muscovite), and less commonly with chlorite- or graphite-rich layers. Minerals in these layers tend to be oriented parallel to the colour layering.

The quartz-rich layers consist of tiny interlocking anhedral grains that have a crude parallel orientation; both physically and optically. Individual quartz-rich layers or lenses tend to be equigranular, but adjacent quartz-rich layers or lenses may differ markedly in grain size, (Figure 6). Tiny micaceous laths (usually sericite), occur interstitially to the quartz grains, and these are oriented parallel to either the foliation or to an incipient axial plane cleavage that is visible in the more crumpled mica-rich layers.

The micaceous layers consist largely of fine-grained sericite (muscovite) associated with minor amounts of

Figure 6

Photomicrograph of quartz-sericite phyllonite. Microcrumpling is shown in the sericite-rich layers. Note the sharp contacts between equigranular layers of quartz. A few lenses of more coarse-grained recrystallized quartz are shown (X16)

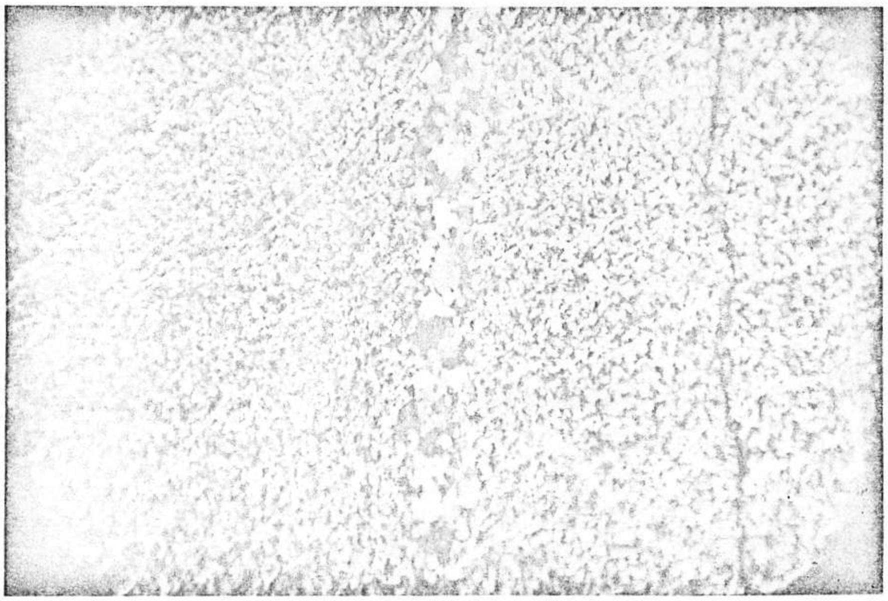


Figure 7

Photomicrograph of a quartz-sericite phyllonite showing an axial-plane cleavage filled with late quartz. Note that schistosity is marked by the tiny laths of sericite (light) (X42).

chlorite and biotite. Microcrumpling may be well-developed in these layers with a new S- plane produced that tends to parallel the axial plane cleavage in the larger folds.

Locally, graphite-rich layers are present in these phyllonites. Fine-grained graphite occurs interstitially to, and is included in fine-grained quartz.

More coarse-grained quartz (up to 0.60 mm diameter) is found frequently in lenses that parallel the schistosity at the crest of folds; and also in fractures that parallel axial-plane cleavage, (Figure 7). With, or near some of these coarser grained aggregates are grains of sericite, iron ore, chlorite, carbonate, and tourmaline (both dravite and schorlite). The quartz shows undulatory extinction and the development of Boehm lamellae, and some of the other minerals are bent or slightly fractured.

Some of the specimens contain a few anhedral porphyroblasts of plagioclase (An_7) that are as large as 0.30 mm in diameter. Tiny grains of apatite and sphene are present as accessories.

An average composition for eight quartz-sericite samples from the surface is as follows:

Quartz	56%
Sericite (Muscovite)	23%
Graphite	10%
Biotite	3%
Albite (An_7)	2%

Carbonate	2%
Chlorite	2%
Dravite & Schorlite	1%
Apatite, sphene, iron ore	1%

Macroscopically, samples of quartz-sericite phyllonites from underground are identical to types obtained from the surface section. However, in thin-section several notable differences in composition were observed. Little or no graphite is present, and the percentages of carbonate and chlorite are much higher. An average of five quartz-sericite phyllonites from underground is as follows:

Quartz	53%
Sericite (Muscovite)	22%
Carbonate	9%
Chlorite	9%
Albite (An_6)	3%
Iron ore	2%
Biotite	1%
Sphene, Apatite	1%
Epidote	1%
Schorlite, Dravite	1%

Carbonate and chlorite occur in porphyroblastic grains (up to 0.50 mm in diameter) throughout the rock; in anhedral grains in fractures; and associated with more coarse-grained lenses and lenticles. Some of the porphyroblastic grains poikiloblastically include small grains of quartz and sericite. Tourmaline (dravite and schorlite), iron ore, a and coarse-grained quartz are commonly associated with the carbonate and chlorite.

As the ore zones are approached, there is a gradational increase in the biotite content of these rocks, with a corresponding decrease in the sericite and chlorite content.

Quartz-Biotite-(Chlorite) Phyllonite

In hand specimen these rocks are texturally very similar to the quartz-sericite phyllonite just described. However, they are much darker in colour, ranging from medium to dark brown to dark greenish-grey. Foliation is marked by alternating thin layers of browns and greys of varying shades. Pyrite is commonly present in trains of small grains that parallel the foliation.

In thin-section these rocks are very fine-grained, (averaging 0.01 mm.) schistose, and slightly porphyroblastic. Compositional layering is well-developed with thin alternating layers of quartz-rich, biotite-rich, and biotite-chlorite-rich material. The biotite varies in colour from brown to olive-green, with a single colour generally predominating in a particular specimen.

Sericite is present in appreciable quantities in some of these rocks generally as tiny laths in the quartz-rich layers. Rarely, sericite is found in the micaceous layers,

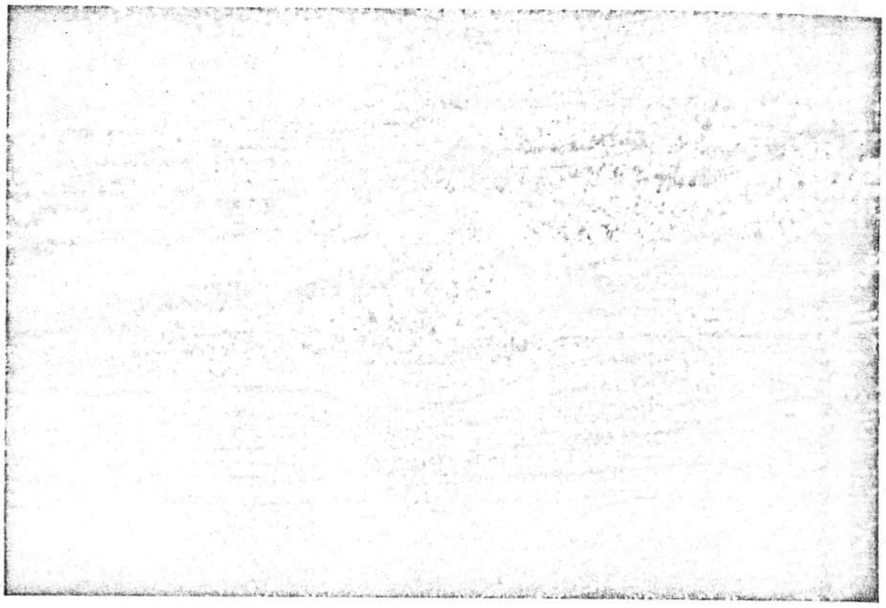


Figure 8

micrograph of a quartz-biotite phyllonite. Note
al zone containing "rolled" aggregates of more
e-grained quartz, "iron ore" and carbonate. S_2
s are incipiently developed in the fine-grained
onite (X16).

Figure 9

hotomicrograph of a lense of more coarse-
rained quartz in a quartz-biotite phyllonite.
ote the thickening of the lense in the crests
f the microfold (X16).

and it appears that most of the biotite, and at least some of the chlorite, has formed at the expense of sericite.

Epidote, schorlite, iron ore, chlorite, carbonate and lenses of coarser grained quartz occur in or adjacent to the micaceous layers (Figures 8 and 9). Most of these minerals occur in subhedral to anhedral grains up to 0.20 mm in diameter, many of which are unoriented. The quartz shows undulatory extinction, and some of the other minerals are bent or slightly fractured.

Albite occurs in anhedral porphyroblasts up to 0.20 mm in diameter. Only a few of these grains exhibit simple albite twinning. The porphyroblasts do not show a preferred orientation, some have their longest axis perpendicular to the foliation of the more fine-grained schistose groundmass.

Tiny grains of apatite, epidote, and sphene are present as accessories in the fine-grained quartz-rich bands.

The average composition of six quartz-biotite (chlorite) phyllonites is as follows:

Quartz	47%
Biotite	26%
Sericite	6%
Plagioclase (An_6)	6%
Epidote	4%
Tourmaline	3%
Opaques	3%
Carbonate	2%

Chlorite	2%
Apatite, Sphene	1%

Plagioclase-Biotite-Chlorite-(Calcite) Schists

On the south side of Granduc Mountain, these rocks occur on both sides of the limestone bed. To the west of the limestone, these rocks grade imperceptably into sheared dioritic rocks that will be described presently. The rocks are dark brown to green in colour, and although fine-grained, their average grain size is much larger than that of the biotite-rich phyllonitic rocks. Locally these rocks appear markedly porphyroclastic with elongate "metacrysts" of plagioclase up to 3 mm long, set in a fine-grained schistose groundmass. Foliation is defined by the subparallel orientation of biotite, plagioclase porphyroclasts (when present), and by thin colour layering.

Microscopically, these rocks are composed chiefly of anhedral porphyroclasts of plagioclase (An_{42}) that range in size up to 2.5 mm in length (Figure 10). These are set in a fine-grained biotite-rich groundmass. Many of the large grains of porphyroclastic plagioclase are well twinned, and to some degree all are fractured. Smaller grains of plagioclase in the biotite-rich groundmass appears to be porphyroblastic. Both the porphyroblastic and porphyroclastic plagioclase have the same composition. As the original plagioclase was reduced in grain size by shearing of in-

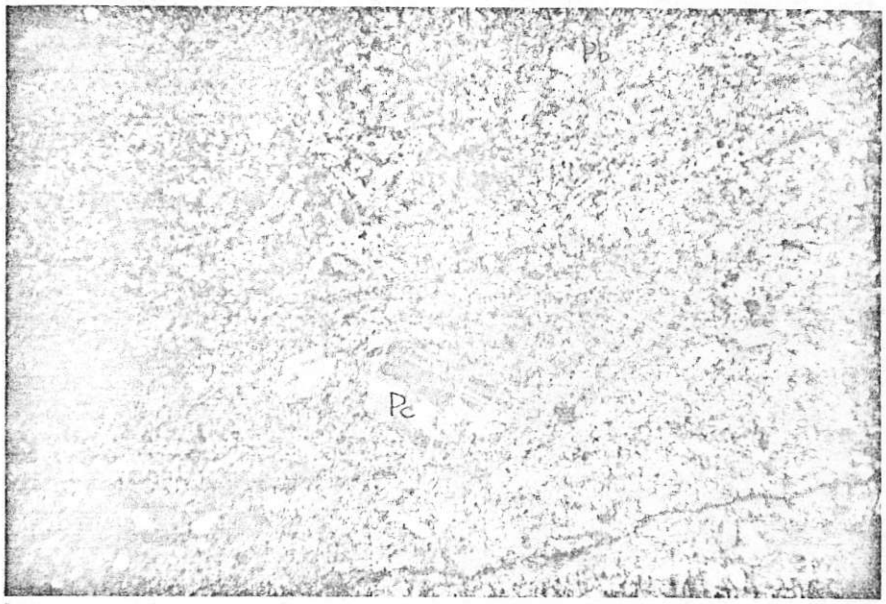


Figure 10

tomicrograph of a porphyroclastic plagioclase-
tite-chlorite-(calcite) schist. Porphyroclastic
gioclase (Pc) as well as smaller grains of porphyro-
stic plagioclase (Pb) are shown (X16).

Figure 11

otomicrograph of sheared limestone. Some patches
fine-grained granular quartz (Q) are present.
te orientation of calcite cleavage traces (X42).

tensity, the relative proportion of the porphyroblastic plagioclase increased. The plagioclase has been altered variably to fine-grained aggregates of epidote and sericite.

A few relict grains of actinolite were noted in some specimens, the amphibole was largely altered to biotite. In some cases biotite appears to have altered to chlorite, particularly near lenses of coarse-grained carbonate-chlorite-quartz aggregates.

Carbonate, chlorite, and some quartz occur in more coarse-grained (to 0.30 mm diameter) lens-shaped aggregates that cut across the foliation and include grains of plagioclase and biotite. Fine-grained carbonate also "floods" the groundmass in irregular zones that parallel the foliation. Some carbonate and quartz grains show optical stain.

Fine-grained epidote, quartz, apatite, and sphene are present as accessory minerals in the fine-grained biotite-rich groundmass.

An average composition of these porphyroclastic schists is

Plagioclase (An_{42})	43%
Biotite	20%
Carbonate	11%
Chlorite	9%
Sericite	7%
Epidote	3%

Quartz	2%
Apatite, Sphene	1%
Iron Ore	1%
Actinolite	1%

Amphibolite

An irregular narrow layer of a fine-grained, dark green schistose rock was observed at the 2C surface showing, where the rock was closely associated with the porphyroclastic plagioclase-biotite schists. Fragments of a similar rock were found in some of the ore specimens from the underground workings. Microscopic study showed that this rock is an amphibolite.

In thin-section, the rock is fine-grained, schistose, and porphyroclastic, and is composed almost entirely of actinolite. The actinolite occurs in subhedral to anhedral porphyroclasts up to 0.40 mm in length set in a fine-grained matrix of the same material. Most grains are bent and shredded. Actinolite appears to be altering to chlorite and biotite along grain boundaries and cleavage traces.

"Iron ore" and chalcopyrite(?) occur in euhedral to anhedral grains of varying size included in or interstitial to actinolite. "Trains" of opaque minerals tend to parallel the schistosity. A little quartz and sericite form fine-grained lenses that parallel the schistosity.

Limestone

The limestone occurs as a thin, highly contorted, bed near the hanging wall of the Mine member sediments, on the south side of Granduc Mountain. In hand specimen the limestone is fine-grained and varies in colour from light to dark grey or green. Where weathered the limestone has a rough surface produced by small lenses and individual grains of more resistant material. Weakly-developed colour layering and mottling plus the orientation of lenses of other minerals produce a foliation that is parallel to the contacts of the bed. Staining with potassium ferricyanide and ferric chloride shows that the carbonate is calcite.

Two beds of limestone are reported underground whereas only one was observed on surface on the south side of Granduc Mountain. On the northeast corner of Mt. Willibert, only a single bed of limestone is present in what appears to be a continuation of the Mine member sediments. On the north side of Granduc Mountain limestone and Mine member rocks have been involved in extremely complex folding. Both repetition and locally great apparent thicknesses of these beds can be explained by tight folding.

In thin-section, these rocks consist almost entirely of anhedral interlocking grains of calcite that average about 0.15 mm in diameter. An incipient foliation is marked by the sub-parallel arrangement of coarser and finer-grained lenses of calcite. Some lenses contain carbonate that includes tiny grains of opaque minerals, feldspar quartz, and epidote, whereas other lenses consist of clear, clean calcite. One set of twin lamellae in the calcite tends to parallel the foliation, (Figure 11).

Small grains of feldspar, epidote, apatite, opaque minerals, quartz and chlorite occur interstitially to the carbonate grains. Most of the plagioclase (An_{35}) is altered to sericite and epidote. Many of the quartz grains show strain shadows, and in many instances the grains appear to have been granulated.

The finer-grained and inclusion-free calcite appears to have been recrystallized during metamorphism with subsequent granulation and bending of twin lamellae.

The absence of any indication of reaction of the calcite with the included quartz during metamorphism, indicates that a high pressure was maintained in the pore fluids.

SCHIST MEMBER

A. Distribution

Rocks of the Schist member of the Metasedimentary formation outcrop over most of the western part of the map sheet. Because of complex folding the true thickness of these rocks could not be determined accurately, but it is thought to be several thousand feet.

B. Petrography

Plagioclase-biotite-actinolite-epidote schists with interbedded amphibolites are the predominant rock types in the Schist member. Several quartz-rich schists and one thin band of limestone are also present. The Schist member is divided into the following units for study and description.

(i) Plagioclase-biotite-actinolite-epidote schist
(ii) Amphibolite
(iii) Quartz-rich schist
(iv) Limestone

Plagioclase-Biotite-Actinolite-Epidote Schists

These rocks are generally fine-grained, schistose, and are either a dark reddish-brown or greenish-grey in colour. Commonly the schists have alternating layers of these colours. Such layering is parallel to the schistosity.

From the microscopic study it was found that the schists can be reliably sub-divided into two major groups on the basis of colour. The reddish-brown schists consist essentially of plagioclase and biotite, whereas the greenish-grey varieties consist largely of plagioclase, actinolite, and epidote.

(i) Plagioclase-Biotite Schist. Megascopically the plagioclase-biotite schist is fine-grained and has an overall reddish brown colour with thin alternating layers of lighter shades of brown and green. Foliation is expressed both by colour layering and by a pronounced cleavage that has a micaceous sheen.

Microscopically the rock is found to consist essentially of small (0.10 mm diameter), anhedral, interlocking grains of plagioclase (An_{34}), closely associated with interstitial, fine-grained, dark brown biotite. Both plagioclase and biotite tend to be oriented parallel to the foliation. Most of the plagioclase grains are untwinned with only a few exhibiting simple albite twinning.

Actinolite occurs in slightly larger, subhedral to anhedral grains that are oriented parallel to the schistosity. This mineral is found disseminated throughout the rock, and it is abundant in the thin greenish layers noted above. Optical characteristics of the actinolite are $Z \wedge C = 20^{\circ}$, and the mineral is pleochroic n_x = pale yellow, n_y = pale yellowish green, n_z = pale green.

The average mineral composition of this variety of schist is as follows:

Plagioclase (An_{34})	50%
Biotite	27%
Actinolite	7%
Chlorite	6%
Epidote	2%
Quartz	2%
Carbonate	2%

Sphene, Opaque minerals	3%
Carbonate	2%
Tourmaline (Schorlite)	1%

Chlorite occurs throughout the rock as small laths and aggregates associated with actinolite and biotite, apparently an alteration product. In some places biotite appears to have formed at the expense of actinolite. Such actinolite generally is not as pleochroic as the unaltered types, possibly because of loss of iron to biotite. More coarse-grained lenses parallel to the foliation, and some cross-cutting fractures contain aggregates of quartz and carbonate with lesser amounts of epidote, chlorite, schorlite and "iron ore", (Figure 12).

(ii) Plagioclase-Actinolite-Epidote Schist.

This variety of schist is fine-grained, compact and generally of a medium to dark green colour. Foliation is marked chiefly by the presence of thin lighter green layers. Cleavage is not as well-developed as in the plagioclase-biotite rich schist.

Microscopically, these schists are found to consist essentially of subhedral grains of light green actinolite averaging 0.15 mm in length, set in a matrix of fine-grained (0.02 mm diameter) plagioclase. Interlayered with this material are thin lenses and layers that are composed chiefly of anhedral interlocking grains of quartz and

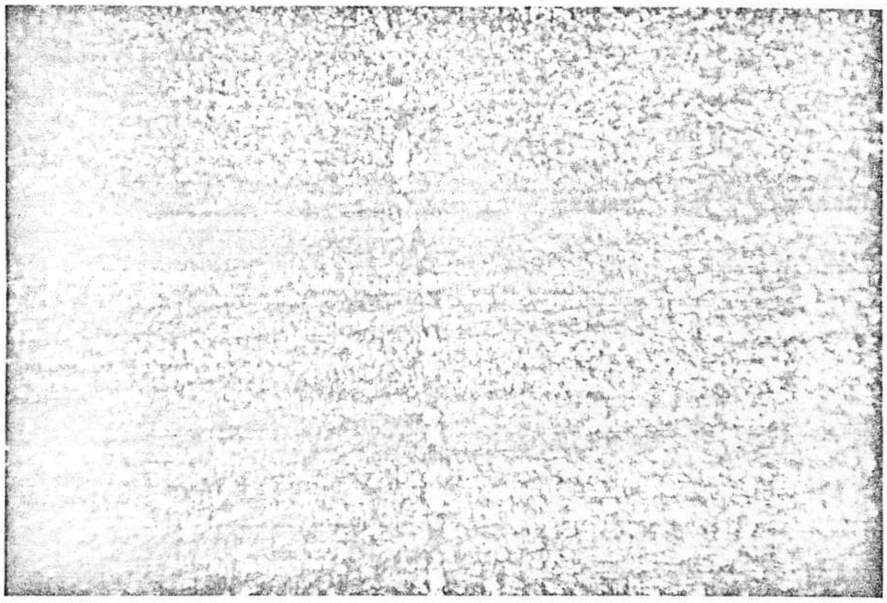


Figure 12

tomicrograph of a plagioclase-biotite schist
ving a fracture filled with more coarse-grained
tz, chlorite and "iron ore" (X16).

Figure 13

tomicrograph of a crumpled plagioclase-actinolite
dote schist. The dark material is actinolite
6).

epidote up to 0.10 mm in diameter. These produce the lighter coloured layers noted in the hand specimens. Sphene and iron ore are present as accessories.

Biotite is closely associated with actinolite and appears to be an alteration product of that mineral. In this variety of schist, as in that described previously, altered actinolite is not as strongly pleochroic.

Most grains, and in particular those of actinolite, tend to be oriented producing a well-defined microscopic schistosity that parallels the compositional banding (Figure 13).

An average plagioclase-actinolite-epidote schist has the following mineral composition.

Actinolite	40%
Plagioclase (An_{31})	30%
Epidote	10%
Quartz	15%
Biotite	3%
Chlorite	1%
Sphene and Opaques	1%

Amphibolite

Zones of amphibolite as much as 400 feet wide occur in the Schist member conformable to the foliation of the enclosing schists.

In hand specimen the amphibolite is dark green and medium- to fine-grained. Small (1.0 mm diameter) dark green grains of hornblende are conspicuous in the fine-grained green matrix. Foliation is well-developed, expressed mainly by the parallel orientation of hornblende. A good cleavage parallels the foliation. Near contacts with the batholithic rocks, the amphibolite is commonly more coarse-grained.

In thin-section, the amphibolite is found to consist essentially of almost equal amounts of olive-green hornblende, and plagioclase (An_{44}). The hornblende occurs as subhedral to anhedral grains up to 1.0 mm long, a few of which are twinned on (100). Foliation is marked by the subparallel orientation of hornblende grains which are set in a granoblastic matrix of interlocking, anhedral grains of plagioclase up to 0.30 mm in diameter, (Figure 14). Plagioclase exhibits both albite and pericline twinning. "Iron ore", apatite, sphene and epidote are accessories. Plagioclase is slightly sericitized, and some of the hornblende appears to be partly altered to biotite.

The average mineral composition of five amphibolites is as follows:

Plagioclase (An_{44})	46%
Hornblende	39%
Biotite	3%
Quartz	3%
Sericite	2%

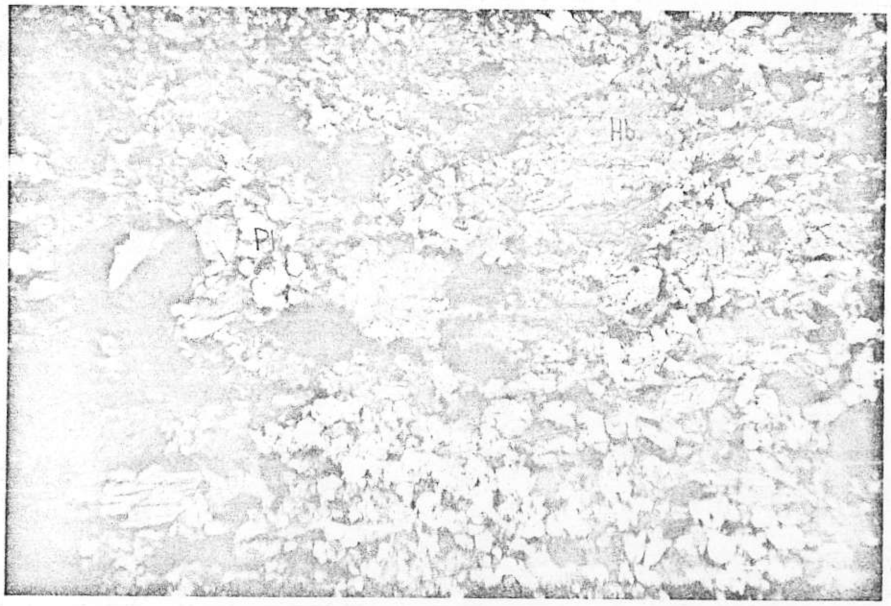


Figure 14

Photomicrograph of amphibolite. Subhedral grains of hornblende (Hb) are set in a more fine-grained granoblastic groundmass of plagioclase (Pl). Some of the hornblende is slightly porphyroclastic (X42).

Sphene	2%
Epidote	2%
Apatite	1%
Opaques	1%

These rocks are holocrystaline, medium- to fine-grained, with a pronounced nematoblastic texture. In some specimens incipient cataclastic effects were noted. Some of the plagioclase grains are granulated and exhibit sutured contacts, and some hornblende laths are bent and shredded. Alteration effects are slight. Compositional layering is present in some amphibolites, with plagioclase-rich lenses alternating with hornblende-rich lenses.

Quartz-Rich Schist

Numerous layers of quartz-rich schist occur throughout the Schist member. Most of these are less than 30 feet wide, but several in the southwest portion of the map-area (Map 1) may have a true thickness of several hundred feet.

Macroscopically these rocks are medium-grained, reddish-brown to pale grey or green in colour, and consist essentially of layers of granoblastic quartz. Colour layering is generally well-developed and locally thin (2.0 mm) lenses of more coarse-grained quartz accentuate the foliation. An excellent cleavage parallels the foliation, and on cleavage surfaces a micaceous sheen is prominent. Finely disseminated pyrite and a few small grains of feldspar and amphibole were noted in some specimens.

Although these rocks were not studied microscopically it is suspected that most have a considerable content of fine-grained micaceous minerals.

Limestone

A single band of limestone that ranges in width from 15 to 30 feet was traced along the southeast side of Mount Willibert and its probable continuation outcrops on the south side of the Leduc glacier. This map-unit is interbedded with plagioclase-biotite-actinolite-epidote schists.

In hand specimen, the limestone is medium-grained, pale grey to green in colour, and consists essentially of interlocking anhedral grains of carbonate. Ready effervescence with cold dilute HCl indicates that the carbonate is calcite. Weathered surfaces are generally rough due to the presence of thin lenses and individual grains of material that is more resistant to weathering. Colour banding and the subparallel orientation of lenses of less soluble material produce a foliation in the limestone. This limestone is very similar in appearance to that which occurs in the Mine member.

INTRUSIVE ROCKS

Distribution

The eastern contact of the main batholithic complex is approximately two miles due south of the Granduc mine, where it is relatively regular and trends approximately north 80° west. A few miles both east and west of the map-area, the contact resumes its normal northwesterly trend. Two miles northwest of the mine, irregular migmatite zones are present near the contact of the Metasedimentary formation and the batholithic rocks. In this vicinity, an irregular apophysis of granodiorite projects eastward from the main body of the intrusive mass. This protrusion is shown on the western edge of Map 1. . Here, as well as at the contact to the south, the batholithic rocks cut across the north-trending schistosity of the metamorphic rocks.

Several smaller satellitic intrusions outcrop on and north of Granduc Mountain. The largest of these is a subconcordant, elongated mass of foliated hornblende granodiorite, the south end of which is shown on the top of Map 1. To the east of the body of hornblende granodiorite there is a thinner (1000 feet) subconcordant body of foliated diorite. It is probable that this is related to the irregular, highly sheared and closely folded dioritic zone on Granduc Mountain that extends from west of the mine northward into the "limestone basin". Small irregular outcrops of diorite are found both east and north of the mine intruding volcanic rocks.

Aplite and granodiorite sills occur in swarms as much as 800 feet wide on the mountains to the south and west of the mine. Quartz diorite sills and dikes that range in width from one foot to several tens of feet are found on Granduc Mountain.

Petrography

The intrusive rocks are divided into the following units for study and description:

(i) Hornblende granodiorite
(ii) Dioritic phase of the hornblende granodiorite
(iii) Diorite "Sill"
(iv) Granodiorite
(v) Aplite and granodiorite sills
(vi) Quartz diorite - granodiorite sills and dikes

Hornblende Granodiorite

The hornblende granodiorite is a medium-grained, leucocratic, porphyritic rock, consisting essentially of phenocrysts of dark green hornblende and pale grey plagioclase up to 1.0 mm in diameter, set in a finer-grained groundmass of anhedral quartz and feldspar. A well developed foliation is produced by the common orientation of the hornblende.

In thin-section this rock was found to consist essentially of subhedral to anhedral phenocrysts of plagioclase (An_{32}) and hornblende that average 1.0 mm in size, set in a finer grained (0.30 mm) matrix of potash feldspar, quartz, and plagioclase. The feldspars are partly sericitized.

A strongly-developed preferred orientation of the phenocrysts, and to a lesser extent of the material in the groundmass, produces the foliation and lineation that can be observed in the hand specimens. Sphene, apatite and titanite(?) occur as accessories. Epidote, chlorite and sericite are probably deuteric.

A typical hornblende granodiorite sample has the following mineral composition:

Plagioclase (An_{32})	43%
Quartz	18%
Hornblende	12%
K-feldspar	10%
Epidote	7%
Sphene, Apatite	5%
Sericite	3%
Chlorite	2%
Opaques (Titanite ?)	1%

Dioritic Phase of the Hornblende Granodiorite

Irregularly shaped dioritic phases occur throughout the hornblende granodiorite mass, but are most abundant near the western contact of this body where it has intruded porphyritic andesite.

The diorite is a medium-grained, mesocratic porphyritic rock with a hypidiomorphic granular texture. Phenocrysts of dark green hornblende and light greenish plagioclase are set in a fine-grained green groundmass. Commonly the phenocrysts have a preferred orientation producing a well-developed foliation. The dioritic phases appear to be the result of assimilation of and/or reaction with the country rock.

In thin-section, the diorite consists essentially of phenocrysts of plagioclase (An_{48}) and hornblende that average 1 mm in size. These are set in a finer-grained (0.10 mm) groundmass of sericite, epidote, chlorite, plagioclase, and hornblende. The texture of the rock is holocrystalline, medium-grained, porphyritic, and hypidiomorphic granular. An incipient porphyroclastic texture is expressed locally by fractured grains and bent cleavage and twin lamellae. Much of the plagioclase is altered to sericite and epidote, and chlorite appears to have formed at the expense of hornblende. Sphene, apatite and titanite are accessories.

An average mineral composition of this dioritic phase is as follows:

Plagioclase (An_{48})	46%
Hornblende	35%
Sericite	10%
Chlorite	3%
Epidote	3%
Sphene, Apatite	2%
Opaques (titanite?)	1%
Carbonate	1%

Smaller bodies of diorite that intrude the volcanic rocks to the north and east of the mine are texturally and compositionally similar to this hybid phase of the hornblende granodiorite.

Diorite "Sill"

This is a zone of essentially dioritic composition roughly conformable with the metasedimentary rocks, that is itself marginally sheared and locally closely folded. The zone extends from a point immediately west of the mine northward to the "limestone basin", and its probable northern continuation occurs east of the hornblende granodiorite mass. On the north side of Granduc Mountain diorite has been closely folded along with the limestone unit of the Mine member. At this place transitions can be traced from normal diorite through carbonatized greenstones and greenschists to mixed calc-silicate rocks. On the south side of Granduc Mountain, the diorite occurs in a zone 500 to 600 feet wide immediately west of the mine. This concordant body consists of a thin irregularly-shaped core of diorite that grades through greenstone and greenschist, to very fine-grained green phyllonitic rock. The gradation represents progressive stages in the cataclastic destruction of the original dioritic mass by dislocation metamorphism. The petrographic study is restricted to that part of the diorite zone on the south side of Granduc Mountain where the zone can be divided into three map units: (i) the dioritic core,

(ii) the adjacent greenstone-greenschist zone, and (iii) the marginal green phyllonite zone.

Dioritic Core. Megascopically, this rock is a green medium-grained, slightly porphyritic diorite. Dark green phenocrysts of hornblende(?) and cloudy greenish-grey grains of plagioclase are set in an altered fine-grained green matrix. A fairly well-developed foliation is produced by the subparallel orientation of some of the phenocrysts.

Microscopically, the rock is foliated and holocrystalline, and consists essentially of highly altered porphyroclasts of actinolite-hornblende and plagioclase set in a fine-grained matrix of epidote, sericite, chlorite, plagioclase, and amphibole, (Figure 15). The original texture appears to have been hypidiomorphic granular, but this has been masked by the extensive alteration and granulation of the primary silicates.

Plagioclase (An_{38}) occurs in anhedral grains up to 1.5 mm in diameter, now almost completely altered to sericite and epidote. Albite twinning can be seen in the less altered areas.

Most of the amphibole present in the section appears to be iron-rich, actinolite ($Z \wedge C < 20^\circ$). The actinolite is pleochroic. (n_x= yellowish to colourless, n_y = yellowish-green, n_z= pale green to dark bluish green). Some green hornblende ($Z \wedge C = 28^\circ$) is also present, but the relative proportions of the two minerals could not be accurately determined because of their similar colour. The amphibole appears to be altered to chlorite along grain boundaries. Some of the amphibole is pseudomorphic after pyroxene, possibly augite, a few small isolated relicts of which persist in some amphibole grains. This pyroxene has moderate birefringence and a maximum $Z \wedge C = 48^\circ$, and in one instance, pyroxene cleavage was observed.

The mineral composition and relative mineral percentages are as follows:

Plagioclase (An_{38})		23%
Actinolite	20%±	25%
Hornblende	5%±	
Chlorite		10%
Epidote		25%
Sericite		10%
Sphene		5%
Apatite		1%
Augite		1%

Greenstone-Greenschist Zone. These rocks border the diorite core and represent an intermediate stage in the cataclastic destruction of the diorite.

Megascopically, these rocks are generally fine-grained, dark to medium green in colour, and may, or may not

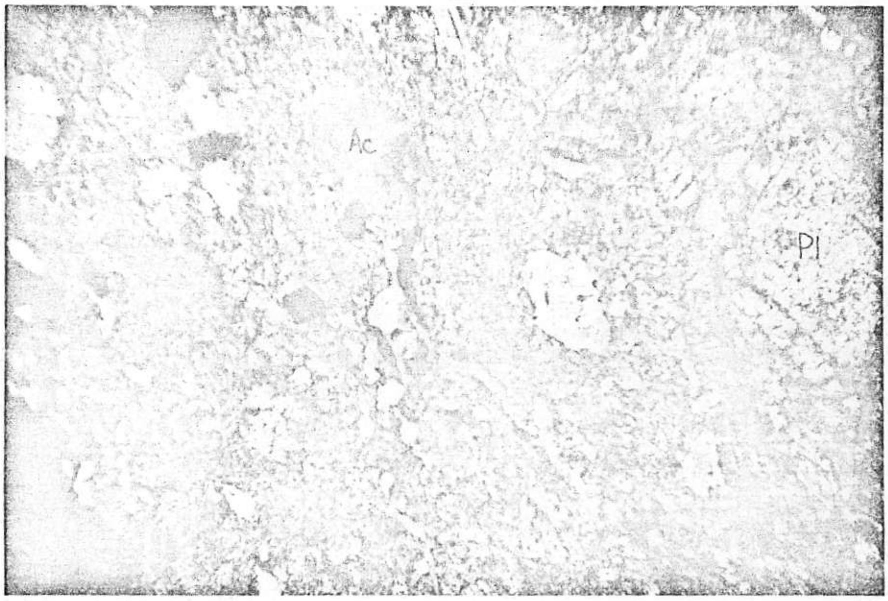


Figure 15

Photomicrograph of sheared diorite. Porphyroclasts of plagioclase (Pl) and actinolite (Ac) set in a fine-grained matrix of plagioclase, amphibole, epidote, chlorite and sericite (X16).

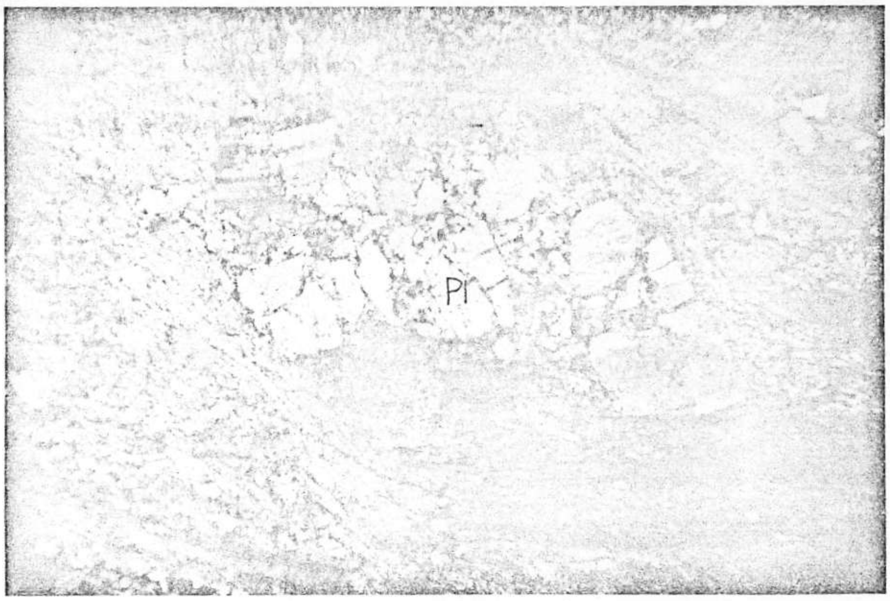


Figure 16

Photomicrograph of a greenschist. Note porphyroclasts of plagioclase (Pl) set in the fine-grained groundmass (X42).

be foliated or schistose. An occasional small porphyroclast of amphibole and feldspar may be observed. Thin bands of lighter coloured material that parallel the foliation are present in the more schistose types.

In thin-section, the rock has a well-developed porphyroclastic texture. Sericitized plagioclase (An_{35}) and amphibole grains are extensively fractured, shredded and oriented parallel to the foliation. The porphyroclasts of plagioclase and amphibole (up to 1.0 mm in the largest dimension) are set in a finer-grained matrix consisting of epidote, sericite, chlorite, plagioclase, and amphibole, (Figure 16).

Two varieties of amphibole are present, iron-rich actinolite and hornblende. Some values of $Z \wedge C$ approach 28°, while others are less than 20°. Both minerals are similar in colour, so that an accurate estimate of their relative proportions could not be made.

The composition of a typical greenstone is as follows:

Plagioclase (An_{35})		35%
Actinolite	12%$\pm$	22%
Hornblende	10%$\pm$	
Epidote		27%
Chlorite		8%
Sericite (Muscovite)		5%
Carbonate		3%
Biotite		2%

Incipient metamorphic differentiation appears to have taken place producing compositional layering on an almost microscopic scale.? Alternating thin layers and lenses of material rich in epidote, plagioclase or amphibole are common.

Most of the chlorite, epidote, biotite, and sericite present in the rock is probably an alteration product of the primary silicates.

Green Phyllonite Zone. The rocks of this zone, marginal to the diorite "sill", have undergone the greatest effects of dislocation metamorphism.

In hand specimen, these rocks are very fine-grained, and generally medium to light green in colour. Foliation is marked by thin, alternating bands of light and dark green material. An excellent cleavage parallels this foliation. Such rocks effervesce readily in cold dilute HCl indicating a high calcite content.

In thin-section, these rocks consist essentially of porphyroclasts of plagioclase (An_{33}) set in a fine-grained (0.10 mm in diameter) matrix of chlorite, carbonate, and plagioclase (Figure 17 and 18). Grain size of the sericitized porphyroclasts of plagioclase has been reduced to an average of 0.45 mm diameter. A typical green phyllonite had the following composition.

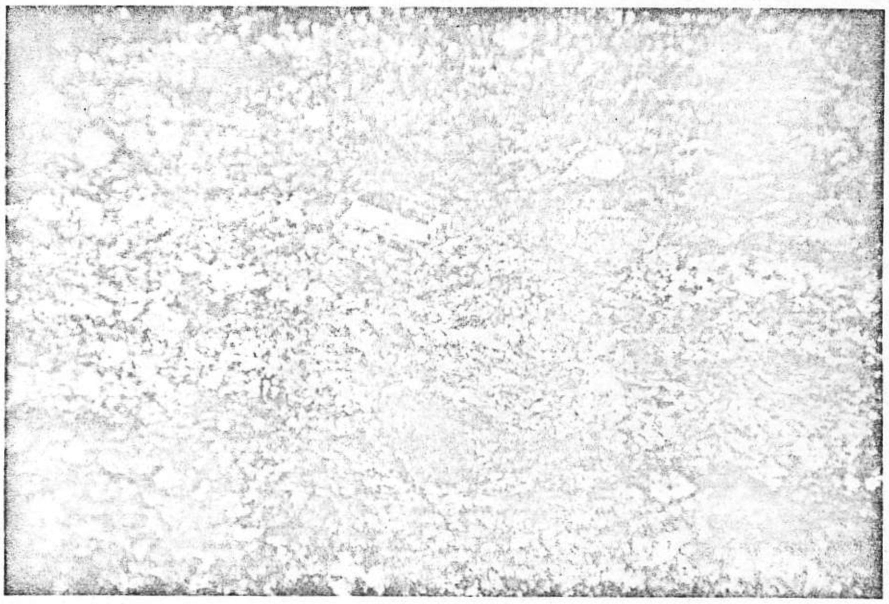


Figure 17

hotomicrograph of a green phyllonite. Note the
lagioclase porphyroclasts set in the fine-grained
chistose matrix (X42).

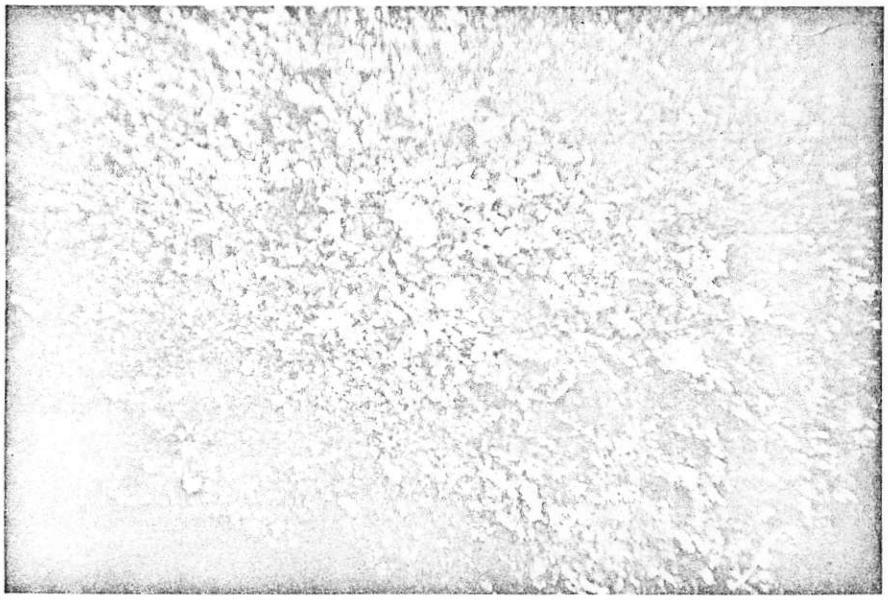


Figure 18

hotomicrograph of a green phyllonite. Note zone
flooded" with carbonate (light)(X42).

Plagioclase (An_{32})	40%
Chlorite	30%
Carbonate	25%
Sericite	3%
Opaques	2%

Chlorite and carbonate appear to have formed at the expense of the amphiboles and epidote.

Granodiorite

No samples of rock from the main body of batholithic rocks were studied. Buddington (1928, p. 180) found that 16 analysed specimens of batholithic rock from an area about 10 miles south of the mine had the average composition of quartz monzonite. Bacon (1955) mapped the igneous rocks 2½ miles south of the mine, and called them medium-grained granodiorite of the following composition:

Plagioclase (Oligoclase-Andesine)	45%
Quartz	26%
Potash Feldspar	18%
Biotite + Hornblende	9%
Accessories	2%

The rock in the apophysis that cuts the Schist member on the west side of the map-area is a medium-grained, locally porphyritic, leucocratic biotite granodiorite that consists essentially of plates of dark green biotite set in a groundmass of interlocking anhedral grains of feldspar and quartz. Biotite and feldspar commonly show a preferred orientation that produces an incipient foliation.

Aplite and Granodiorite Sills

Aplitic sills predominate in the sill swarms on the mountains to west and south of Granduc Mountain, but a few granophyric granodiorite sills are present also in these swarms. The sills range from a few feet to 50 feet in thickness. Locally they cut the Schist member with slight discordancy.

Macroscopically the aplite is leucocratic, medium-grained, and consists almost entirely of anhedral interlocking grains of white feldspar and quartz which are set in a fine-grained siliceous matrix. In places these rocks are markedly porphyritic, and some have a graphophyric texture.

In thin-section the aplite consists of anhedral grains of quartz, albitic plagioclase, and some potash feldspar up to 2.0 mm in diameter. These are set in a fine-grained matrix of quartz, microperthite, microcline, and potash feldspar. Biotite, muscovite, apatite and epidote are present in small amounts. The rock is holocrystalline, hypidiomorphic granular, medium- to coarse-grained and porphyritic. A typical specimen has the following composition:

Plagioclase (An_9)	45%
Quartz	30%
Potash Feldspar	20%
Muscovite	2%
Epidote	1%
Biotite	1%
Apatite	1%

The less numerous granodiorite sills are similar to those found on Granduc Mountain, except that many have a more pronounced granophyric texture in the groundmass.

Quartz Diorite - Granodiorite Sills and Dikes

Numerous sills and dikes are found on Granduc Mountain. These range in width from one foot to several tens of feet. In handspecimen, the rocks are medium-grained, porphyritic, leucocratic and consist essentially of altered, subhedral to anhedral phenocrysts of plagioclase (An_{30} - An_{36}) up to 1.5 mm in length set in a finer-grained groundmass. Some phenocrysts are normally zoned, having more albitic rims. The groundmass consists of plagioclase (generally more albitic than An_{30}), quartz, hornblende, and chlorite. Potash feldspar may or may not be present. Quartz and feldspar may form granophyric intergrowths in the groundmass, particularly in dikes to the south of the mine near the contact with the batholithic rocks.

Much of the feldspar is altered to sericite and epidote, and some chlorite appears to have formed at the expense of hornblende. Sphene, apatite and titanite(?) occur as accessories.

The compositions of these dikes vary from granodiorite to quartz diorite. Relative proportions of plagioclase to potash feldspar could not be accurately determined because of the intensive alteration of much of the feldspar, but plagioclase appears to predominate. The average composition of four specimens from Granduc Mountain is:

Plagioclase (An_{30}-An_{36}	39%±)	49%
K-feldspar	10%±)	
Quartz		15%
Sericite		10%
Chlorite		10%
Epidote		6%
Hornblende		3%
Biotite		2%
Apatite, Sphene		2%
Carbonate		1%
Opaques (titanite?)		1%

STRUCTURAL GEOLOGY

The "tops" of the steeply dipping stratified rocks could not be ascertained with the available evidence. Locally, pillow structure was seen in the porphyritic andesite east of the mine, and structures that might be graded bedding were observed in the Schist member in the southwest corner of the map sheet, but because of complex folding these "top" determinations could not be related to the overall structure. However, the orientation of drag-folds, both small and large, on Granduc Mountain is compatable with the presence of a major anticlinal axis to the east.? Further, the volcanic rocks structurally underlie the metasedimentary rocks with apparent conformity, so that unless the stratified rocks are completely overturned, the volcanic rocks must be older. Overturning on a large scale would be required because the westerly dips in the volcanic rocks flatten markedly to the east of the mine. If the volcanic rocks are older, their map distribution also indicates a major anticlinal axis to the east. Therefore, although the evidence is not conclusive, it is believed that the Granduc mine is on the west limb of a major anticline.

The metasedimentary formation is characterized by tight isoclinal folding with sharp crests, (Figures 19 and 20). Folds in the metavolcanic rocks tend to be more open and have more rounded crests, (Figures 21 and 22). Amplitudes of the folds range from a few millimeters to hundreds of feet. Much of the apparent interbedding of map units seen both on surface and underground is attributed to repetition by close folding. Ptygmatic folding is found in the igneous-metasedimentary complex of the dike swarms and migmatite zones on Mount Willibert.

Figure 19

Tight folding in metasediments displayed on a faceted spur.

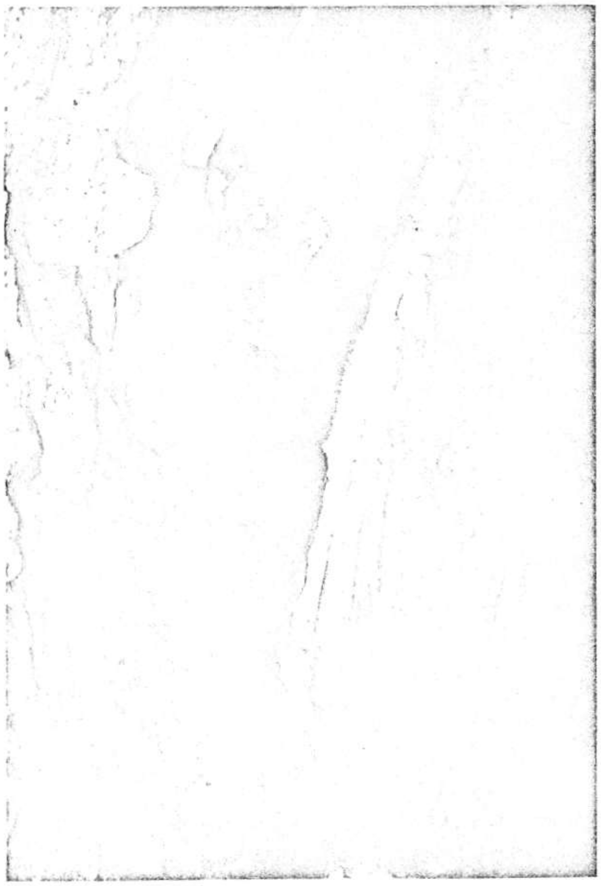


Figure 20

Isoclinal folding in a quartz-biotite phyllonite in the 3250 level. Face is approximately 6 feet high.

Figure 21

Folding in metavolcanics to the east of the mine on Granduc Mountain. View looking northeast.

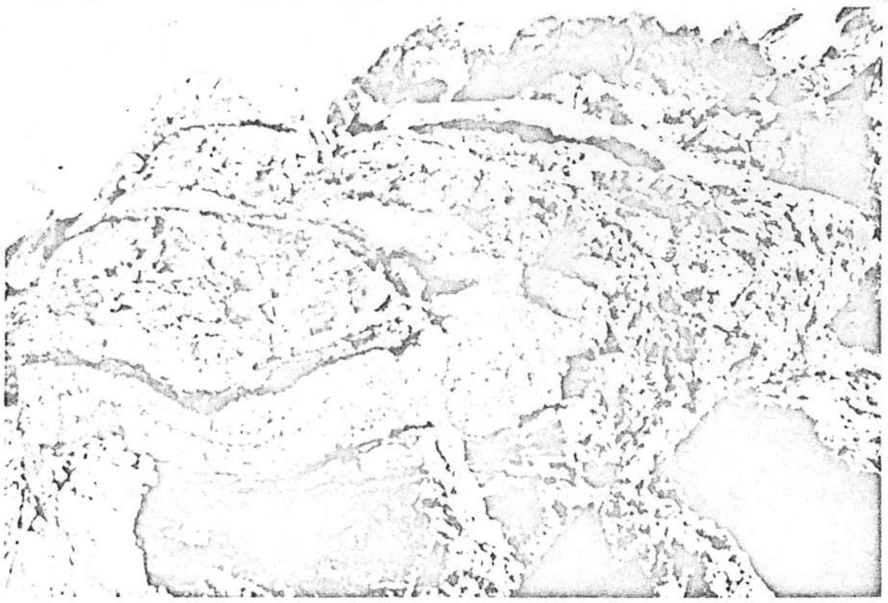


Figure 22

Recumbent fold in sheared andesite on top of Granduc Mountain 1½ miles east of the mine. Note thickening at the crest. This outcrop is approximately 20 feet wide.

Most of the rocks in the area are foliated, and locally sheared and faulted. The structural elements are considered in detail in the following sections.

ANALYSIS OF FOLD STRUCTURES, FOLIATIONS AND LINEATIONS

The Granduc Area is divided into five zones (Map 3), for the fold analysis. Within each of these zones the orientation of foliations were measured and the poles to planes plotted and contoured on a stereographic net (lower hemisphere projection). Lineations were plotted on the same diagram but were not contoured. Poles to axial-planes of drag folds were plotted on separate diagrams. In all zones, there is a striking concentration of poles to foliation and a correspondence of poles to axial planes that is indicative of isoclinal folding.

On the south side of Granduc Mountain the average strike of both foliations and axial-planes is north 31° west with a dip of 62° west in Zone I, and north 29° west with a dip of 83° west in Zone II. In each zone, there is a concentration of lineations (fold axes) near the pole to the great circle that can be drawn through the contoured poles of foliation. This indicates that the lineations are related to isoclinal folding. In Zones I and II the average lineation trends south 52° west with a plunge of 60° to the southwest, and south 30° west with a plunge of 50° to the south respectively. A few scattered lineations are present, and these probably represent the incipient modification of the isoclinal folds by a second period of folding. A marked flattening of fold axes to the north was found in a study made along the 3750 drift at the mine. The plunges of fold axes were measured and the results averaged for each 400-foot interval of the 1600 foot tunnel. From south to north the averages were 51°, 39°, 38° and 23° respectively.

On the northwest corner of Granduc Mountain and on the east side of Mount Willibert (zones IV and V respectively) there is a pronounced change in the structural trend as compared with the area previously mentioned. In zones IV and V, the average trend of foliations and axial planes is north 44° west with a dip of 80° to the west, and north 34° west with a dip of 50° to the west respectively. In both zones, lineations tend to plot along a line that bisects a great circle drawn through the concentration of poles to foliations. A weakly developed concentration of lineations about the pole (B) of this great circle shown in Zone IV, indicates that a fold axis trending S38°E and plunging moderately south is related to isoclinal folding. A second period of folding is suggested by the scattering of the remaining lineations. Lineations in zone V trend both northwesterly and southeasterly with no apparent concentration. These lineations represent fold axis of isoclinal folds, hence the absence of a concentration is indicative of a second period of folding.

Zone III is an area of inflection in which the northeast structural trend of zones I and II swings to the northwest trend that is established in zones IV and V. Isoclinal folding is indicated by the concentration of poles to foliations and axial-planes on the stereographic projection. Two "high" points of poles to foliations are apparent, one indicating an average attitude of north 8° east with a vertical dip and the other north 19° west with a vertical dip. The former is thought to reflect the structural trend of zones I and II, whereas the latter reflects the northwesterly trend of zone IV and V. Lineations (fold axes of isoclinal folds) trend roughly north and south, with plunges to the south tending to be steeper than those to the north. The absence of a concentration of lineations is indicative of a second period of folding.

Drag folding in the metasedimentary and metavolcanic rocks indicates that the isoclinal folding is related to the formation of the large anticline that is believed to lie to the east of the mine. The anticlines and synclines in Zones III and IV and on the northwest corner of Granduc Mountain are interpreted as large drag folds which have the same sense as the minor folds. The original "b" lineations (i.e. fold axes of isoclinal folds) produced by regional metamorphism probably paralleled the kinematic "b" axis, with compressional forces acting along east or northeast axes.

Both field observations and graphic analysis suggest that a later period of folding is involved in the deformational history of the area, and this is represented by warping of the structural elements related to the isoclinal folding. The axial trace of these broad, younger folds trend westerly (see Zone III and IV). A cyclographic representation of the average foliation in zones II and IV shows that the fold axis of the younger fold trends approximately due west, and plunges steeply. However, the distribution and orientation of lineations (isoclinal fold axes) in zones III, IV and V requires a more horizontal axis for the younger folds, as regardless of plunge the trends of lineations have not been swung appreciably to the east or west. This crinkling of the old "b" axis does not appear to have taken place in zones I and II, as here the plotted lineations have a pronounced concentration.

The strongly-developed structural trend (northerly) of the isoclinally folded stratified rocks continues south of the map-area and eventually is sharply terminated by the contact of the Coast Range batholith. The cross-cutting relationship of the batholithic rocks with respect to the isoclinally folded stratified rocks is shown also by the granodiorite apophysis on the east side of Mount Willibert. Hence, isoclinal folding preceded the intrusion of the batholithic rocks. The second period of folding is believed to have taken place during, or after intrusion of the Coast Range batholithic rocks. Post-folding intrusion of quartz diorite sills and dikes (considered closely related to the batholithic rocks) is suggested by a sill-like body that cuts across a warped band of amphibolite on the west side of Granduc Mountain. On the other hand, a fairly large continuous quartz diorite sill that is present near the snow line in Zone III appears to have been flexed by the second period of folding. Buddington (1928, p. 288) and MacKenzie (1916, p. 111) have recognized Eocene folding in Alaska and northeastern British Columbia with compressional forces acting almost at right angles to those that acted during Mesozoic orogeny. The sense and time relationship of such a compression is compatible with the flexuring produced by the younger folds in the Granduc area.

SHEARING AND FAULTING

A 1000-foot zone to the west of, and including the Mine member-metavolcanic contact on the south side of Granduc Mountain appears to have been a zone of structural weakness over a considerable period of geologic time. The rocks in this zone were dynamically metamorphosed to phyllonites in the late stages of regional metamorphism. Drag folding and the development of axial plane cleavage indicate that this initial differential movement was related to the formation of the postulated anticline that lies to the east of the mine.

Evidence of particularly intense deformation at a late metamorphic stage is evidenced by brecciated ore specimens that contain fragments of both regionally metamorphosed schists and phyllonitic rocks. The brecciated zone appears to have been a major channel for mineralizing solutions. Some question arises as to the time relationship of this economically important period of differential movement and the second period of folding. Several possibilities are discussed under the heading "Ore Controls".

A set of late longitudinal faults is found in the area. These are post-intrusive, and later than the secondary period of folding. On the south side of Granduc Mountain these faults trend approximately north 20° east and are essentially parallel to the foliation in the phyllonitic rocks. To the north however, these faults appear to cut across the foliation where the isoclinally folded rocks have been flexed by second-period folding. Right-handed movements are indicated by faulted quartz diorite dikes and steeply plunging drag folds near the fault planes. Three such faults have been recognized in surface mapping above the mine and the total apparent horizontal displacement of a quartz diorite dike is in the order of 1000 feet. The vertical component of this movement is not known.

The underground workings are essentially bounded by two major faults, both of which are represented by gullies on the surface. The eastern most of these is the Crapper Creek Fault which is well displayed underground just west of the shaft on the 3250 level, where porphyritic andesites have been intensely sheared to green phyllonite and chloritic schists over a wide zone.

Mineralized shear zones of a minor nature are found to the east of the map-area in the volcanic rocks, but these are not of economic significance. It is not known to which period of shearing these are related.

PETROGENESIS

Metavolcanic Rocks

The andesitic volcanic rocks are extensively altered, even where dislocation metamorphism has not been active. Original ferromagnesian minerals have been altered to actinolite, chlorite and epidote, and the primary feldspars have been altered to sericite and epidote.

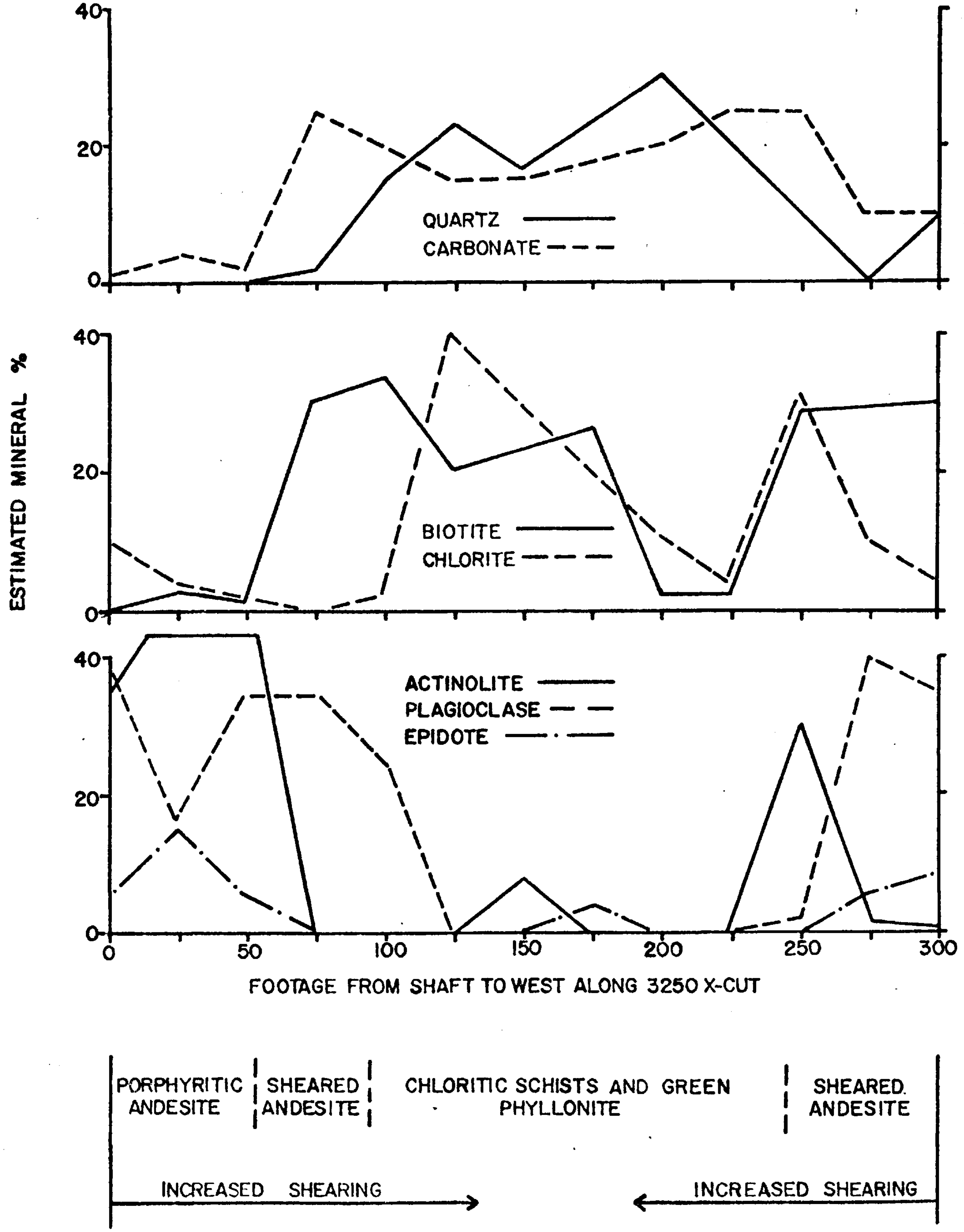
The actinolite and epidote present in the unsheared metavolcanics appears to have been unstable under the conditions that existed in zones of differential movement, and these minerals progressively disappeared as the intensity of shearing increased. Much of the biotite, chlorite and carbonate found in the sheared metavolcanics appears to have formed at the expense of actinolite and epidote. Except in the more intensely sheared zones, plagioclase has been only granulated.

In the 3250 level, specimens were taken at 25 foot intervals across the Crapper Creek fault zone, from altered porphyritic andesite on the east, westerly through greenstones and greenschists, to chloritic schists and green phyllonites. The marked changes in mineralogy with the intensity of shearing are graphically illustrated in Figure 23. Actinolite is the first mineral to be affected in the high stress environment, altering to biotite, chlorite and carbonate. Much of the quartz, and some of the carbonate and chlorite present in the chloritic schist and green phyllonite zone appears to have been derived from plagioclase and epidote in this zone of intense shearing.

Concordant, more coarse-grained, quartz-rich and carbonate-rich lenses are commonly found in the schistose and phyllonitic rocks. The mineral constituents in these lenses show little evidence of straining (incipient undulatory extinction in quartz, and bent cleavage traces in the carbonate). It is thought that this material was "mobilized" during shearing with subsequent recrystallization at a late stage of the dislocation metamorphism. Schorlite and some of the "iron ore" in the more highly sheared rocks is thought to have been introduced at a late stage.

FIGURE 23

SECTION ALONG 3250 CROSS-CUT THROUGH THE CRAPPER CREEK FAULT ILLUSTRATING CHANGES IN MINERALOGY IN THE VOLCANICS WITH INTENSITY OF SHEARING



Ignoring the relict porphyroclastic plagioclase and actinolite, the mineral assemblage in the sheared andesites can be classified in the biotite-chlorite subfacies of the greenschist facies (Turner and Verhoogen (1951)). Locally, in more highly sheared zones, the rocks contain appreciable muscovite. These rocks could be classified in the muscovite-chlorite subfacies of the greenschist facies.

The extensive alteration of primary silicates to chlorite, biotite, epidote and sericite, and the more marked changes in mineralogy in zones of differential movement, are a result of retrogressive metamorphism of an initial high temperature mineral assemblage.

MINE MEMBER

Quartz-Sericite-(Graphite-Chlorite) Phyllonite

The mineral assemblage in these rocks appears to be in equilibrium (with the exception of the incipient alteration of sericite and chlorite to biotite) and the rocks can be classified in the muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen 1951). The original rock was probably an impure sandstone, composed largely of quartz and argillaceous material, with local concentrations of carbonaceous material.

The more coarse-grained quartz lenses that are found parallel to the schistosity, at the crest of folds, and in fractures that parallel axial plane cleavage, represent mobilization and recrystallization at a late stage in the history of the rock. Associated with these coarser-grained aggregates are grains of sericite, iron ore, chlorite, carbonate; dravite and schorlite. Abundant tourmaline is found associated with sulphides in the ore zone, and it is postulated that the tourmaline minerals, and possibly some of the chlorite, carbonate and iron ore, have been hydrothermally introduced into the phyllonitic rocks. Strain effects are exhibited by the quartz and some of the other minerals, indicating that crystallization took place before differential movement had ceased.

Quartz-Biotite-(Chlorite) Phyllonite

The mineral assemblages in these rocks do not permit classification of the whole group into a single subfacies of the greenschist facies. Biotite predominates in the micaceous bands of all rocks in this group, but most of this material appears to have formed as a result of hydrothermal alteration. The micaceous bands appear to have offered a more permiable channel for hydrothermal solutions than did the dense, fine-grained, quartz-rich bands. This is supported by the more common occurrence of introduced and/or remobilized minerals such as epidote, schorlite, iron ore, chlorite, carbonate and coarser-grained quartz, in, or adjacent to the micaceous bands. In many biotite-rich rocks sericite persists as tiny laths in the dense fine-grained quartz-rich bands, and in others, some or all of the sericite appears to have formed biotite. Apparently the rocks closer to the ore zones have been subjected to sufficiently high temperatures during mineralization to attain equilibrium in the biotite-chlorite subfacies of the greenschists facies, whereas rocks further away are gradational into the muscovite-chlorite subfacies of the greenschists facies.

The original sediment from which those rocks were formed was probably pelitic, possibly a sandy shale. Small scale (i.e. in the order of mm's). Compositional banding and lensing in these rocks is attributed to metamorphic differentiation during the milling down of an assemblage that was originally of higher metamorphic grade.

Plagioclase-Biotite-Chlorite-(Calcite) Schists

The mineral assemblage in these rocks does not permit classification in a metamorphic facies. The relict plagioclase is indicative of a moderate to high-grade mineral assemblage, but the extensive alteration of actinolite to biotite is suggestive of a much lower metamorphic rank.

These schists are assumed to have formed from medium-grained rocks that consisted largely of plagioclase and actinolite. Dioritic and andesitic rocks that consist chiefly of these minerals, have produced similar porphyroclastic plagioclase-biotite schists in shear zones.

A dioritic parentage for these rocks seems unlikely since the porphyroclastic schists are found immediately on either side of the limestone band on surface. No cross-cutting relationships were observed, and it is difficult to see how an intrusive could have been so neatly placed along both contacts of the limestone band without disrupting it on surface or at depth.

The possibility of a volcanic origin for these schists is ruled out because none of the known volcanic rocks contain plagioclase grains as large as the feldspar porphyroclasts found in the schists.

The close association of these schists with sedimentary rocks seems to favour a sedimentary origin. Amphibolites of an appropriate composition are found in the Schist member to the west. These consist almost entirely of actinolite, and a plagioclase (An_{44}) that is somewhat more calcic than that found in either the dioritic or volcanic rocks.

The existence of these coarser-grained schists in a zone that is characterized by fine-grained phyllonitic rocks can be attributed to at least one of two factors. Shearing intensity may have been less near the hanging wall of the Mine member, or most of the effects of dislocation metamorphism may have been taken up in the quartz rich sediments which would be much more unstable in a high stress environment.

In any event, the shearing effects were not strong enough to initiate the chemical breakdown of the plagioclase in the porphyroclastic schists. Actinolite, however, has altered readily to biotite and chlorite. The co-existence of these two minerals may permit classifying these rocks in the biotite-chlorite subfacies of the greenschist facies.

Amphibolite

The incipient alteration of actinolite to biotite and chlorite indicates that the mineral assemblage is not in equilibrium. However, dislocation metamorphism at this point must have been of a minimum intensity. In all other amphibole-rich rocks in the area, the actinolite is one of the first miaerals to chemically break down in a stress environment. As the adjacent plagioclase-biotite-chlorite-(calcite) schists appear to be approaching equilibrium in the biotite-chlorite subfacies of the greenschist facies, the amphibolite is also assigned to this metamorphic grade. The plot of the composition of this rock on an appropriate ACF diagram (Turner and Verhoogen 1951, p. 466) indicates that the amphibolite was derived from a calcareous assemblage, possibly a marl. A sedimentary origin is favoured because of the close association of the amphibolite with limestone and other metasedimentary rocks.

Limestone

The finer-grained and inclusion-free calcite appears to have recrystallized during metamorphism, with granulation and bending of twin lamellae taking place at a later time. The interstitial fine-grained feldspar, quartz, epidote, and chlorite probably represent siliceous and argillaceous impurities in the parent limestone.

SCHIST MEMBER

Plagioclase-Biotite-Actinolite-Epidote Schist

The mineral assemblage present in these rocks does not permit ready classification in a conventional metamorphic facies. The presence of moderately calcic plagioclase (An_{34}), epidote and amphibole is suggestive of an assemblage of moderate metamorphic grade. Ignoring the incipient alteration of biotite to chlorite, and actinolite to biotite and chlorite, the rocks could be classified in the almandine amphibolite facies (Fyfe, Turner and Verhoogen 1958, p. 230). The coexistence of medium plagioclase and epidote is considered to be characteristic of the staurolite-quartz subfacies of this facies; which in turn is indicative of high grade regional metamorphism. However, on the northeast corner of Mount Willibert, these schists are separated by approximately 300 feet of Mine member rocks, from massive, slightly altered, porphyritic andesites. Neither the volcanics nor the phyllonitic rocks have been involved in high grade regional metamorphism.

Tilley (1924) showed that the greenschist facies of Eskola embraced two distinct facies, one characterized by chlorite-epidote-albite, and the other by hornblende-oligoclase-epidote. Turner's (1933) work in Otago, New Zealand, showed that schists consisting of pale hornblende-oligoclase-epidote appear to be the product of progressive regional metamorphism of rocks which had already formed as chlorite-epidote-albite-calcite schists at lower grades of regional metamorphism. Turner modified Tilley's subdivision by making calcite an addition constituent of the lower grade assemblage, thus giving the two facies characterized by chlorite -epidote-albite-calcite, and hornblende-oligoclase-epidote. Actinolite could be present in grades of metamorphism that were transitional to these two facies. The essential factors relating the two facies is the instability of chlorite in the presence of calcite, and the necessity of maintaining a high enough pressure of CO_2 to keep the carbonate from breaking down. The presence of hydrous silicates (micas and amphiboles) in the Metasedimentary formation, indicates that a high pore pressure did exist.

Turner (1935) proposed subfacies of the greenschist facies based on CO_2 pressure, but this has since been abandoned. However, he did show that an assemblage equivalent to that found in the Schist member can form under pressure and temperature conditions that exist in the upper part of the greenschist facies.

Ignoring the anorthite content of the plagioclase, the mineral assemblage of these schists can now be classified in the quartz-albite-epidote-biotite subfacies of the greenschist facies. (Fyfe, Turner, and Verhoogen 1958). This subfacies is characteristic of low to moderate regional metamorphism, and more readily explains the close association of these schists with the relatively unaltered porphyritic andesites.

Near the batholithic contacts there is an increase both in grain size and metamorphic grade of the schists. This is chiefly due to thermal metamorphism. Some of these rocks undoubtedly reach the amphibolite facies, since they grade into migmatites in some places at the contact with the batholith.

A plot of the composition of these schists on the appropriate ACF diagram (Fyfe, Turner and Verhoogen 1958, p. 222) indicates that the rock is a "basic assemblage". The original sediment therefore is probably the derivative of a basic or semibasic rock, possibly from a terrain that consisted of the older andesitic assemblage. The great thickness and relatively uniform composition of these rocks suggest rapid erosion and deposition and the close association with semibasic volcanic rocks is characteristic of a eugeosynclinal environment. A typical sediment of this environment is greywacke. Schists derived from greywackes in Otago New Zealand have been described by Turner that are almost identical to those of the Schist member. It is therefore concluded that the plagioclase -actinolite-epidote-biotite schists of the Schist member also were originally greywackes, or tuffaceous greywackes. The greater percentage of lime silicates in the plagioclase-actinolite-epidote subdivision of these schists, suggests that the greywackes locally were more calcareous.

Lenses of coarser-grained quartz and epidote are commonly found in the crests of both macrofolds and microfolds. Apparently these minerals "flowed" from areas of high stress, and recrystallized in the crests of folds where the confining pressures would be lower. Carbonate, schorlite and iron ore are commonly found associated with the more coarse-grained quartz-rich aggregates. All of these coarse-grained minerals appear to have crystallized near the close of differential movement. Quartz and carbonate show only slight strain effects.

Amphibolite

The mineral assemblage of these rocks permits classification in the staurolite-quartz subfacies of the almandine amphibolite facies (Fyfe, Turner and Verhoogen 1958). However, they are intimately associated with the plagioclase-actinolite-biotite-epidote schists which have been established as being in the quartz-albite-epidote-biotite subfacies of the greenschist facies, and therefore must have been subjected to the same pressure and temperature conditions during regional metamorphism. The lack of relict igneous textures, the lack of thermal effects on the adjacent metasedimentary rocks, their uniform texture regardless of width, and the complete absence of retrograde metamorphism seems sufficient evidence to eliminate the possibility of these being basic sills. It is therefore postulated that the amphibolites were originally lime rich sedimentary beds, possibly interbedded limy marls. Their coarser-grain size and anomolous composition (i.e. an apparent higher grade metamorphic assemblage) may be the result of the original assemblage being more sensitive to metamorphism.

Quartz-Rich Schists

These rocks are believed to represent argillaceous sandstones that have been regionally metamorphosed to quartz-rich schists or impure quartzites. Grain size is much larger than that found in the quartz-rich phyllonites in the Mine member. Apparently dislocation metamorphism was not as intense in rocks of the Schist member.

Limestone

The thin limestone band present in the Schist member was not studied microscopically. Handspecimens of this rock closely resemble the limestone unit of the Mine member, and it is assumed that the petrogeneses are similar.

INTRUSIVE ROCKS

Hornblende Granodiorite

Irregular dioritic phases occur throughout the hornblende granodiorite mass, particularly at the western contact north of the map-area, where it has intruded porphyritic andesite. The more basic phases appear to be the result of reaction with and/or assimilation of basic volcanic and sedimentary rocks. All rocks in this subconcordant intrusive complex are well foliated.

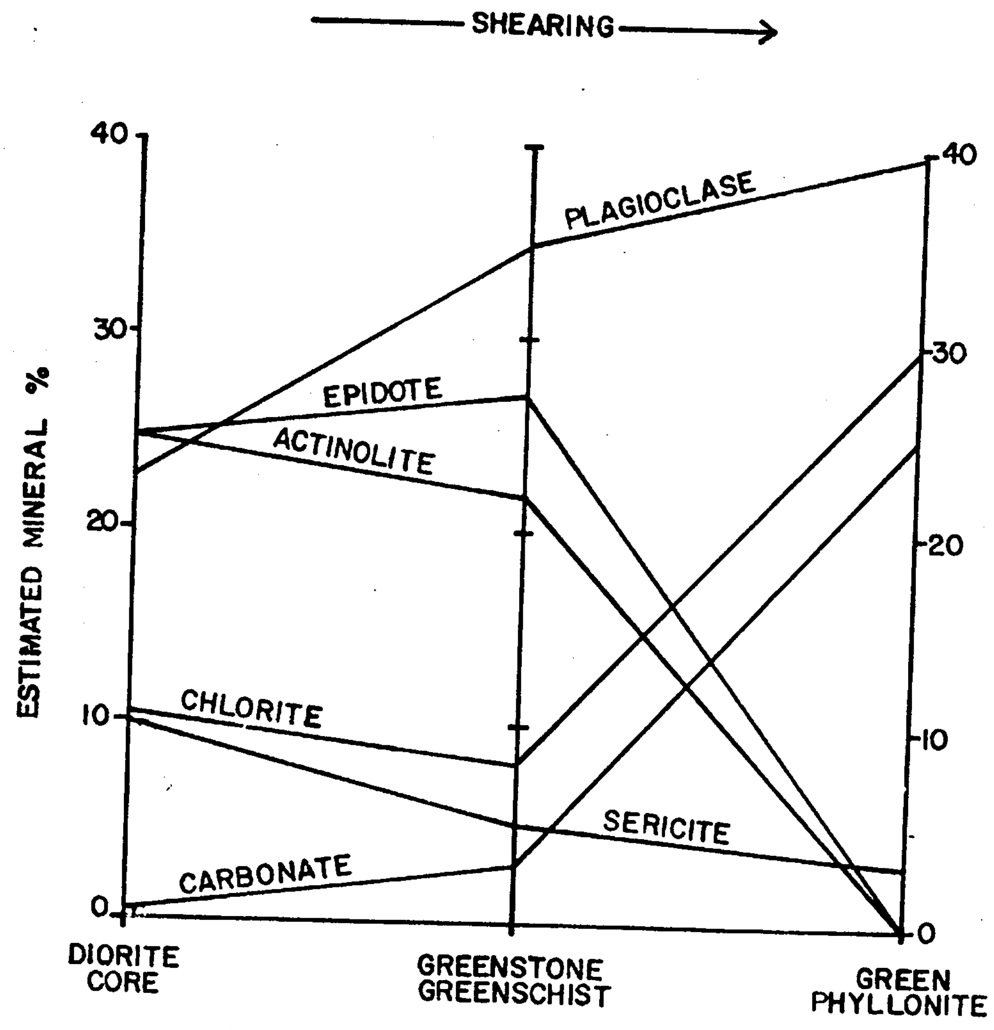
A thinner (1000 feet) subconcordant body of foliated diorite occurs 1/4 mile east of the hornblende granodiorite, and this diorite is similar in composition and texture to the dioritic phases found in the hornblende granodiorite intrusion. This thin diorite body appears to be the northern continuation of the dioritic zone that is found on Granduc Mountain. On the north side of Granduc Mountain, the foliated diorite has been involved in the complex isoclinal folding, and is considered to have been intruded synkinematically during regional metamorphism.

Diorite

The unsheared and relatively unaltered diorite on Granduc Mountain is similar in composition and texture to the dioritic phases that are associated with the hornblende granodiorite. A detailed study was made on the south side of Granduc Mountain west of the mine in the zone where altered diorite has been transformed through greenstones and greenschists to green phyllonites by dislocation metamorphism. Figure 24 illustrates the changes in mineralogy with increased intensity of differential movement.

FIGURE 24

GRAPH ILLUSTRATING CHANGES IN MINERALOGY WITH INTENSITY OF SHEARING IN DIORITE SILL



The altered nature of the unsheared diorite core in this zone indicates that the initial high temperature mineral assemblage of the intrusion has undergone retrogressive metamorphism. Original ferromagnesian minerals have altered to actinolite, and the plagioclase to epidote and sericite. The altered diorite grades into a greenstone-greenschist zone with only slight changes in mineralogy. However, the rocks in this zone are markedly porphyroclastic. With a further increase in the intensity of shearing, the greenstones and greenschists are transitional into a zone of green phyllonites. This transformation is characterized by the chemical breakdown of the lime silicate minerals (actinolite and epidote) to produce calcite and chlorite. The porphyroclastic plagioclase has only undergone further mechanical breakdown in the transition from the greenstone-greenschist rocks to green phyllonite. Excluding the relict plagioclase, the mineral assemblage can be classified in the muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1951), which is characteristic of the lowest grade of regional metamorphism.

The transition of altered diorite to green phyllonite is clearly due to retrogressive metamorphism.

Conclusions

Both the stratified rocks and the earlier intrusive rocks have been involved in regional metamorphism, and all appear to have tended towards equilibrium in the higher grades of the greenschist facies. The greywackes and marls have been progressively metamorphosed to form schists that can be classified in the quartz-albite-epidote biotite subfacies of the greenschist facies. Almost identical mineral assemblages are found in the altered diorite and metavolcanics, and it is concluded that these initial high temperature assemblages have undergone retrogressive metamorphism to attain or approach equilibrium in the same metamorphic facies. With subsequent dislocation metamorphism, the quartz-rich sediments and some of the igneous rocks have undergone retrogressive metamorphism, and have attained equilibrium in lower grade subdivisions of the greenschist facies.

CORRELATION OF THE GRANDUC ROCKS

Metasedimentary and Metavolcanic Rocks

Due to the lack of fossils, and the complex structure in the area, the metasedimentary and volcanic rocks in the Granduc Area can not be readily correlated with established formations to the north or south. A tentative correlation will be attempted on the basis of lithologic similarity.

The presence of a thick series of greywackes and the abundance of semibasic volcanics in the area, is suggestive of a euogeosynclinal environment. Such conditions existed in both Upper Paleozoic and Mesozoic times. These periods of sedimentation were separated by the Cassiar Orogeny which terminated Paleozoic deposition.

Kerr (1948), has mapped Permian and pre-Permian rocks in the Stikine River Area, 25 miles northwest of the Granduc Area. He divided the pre-Permian rocks into two parts, a lower part which consisted chiefly of fine-grained quartz-rich clastic rocks, and an upper part which was made up essentially of impure limestone. Volcanic rocks are of minor occurrence, and are reported only in the lower part of the pre-Permian group. Thick limestone beds are reported north of the Granduc Area, but their relationship to the Granduc rocks is not known.

Triassic rocks in the Stikine Area, consist chiefly of basal andesites, overlain by a thick sequence of greywackes. Some of the basal volcanics are pillowed, and fragmental and porphyritic types are also reported. The volcanic rocks are overlain by greywackes and tuffaceous greywackes, which Kerr believes have been derived largely from the underlying volcanic rocks. Bands of black and dark grey argillite, some of them limy, and beds of brown sandstone are reported to be widely distributed throughout the greywacke sequence. Limestone is present in many places, usually in local lenses, but in a few instances in fairly continuous beds up to 100 feet thick. Fossil evidence indicates that these sediments are Upper Triassic in age.

The Jurassic rocks described by Kerr consist largely of interbedded shales and conglomerates, with some tuffs, greywackes and argillites in the upper part of the series. Locally thin andesite and dacite flows are reported. Jurassic-Cretaceous rocks consist of a basal andesite that is overlain by a sequence of thick, massive, andesitic flows alternating with sediments. These sediments include banded jasper and chert, shales, greywackes and argillites. Upper Cretaceous and younger sediments appear to have been deposited in an increasingly continental environment. Finer-grained sandstones, arkoses, and shales interbanded with conglomerates predominate.

Admitting the possibility of local variations in the depositional environment in a euogeosyncline, it is thought reasonable to assume that the general geological conditions existing in the Stikine Area, some 25 miles to the north, would closely approximate those in the Granduc Area at the time of deposition.

On studying the Stikine lithology, Kerr's basal Triassic andesite and Upper Triassic sediments seems to closely match the lithology found in the Granduc Area. The porphyritic andesites are similar, and the thick greywacke sequence with thinly interbedded limey argillites would readily correlate with the Metasedimentary Series. Further Kerr's Upper Triassic rocks include relatively thin limestone beds and "brown sandstones", which could be equivalent to Mine Series rocks.

Hanson (1935) mapped the Portland Canal Area just to the southwest of the Granduc Area. All of his sedimentary and volcanic rocks (and their metamorphic equivalents), with the exception of very minor amounts of Tertiary volcanics, have been assigned to the Hazelton group. This group includes rocks that are believed to range from Triassic to Lower Cretaceous in age. Sedimentary and volcanic rocks similar to those found in the Granduc Area, are found in the Hazelton group. Sediments that Hanson believes to be of this Group, outcrop on Mount White-Fraser, 6 miles due east of Granduc Mountain.

Bacon (1955) mapped the Granduc Area, and assigned the metasedimentary and metavolcanic rocks to the Hazelton group. In southeastern Alaska, Buddington (1928) mapped a series of sedimentary and volcanic rocks of Upper Triassic to Lower Jurassic age, that seem correlative with the Hazelton group.

The composite evidence suggests that the Granduc metasedimentary and metavolcanic rocks are of Lower Mesozoic age, possibly Triassic or Lower Jurassic. Age, and the lithology of these rocks indicates that they are best correlated with the Hazelton group.

Additional detailed regional work may prove correlation of some of Kerr's Mesozoic groups with Leech's (1901) Hazelton group.

Intrusive Rocks

The foliated dioritic intrusions were intruded into the rocks of the Hazelton group before or during regional metamorphism, and were involved in complex isoclinal folding with the stratified rocks. The well-developed foliation in the diorite favours synkinematic intrusion. Although the relationship of the subconcordant gneissic hornblende granodiorite with other intrusive rocks in the area is not known, it is considered to be closely related in time to the intrusion of the diorite. Kerr (1948 p. 32) sites an example of hornblende granodiorite boulders in Jurassic conglomerates in the Stikine area. Buddington (1928 p. 219, 239) describes hornblende andesine granodiorite intrusions of possible Jurassic age south of the mine, near Hyder Alaska. Both writers consider that the more basic phases of the Coast Range granitic complex are older than the more acid types.

Granodiorite of the main Coast Range batholith cuts the well-developed, northerly trending structures in the Hazelton group rocks. Granodiorite, quartz diorite and aplite sills and dikes in the area are believed to be closely related to the intrusion of the major granitic complex. Quartz diorite dikes cut across the sheared diorite zone on the south side of Granduc Mountain. The major part of the Coast Range batholith in this area appears to be later than both regional metamorphism, and the intrusion of the diorite, and is presumed to be Lower Cretaceous or later in age.

CHAPTER V - ECONOMIC GEOLOGY

DESCRIPTION OF THE ORE BODIES

The ore occurs chiefly in biotite-rich phyllonitic and schistose rocks in the Mine member. Mineralized zones are tabular and essentially conformable with the metasediments on the south side of Granduc Mountain. Two ore zones have been recognized, the A (west) and B (east), which range in width from 25 to 50 feet, and 50 to 150 feet respectively. At the 3250 portal, the two zones are approximately 400 feet apart, but they appear to merge 1700 feet to the north. The ore bodies persist at least 1500 feet below the 3250 level (B.C.Minister of Mines Rept. 1955, p. 16), and there appears to be a convergence of the two zones with depth. 25,600,000 tons of ore averaging 1.62% copper are reported to have been proved by diamond drilling (Bacon 1955).

MINERALOGY

Mineralization consists essentially of pyrrhotite, chalcopyrite, pyrite and sphalerite. A narrow band of magnetite is locally present in the footwall of the 2B surface showing.

Coarse-grained introduced quartz is present in lenses and blebs that commonly parallel the foliation and produce a "knotted" texture in the host rock. This later quartz is also found in fractures and axial plane cleavages that cut the foliation.

Sulphides occur as disseminated grains, stringers, and massive bands or blebs that are commonly conformable with the foliation in the host rock. Concentrations are also found adjacent to lenses of introduced quartz in fractures in the quartz, and in or near micaceous rich bands in the country rock.

In hand specimen, the heavily mineralized samples appear to consist of fine-grained biotite-rich host rock, that is impregnated with concentrations of sulphides and introduced quartz. However, on cutting these specimens for polishing, it became apparent that some of these rocks are brecciated, with sulphides and introduced quartz filling the interstices and replacing fragments of the host rock, (Figure 25).

Unbrecciated ore consists essentially of massive and disseminated replacements of sulphides and coarser-grained quartz along planes that generally parallel the foliation in biotite-rich phyllonites (Figure 26). The content of both sulphides and introduced quartz drops off rapidly away from the brecciated high-grade zones. Local concentrations are present near blebs of introduced quartz and in fractures in both phyllonitic and schistose rocks.

The ore specimens studied microscopically were obtained from the underground workings, as the surface outcroppings were generally too highly fractured and oxidized

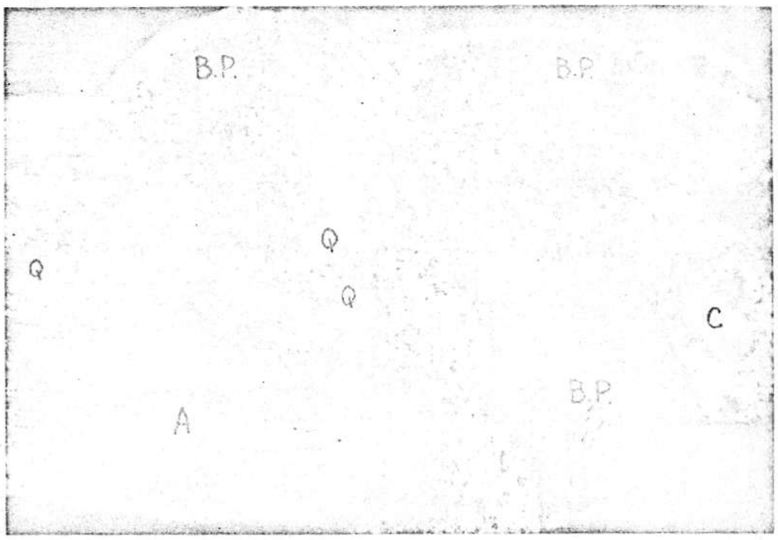


Figure 25

Brecciated ore. Fragments of quartz-biotite phyllonite (B.P.) and amphibolite (A) are conspicuous on the polished surface. Note interstices filled with sulphides and blebs of introduced quartz (Q) and carbonate (C). Specimen is approximately 4 inches across.

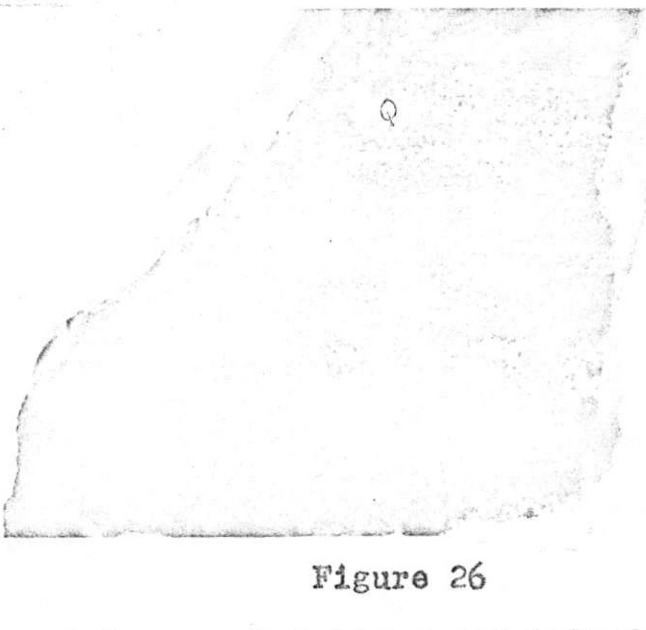


Figure 26

Replacement ore. Sulphides and introduced quartz (Q) replacing quartz-biotite phyllonite along favourable lithologic zones. Specimen is approximately 3 inches across.

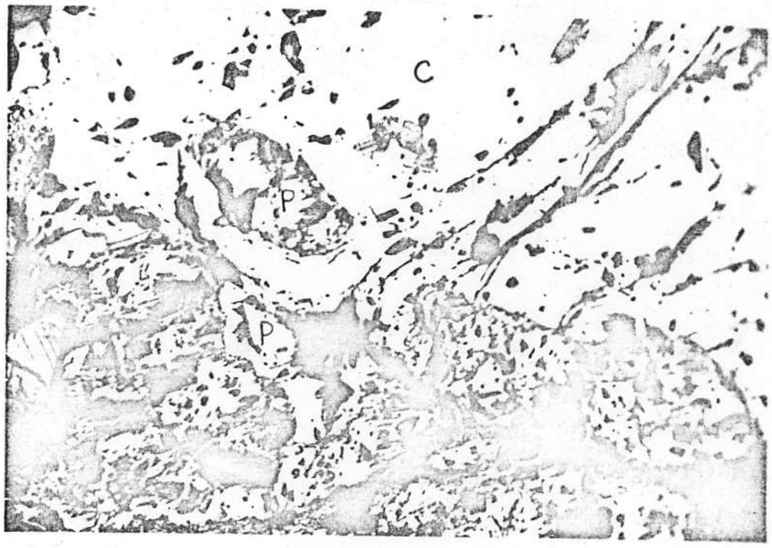


Figure 27

Photomicrograph showing mutual boundary relations of pyrrhotite (P) and chalcopyrite (C). (X20).

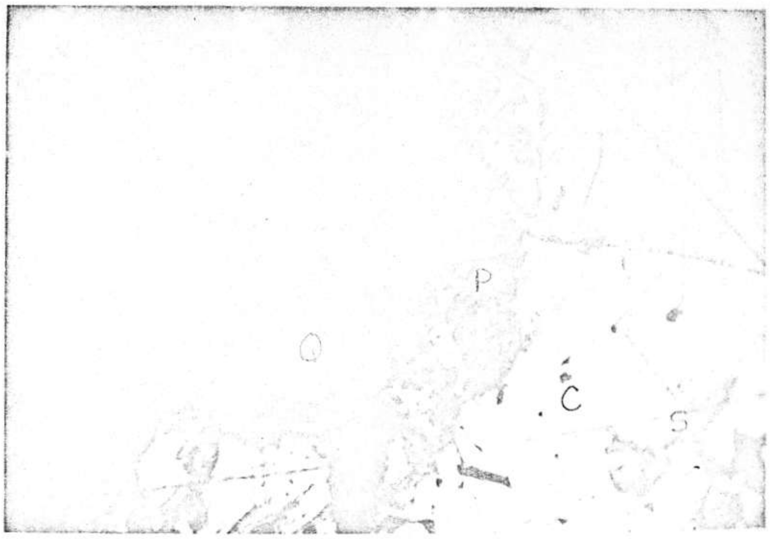


Figure 28

Photomicrograph showing quartz (Q) rimmed by pyrrhotite (P) which is in turn rimmed by an intergrowth of chalcopyrite (C) and sphalerite (S) (X90).

for polished section preparation. Limonite, azurite, malachite, chrysocolla and brochantite were identified in the oxidation products on surface. In the polished sections studied, the mineral assemblage consisted essentially of pyrrhotite, chalcopyrite and sphalerite, with minor amounts of pyrite and galena. Tentatively identified were a few tiny grains of tetrahedrite and loellingite.

Pyrite, tetrahedrite and loellingite occur in anhedral to subhedral grains that average less than 10 microns in diameter. These minerals are included in the coarser-grained quartz and in aggregates of chalcopyrite and pyrrhotite. The strong subhedral habit of some grains, suggests that these minerals crystallized before or during the crystallization of the quartz, and before any of the other sulphides. These minerals were found in isolated grains, and their relativo paragenetic sequence could not be determined.

Pyrrhotite, chalcopyrite and sphalerite occur as fine disseminations in the coarser-grained quartz, but more commonly as replacements along fractures and grain boundaries in the quartz aggregates. For the most part, these minerals appear to be later than the quartz.

Pyrrhotite occurs in large irregular aggregates generally closely associated with chalcopyrite and sphalerite. In many instances these minerals show mutural boundary relations and interpenetrations that are suggestive of simultaneous crystallization (Figure 27). However, in some high grade specimens pyrrhotite is definitely earlier than chalcopyrite and sphalerite. In these, pyrrhotite is seen rimming introduced quartz and in turn is rimmed and locally marginally replaced by a mutual intergrowth of chalcopyrite and sphalerite (Figure 28).

It would appear that pyrrhotite began to crystallize before chalcopyrite and sphalerite, but that its period of deposition was prolonged so that some crystallized simultaneously with chalcopyrite and sphalerite.

Chalcopyrite occurs in irregular aggregates of varying size closely associated with smaller grains of sphalerite. These minerals show mutual boundary relations and interpenetrations that indicate simultaneous deposition. Tiny blebs of chalcopyrite are commonly found in sphalerite and in a high grade, brecciated specimen, these are oriented producing an exsolution texture (Figure 29). Small anhedral grains of sphalerite are found irregularly included in chalcopyrite.

Galena occurs in anhedral grains up to 36 microns in diameter. It is found as a replacement along the margins of sphalerite and chalcopyrite, and at contacts of these sulphides (Figure 30). Smaller grains of galena are also found included in the other sulphides.

Covellite is present in fractures and along grain boundaries in tetrahedrite, apparently an alteration product.

Figure 29

Photomicrograph showing exsolution of chalcopyrite (C) in sphalerite (S) (X90).

Figure 30

Photomicrograph of galena (G) marginally replacing chalcopyrite (C) along a chalcopyrite-quartz (Q) contact (X90).

The paragenetic sequence is illustrated in Figure 31. Pyrite, loellingite, tetrahedrite appear to have been the first minerals to crystallize. Pyrrhotite next began to crystallize, followed by simultaneous crystallization of pyrrhotite, chalcopyrite and sphalerite. Galena appears to have been the last primary sulphide to crystallize.

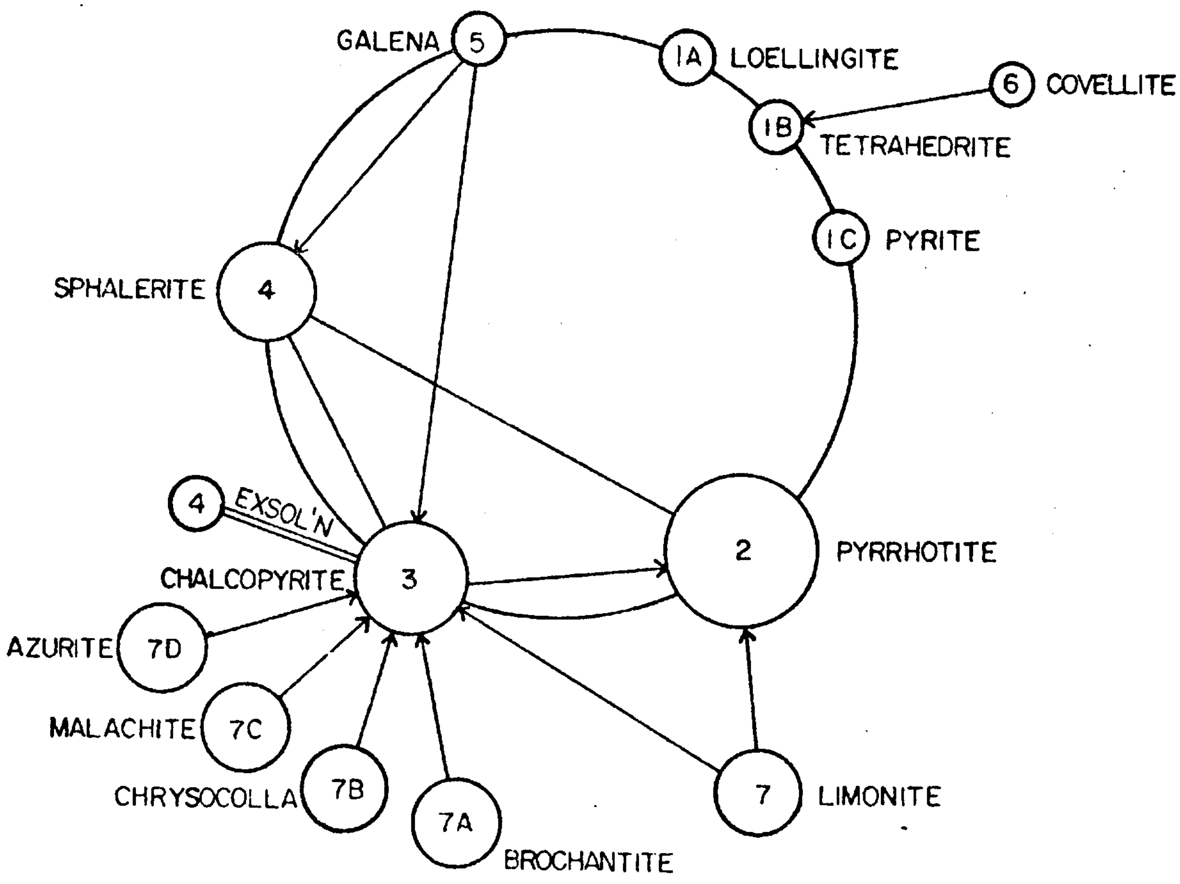
The evidence of early crystallization of pyrrhotite (i.e, before the simultaneous crystallization of pyrrhotite, chalcopyrite and sphalerite) and the exsolution of chalcopyrite in sphalerite is found only in the high grade brecciated specimens. This suggests a higher temperature of the mineralizing solutions in the brecciated zone. The brecciated zone is considered to be a main conduit for the mineralizing solutions, and lowering of the temperature of these solutions away from the brecciated zone is compatible with a hydrothermal origin.

HYDROTHERMAL ALTERATION

Biotite-rich schistose and phyllonitic rocks predominate in the ore zones. Much of the biotite appears to have formed as a result of hydrothermal alteration. Quartz-sericite phyllonites grade transitionally into quartz-biotite phyllonites as the ore zones are approached. Biotite first appears in the micaceous rich bands, where it is commonly associated with tourmaline and other hydrothermally introduced minerals. Sericite persists in the dense, fine-grained

FIGURE 31

VANDERVEEN DIAGRAM SHOWING THE PARAGENESIS OF MINERALIZATION



quartz-rich bands of these rocks well into the ore zone.

The introduction of silica and schorlite, epidote, carbonate and chlorite appear to have been closely associated with mineralization.

Blebs and lenses of coarser-grained quartz flood and replace the host rock producing a "knotted" texture in the ore zones. Silification of rocks immediately removed from the ore zones is slight.

Tourmaline (commonly schorlite), carbonate, epidote and chlorite are associated with the sulphides in the ore zone (Figure 32). These minerals are present also in smaller amounts associated with finely disseminated sulphides and more coarse-grained quartz in the adjacent phyllonitic and schistose rocks where they fill fractures, cut the foliation, and occur in discontinuous lenses parallel to the foliation. Commonly, these introduced minerals are found in, or close to, micaceous-rich bands in the phyllonitic rocks. Possibly the micaceous bands were more permeable than the dense, fine-grained granoblastic quartz rich bands, and afforded channels for the ore bearing solutions.

Further study may show that silicification and the zone of biotite alteration near the ore zones may be used as a guide in the search for ore. However, the intense silicification seems to be too localized, and the available evidence shows that biotite phyllonites and schists that

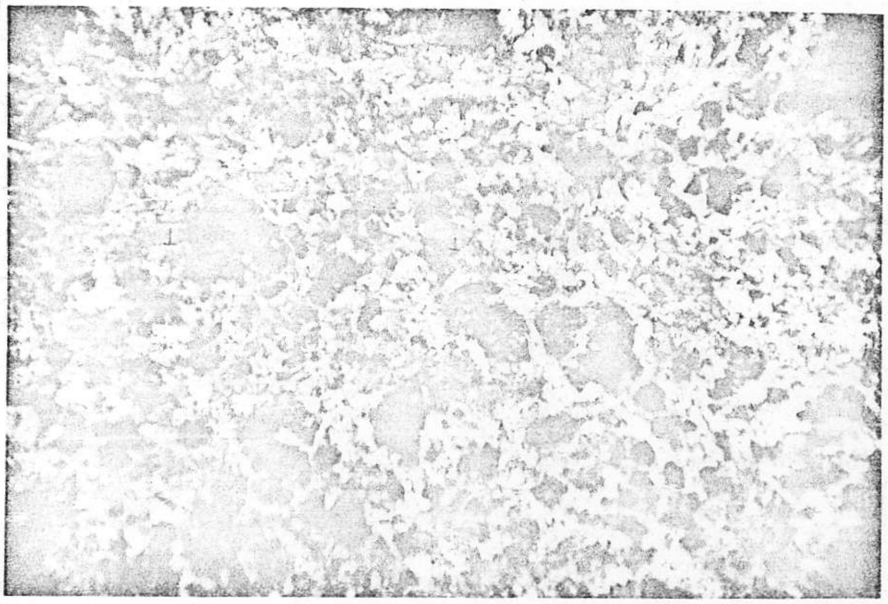


Figure 32

Photomicrograph of replacement ore. Note opaques replacing the quartz-biotite phyllonite. Tourmaline (T) is associated with the sulphides (X42).

are not related to mineralization are common throughout the area.

ORE CONTROLS AND GENESIS OF THE DEPOSIT

It is concluded that the pre-dike zone of brecciation served as the main conduit for mineralizing solutions, and therefore, the major ore control is of a structural nature. Replacement of the host rock away from the brecciated zones appears to have been controlled by favourable lithologic and minor structural features.

Micaceous bands in the phyllonitic rocks seem to have been more favourable for the transmission of sulphide bearing solutions than the dense, fine-grained quartz-rich bands. Higher concentrations of sulphides are commonly found in the crests of drag folds, in fractures, and in axial plane cleavage.

Further work will be required to ascertain the form and the extent of the brecciated zone. The breccia can be dated between syn-or post-regional metamorphism and pre-quartz diorite dike. If the brecciated zone formed during regional metamorphism, it may have been involved in the isoclinal folding. Folding could explain the convergence of two ore zones at depth and to the north. However, if the breccia formed after regional metamorphism, a branching brecciated zone would be required to explain the convergence of the ore zones.

The concentration of sulphides and of slightly fractured and strained grains of hydrothermally introduced silicates and carbonates in the crests of drag folds and in fractures that parallel axial plane cleavage suggest that hydrothermal activity took place at a late stage in the deformational history (Figure 33, 34). The early synkinematic intrusions are therefore eliminated as a possible source of hydrothermal solutions. The alternative source is emanations related to the intrusion of the granodioritic batholith. The ore-bearing emanations from the batholith may have been channelled into the Granduc structure along the south plunging drag folds on the south side of Granduc Mountain. If the crumpling of the old "b" axis of the isoclinal folds occurred during intrusion, but before mineralization, the flattening and reversal of plunge of many of the drag folds to the north would not be a favourable structural feature.

The success of future development will depend on the persistence of the brecciated zone to the north, and the existence of appropriate temperature and pressure conditions to the south and at depth. Mineralographic studies indicate that the mineral assemblage formed under moderate temperature conditions and it is conceivable that as the batholithic contact is approached, temperature conditions may not have been favourable for mineralization.

The dating of mineralization with respect to the intrusion of the quartz diorite dikes cannot be made with

Figure 33

Photomicrograph showing aggregates of more coarse-grained quartz and opaques cutting foliation in a quartz biotite phyllonite (X16).

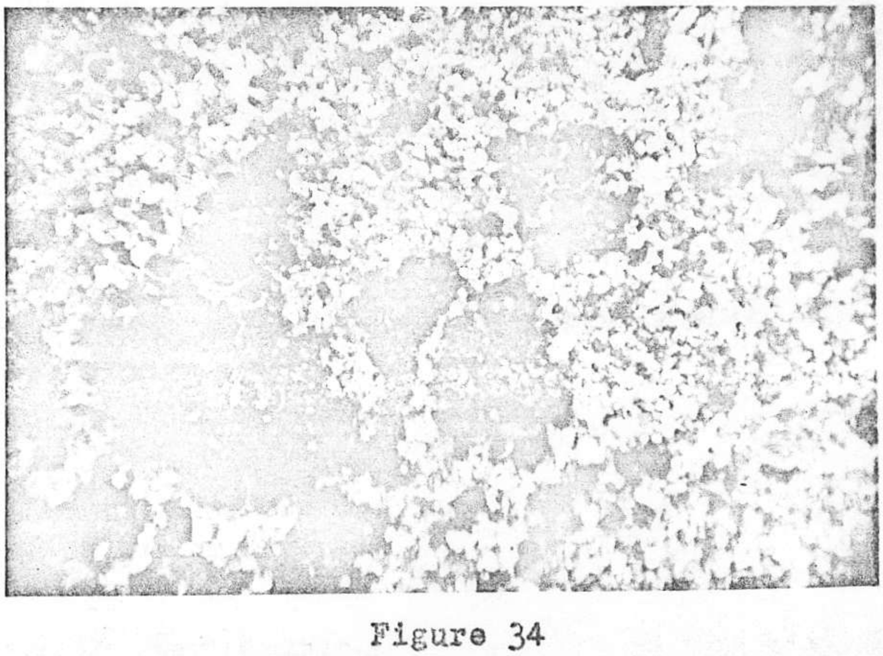


Figure 34

Photomicrograph showing the replacement of a quartz-biotite phyllonite by sulphides (X42).

the available evidence. Although these dikes do cut the ore, it is possible that mineralization occurred in post-dike times, and that the dense dike rock was not susceptible to replacement. However, the brecciated zone which served as a conduit for the mineralizing solutions was formed before the dikes were intruded.

The relative ages of the dikes and the second period of folding is of economic significance. Some of the quartz diorite sills appear to be folded with the metasedimentary assemblage, but it is possible that curved tension fractures opened after the folding had taken place. If the second period of folding occurred after the intrusion of the dikes and sills, then the mineralized shear zone would be expected to swing to the northwest. A similar flexure of the mineralized zone would result if the second period of folding took place after phyllonitization and brecciation, but before intrusion of the quartz diorite sills and dikes. However, if the folding took place during phyllonitization but before brecciation, the brecciated zone would not be bent, and the ore bodies should continue their northerly trend. In the former cases, the late post-dike faulting would offset the ore bodies with the west side moving to the north.

CLASSIFICATION OF THE ORE DEPOSIT

The Granduc ore bodies are thought to have formed during a single generation of mineralization. Estimates of pressure and temperature conditions that existed during deposition of the ore minerals must be obtained from structural and mineralogical features of the ore body. The close association in both time and space of mineralization and the batholithic rocks suggests a hydrothermal origin.

The mineral assemblage found in the brecciated zones is indicative of an intermediate temperature of formation (Edwards 1954). Exsolution of chalcopyrite indicates that the mineralizing solutions had a minimum temperature of 350°C. A more absolute geological thermometer that might be applied to the Cranduc ore is the iron content of sphalerite that has formed in equilibrium with pyrrhotite (Campbell, 1959).

Relatively high pressures appear to have existed during the formation of the ore deposits. The presence of hydrous silicates and the co-existence of carbonate and quartz is indicative of moderately high pressures. Considering the postulated Eocene peneplanation and subsequent uplift, it is suggested that the present ore bodies were buried to a depth of at least 4000 feet during mineralization. However, the existence of the breccia and the hydrothermal effects of only moderate intensity do not imply a particularly deep-seated environment. The deposit is classified as a Mesothermal Replacement.

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AWARDS

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LEGEND

SEDIMENTARY & VOLCANIC ROCS

JURASSIC OR TRIASSIC

SCHIST MEMBER

14	PLAGIOCLASE - BIOTITE - ACTINOLITE - EPIDOTE SCHIST DIFFERENTIATED
13	AMPHIBOLITE
12	LIMESTONE
11	QUARTZ-RICH SCHIST
10	SCHIST MEMBER UNDIFFERENTIATED

MINE MEMBER

9	MINE MEMBER UNDIFFERENTIATED
8	LIMESTONE

METAVOLCANIC FORMATION

7 / 7A	7. PORPHYRITIC ANDESITE 7A. SHEARED ANDESITE

INTRUSIVE ROCKS

LOWER CRETACEOUS (?) OR LATER

6	GRANODIORITE
5	SWARM OF APLITE AND GRANODIORITE SILLS
4	QUARTZ DIORITE, GRANODIORITE DIKES AND SILLS
3	MIGMATITE ZONE, MIXED GRANODIORITE AND MET[illegible]NTS

JURASSIC(?)

2	HORNBLENDE GRANODIORITE
1	DIORITE
1A	GREENSTONE, GREENSCHIST, GREEN PHYLLONITE D[illegible] FROM 1

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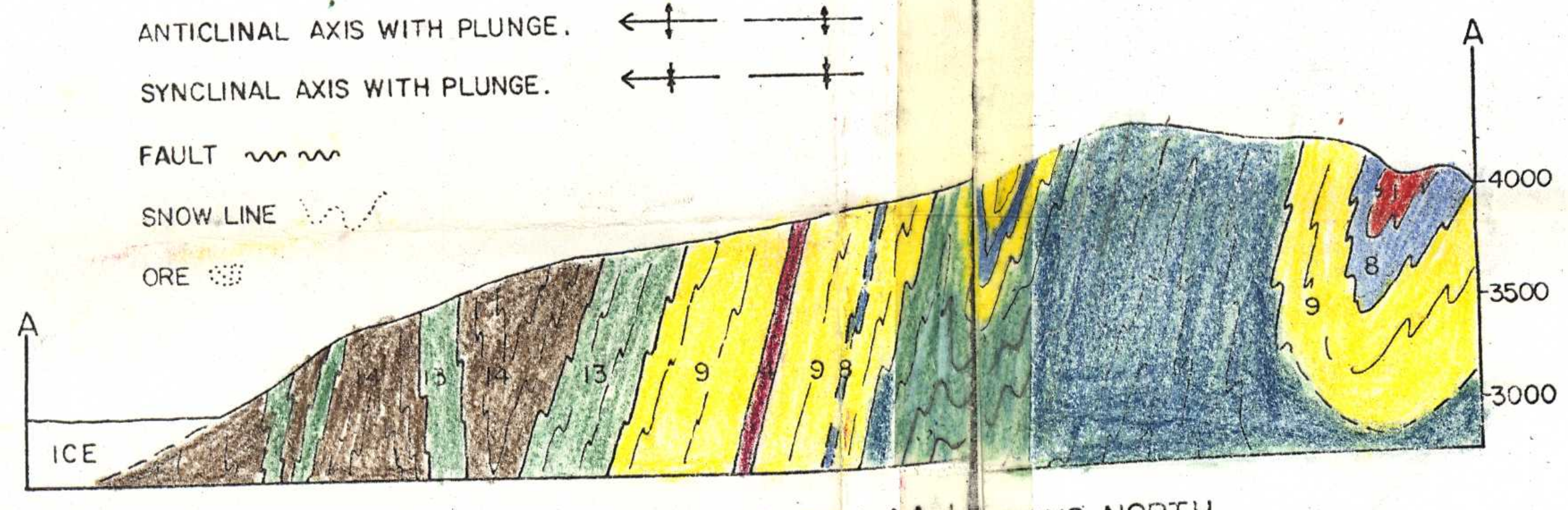
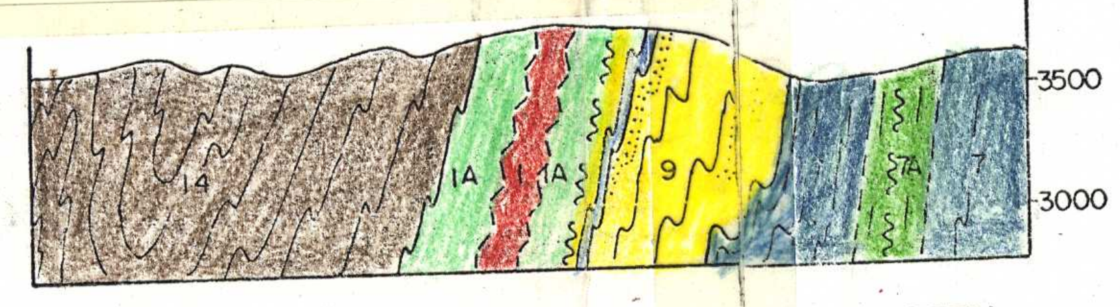
CONTACT; OBSERVED, INFERRED.
FOLIATION; INCLINED, VERTICAL.
ANTICLINAL AXIS WITH PLUNGE.
SYNCLINAL AXIS WITH PLUNGE.
FAULT
SNOW LINE
ORE



GENERALIZED CROSS SECTION AA LOOKING NORTH



GENERALIZED CROSS SECTION BB LOOKING NORTH

MAP I

GEOLOGY OF THE GRANDUC AREA

SCALE I INCH = 800 FEET

CONTOUR INTERVAL 500 FEET

inches
0 1 2
0 1 2 3 4 5
centimetres

BRITISH COLUMBIA GEOLOGICAL SURVEY

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LEGEND

SEDIMENTARY & VOLCANIC ROCKS

JURASSIC OR TRIASSIC

METASEDIMENTARY FORMATION

SCHIST MEMBER

10	PLAGIOCLASE-BIOTITE-ACTINOLITE-EPIDOTE SCHIST
9	AMPHIBOLITE

MINE MEMBER

8	QUARTZ-SERICITE-(GRAPHITE, CHLORITE) PHYLLONITE
7	QUARTZ-BIOTITE-(CHLORITE) PHYLLONITE
6	QUARTZ-SERICITE & QUARTZ-BIOTITE PHYLLONITE UNDIFFERENTIATED
5	PLAGIOCLASE-BIOTITE-CHLORITE-(CALCITE) SCHIST WITH MINOR AMPHIBOLITE
4	LIMESTONE

METAVOLCANIC FORMATION

3	PORPHYRITIC ANDESITE
3A	PLAGIOCLASE-BIOTITE-CALCITE SCHIST DERIVED FROM 3

INTRUSIVE ROCKS

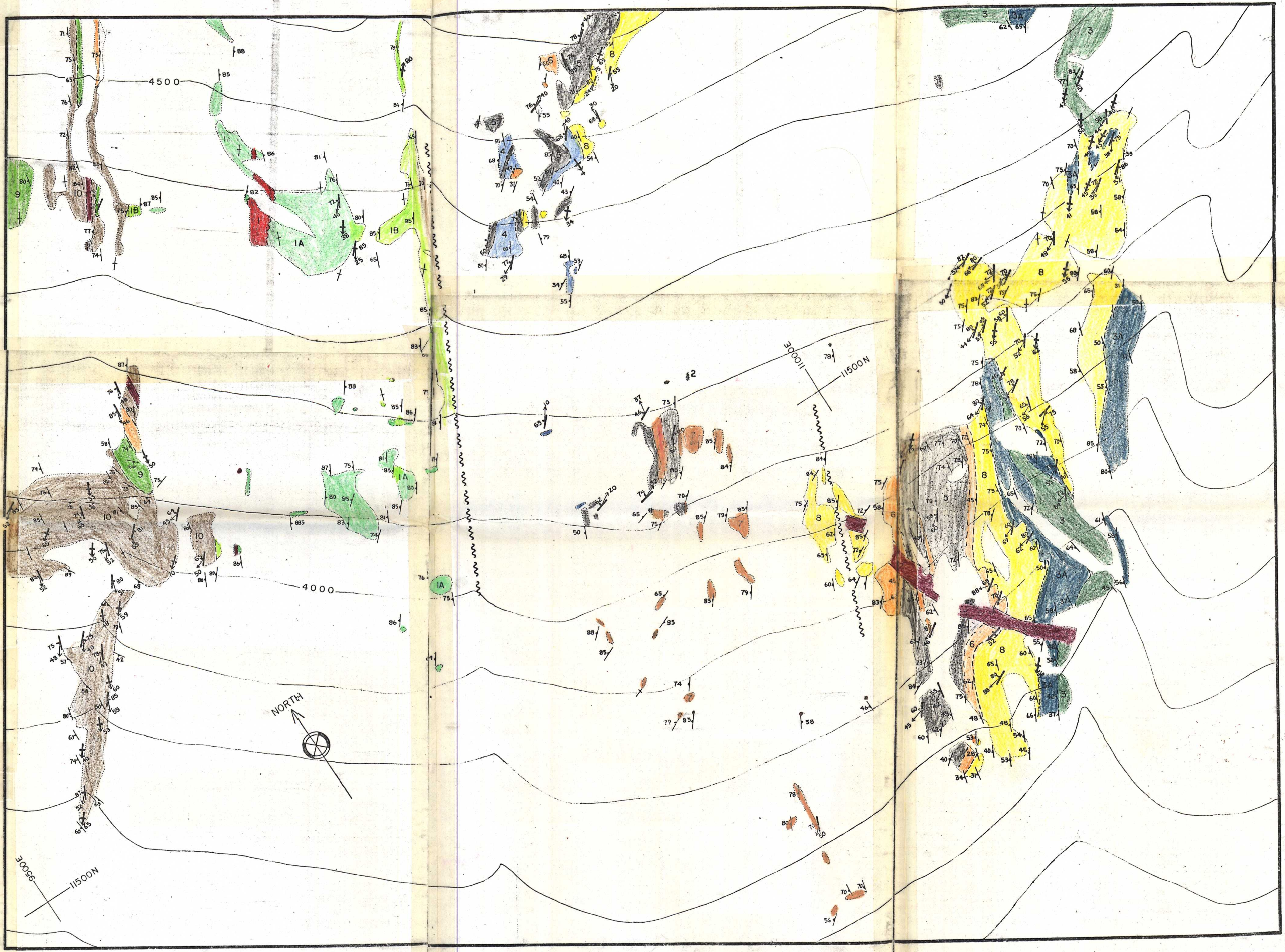
LOWER CRETACEOUS(?) OR LATER

2	QUARTZ DIORITE SILLS & DIKES

JURASSIC(?)

1	DIORITE
IA	GREENSTONE, GREENSCHIST DERIVED FROM I
IB	GREEN PHYLLONITE DERIVED FROM I

FOLIATION ; INCLINED, VERTICAL
AXIAL PLANE OF DRAG FOLDS; INCLINED, VERTICAL
FOLD AXES WITH PLUNGE ↘
FAULT 〰〰
ORE ⁘



MAP 2

OUTCROP MAP SHOWING DETAILED SURFACE GEOLOGY ABOVE GRANDUC MINE

SCALE 1 INCH = 100 FEET

CONTOUR INTERVAL 100 FEET

inches
0 1 2
0 1 2 3 4 5
centimetres

BRITISH COLUMBIA GEOLOGICAL SURVEY

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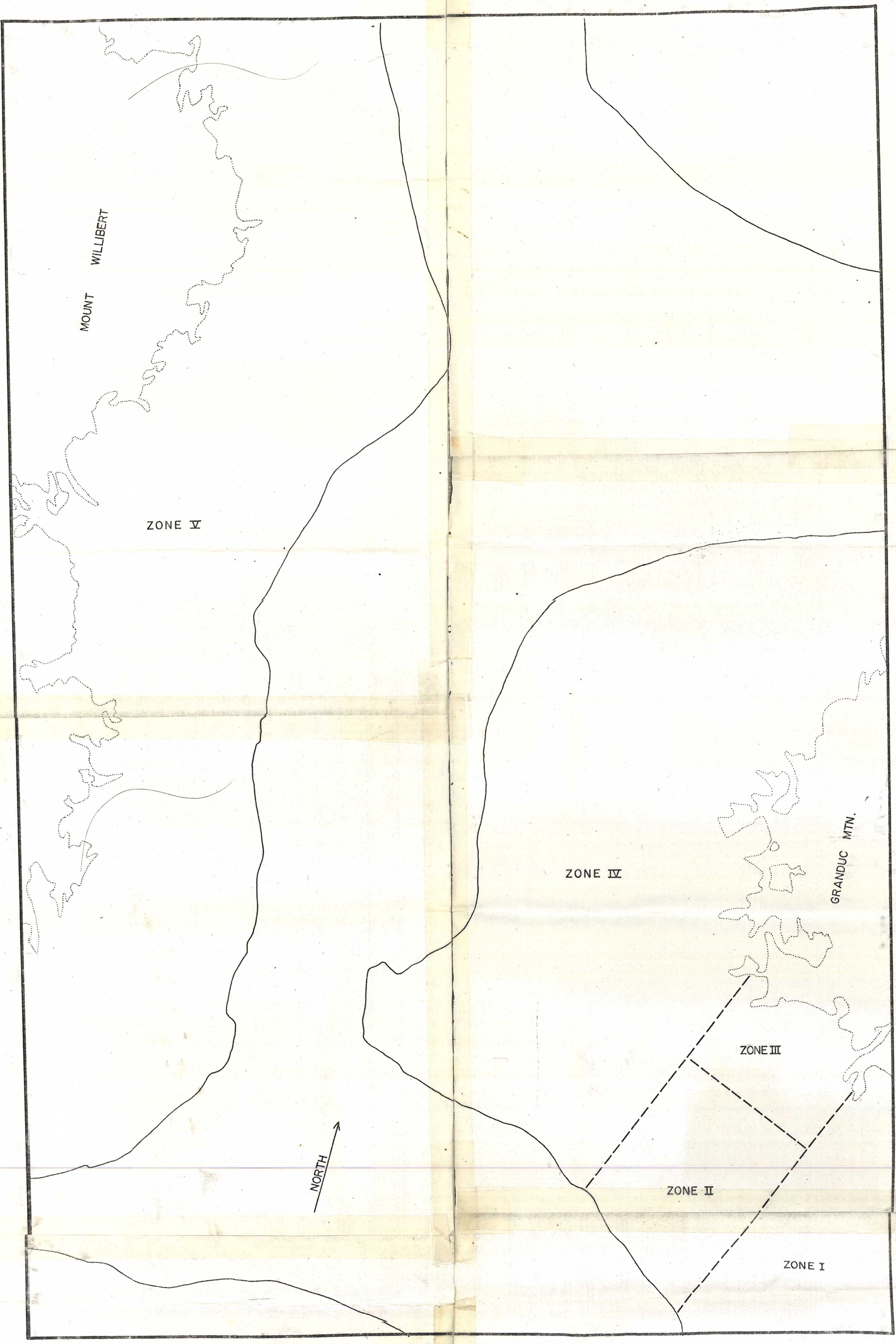


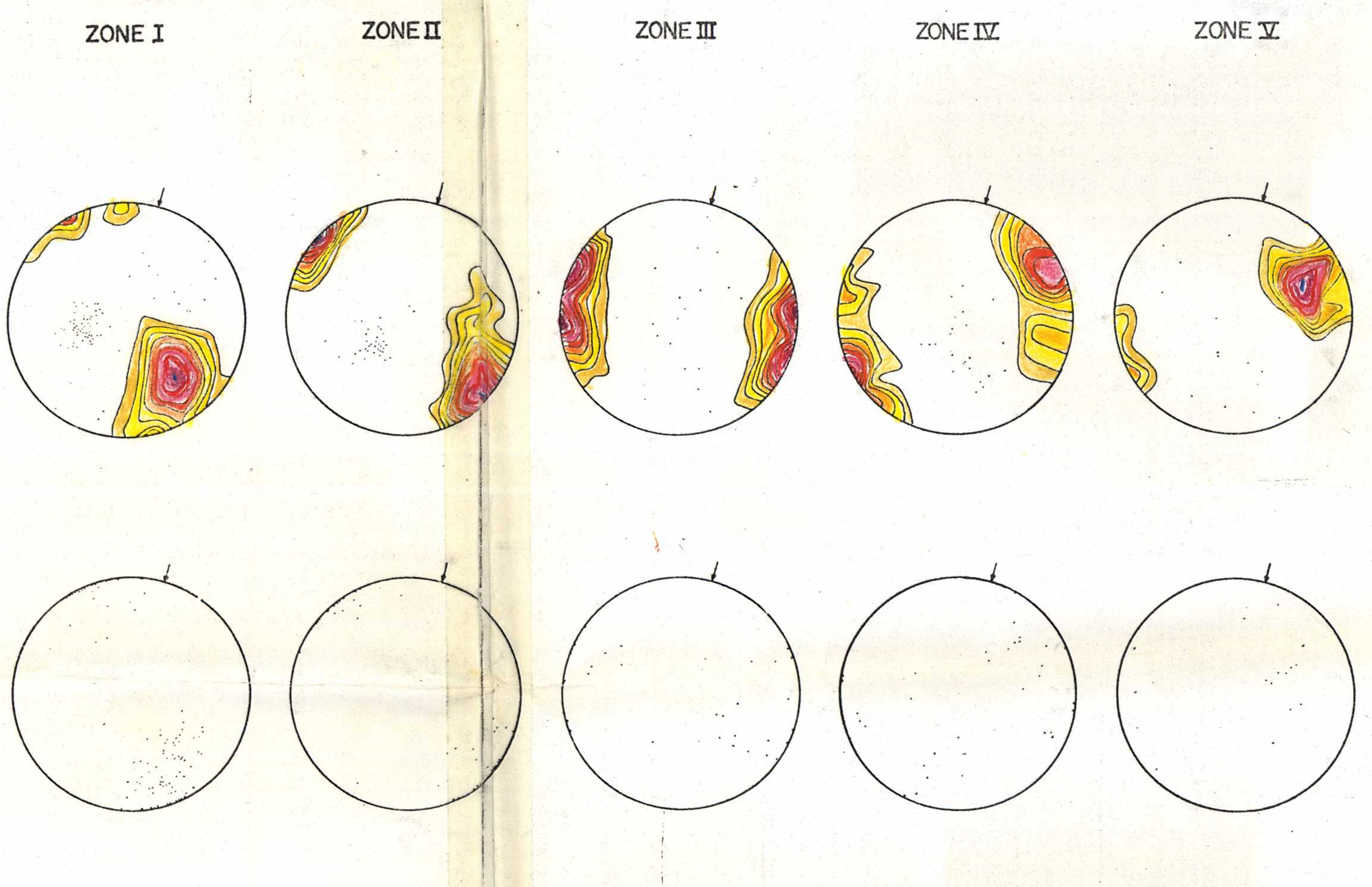
STEREOGRAPHIC PLOTS, LOWER HEMISPHERE PROJECTION.

A. POLES TO FOLIATION (COMPOSITIONAL LAYERING, SCHISTOSITY) CONTOURED (% PER 1% AREA).

- ☐ 0-1 %
- 🟧 1-2 %
- 🟨 2-3 %
- 🟨 3-4 %
- 🟧 4-5 %
- 🟧 5-6 %
- 🟥 6-7 %
- 🟪 7-8 %
- 🟥 8-9%
- 🟪 9-10%
- 🟦 > 10%

LINEATIONS PLOTTED AS POINTS.

B. POLES TO AXIAL PLANES



MAP 3

STRUCTURAL ANALYSIS OF THE GRANDUC AREA

SCALE 1 INCH = 800 FEET

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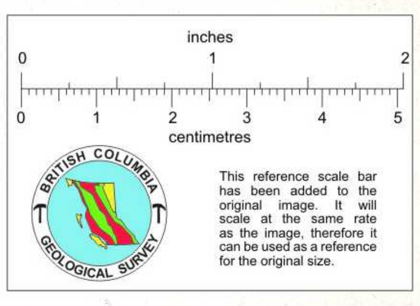

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