GEOLOGY OF THE GARNET MOUNTAIN-AQUILA RIDGE AREA, ICE RIVER, BRITISH COLUMBIA

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
in the Department
of
Geology and Geography

We accept this thesis as conforming to the
standard required from candidates for the
degree of MASTER OF SCIENCE

Members of the Department of
Geology and Geography

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1955

ABSTRACT

The Ice River igneous complex, exposed in the southern part of Yoho National Park in the Field area, British Columbia, is an asymmetrical laccolith made up of several varieties of undersaturated alkaline igneous rocks. Nepheline-sodalite syenite and urtite, two of the major types, are described.

Several theories on the origin of undersaturated alkaline igneous rocks are discussed and it is concluded that Daly's limestone syntexis theory best explains the origin of the Ice River complex.

In the vicinity of Garnet Mountain and Aquila Ridge, the north-west extension of the laccolith has contact metasomatised enclosing limestone and limestone inclusions. The mineralogy and petrology of several extensive skarn zones which carry pyrochlore and radioactive minerals are described. The concentration of certain elements in alkaline igneous rocks is considered and the addition of Na, K, Cb, Zr and others to Ice River limestone is described.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Drs. R.M. Thompson and K.C. McTaggart of the Department of Geology and Geography for their helpful suggestions and criticisms throughout the course of this investigation; to Dr. V.J. Okulitch, Chairman of the Department of Geology and Geography, for his aid with photographing of thin-sections; to Mr. J. Donnan for the preparation of the thin-sections and to Miss P. Everett for the typing of the manuscript.

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GEOLOGY OF THE GARNET MOUNTAIN-AQUILA RIDGE AREA, ICE RIVER, BRITISH COLUMBIA

CHAPTER I

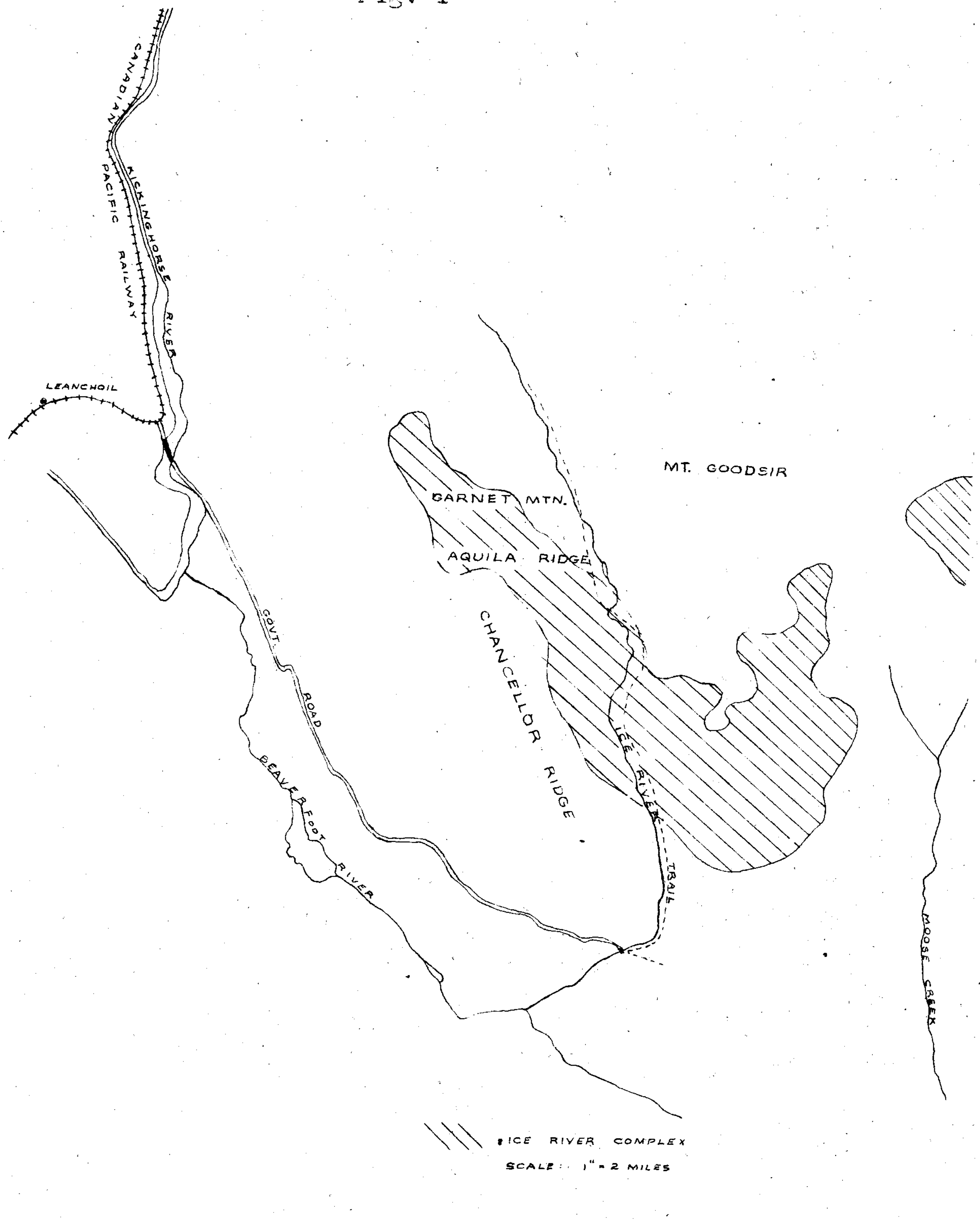
INTRODUCTION AND GENERAL GEOLOGY

Introduction

The area under discussion in this paper lies within the southern tip of Yoho National Park in the western part of the Rocky Mountains in British Columbia. It is easily reached by motor road from Leanchoil which is situated on the main line of the Canadian Pacific Railway and on the Trans-Canada Highway. From Leanchoil, a twelve mile long unpaved government road follows southerly along the north-east side of the Beaverfoot River to a point one mile upstream from the mouth of its south flowing tributary, Ice River. From this junction, a good pack trail leads up Ice River Valley. Garnet Mountain and Aquila Ridge, the areas discussed in this report, are located on the west side of Ice River Valley about six miles from the mouth of the river (see sketch-map, Fig. 1, p. 2).

Some four hundred square miles of Yoho Park and the

Fig. 1



SKETCH - MAP SHOWING LOCATION OF ICE RIVER COMPLEX surrounding region were studied and mapped by J.A. Allan of the Canadian Geological Survey in 1910-1912. His report is entitled: "Geology of Field Map-Area, British Columbia and Alberta", G.S.C. Memoir 55.

Three days were spent by the author in company with Drs. R.M. Thompson and K. C. McTaggart of the Department of Geology and Geography, University of British Columbia, in studying the geology and collecting rock and mineral specimens in the vicinity of Garnet Mountain and Aquila Ridge. Because of the very limited time spent in the area, much of the following general description is taken from Allan's account (1914).

Physiography and Stratigraphy

The Ice River area displays an early mature stage of erosion and consists of rugged, narrow ridges and peaks between which occur broad, relatively flat valleys. Wide streams flow along the valleys and numerous smaller obsequent streams incise the slopes forming the sides. Some peaks attain a height of over 10,000 feet but the average interstream ridge is about 8,000 feet above sea level. Ice River Valley, like other valleys in the district, is believed by Allan to be of pre-glacial origin but has become trough-shaped and deepened by glacial action. It now contains thick alluvial sands and gravels on which the river assumes a meandering course in its upper few miles. Toward its mouth however, the river becomes turbulent. Chancellor Ridge, which forms the west side of Ice River Valley and which separates Ice River Valley from the Beaverfoot Valley, is a rugged, sharp ridge, most of which is over 8,000 feet in elevation. The east side of the valley is formed by a similar ridge which separates

Ice River Valley from Moose Creek Valley and culminates in Mt. Goodsir (elev. 11,676 feet), the highest peak in this section of the Rockies.

In the area mapped by Allan, a thick sedimentary series ranging in age from Pre-Cambrian to Silurian is exposed and within the Ice River Valley, various types of fine-grained marine sediments ranging in age from Upper Cambrian to Ordovician are exposed. These rocks have been folded into a broad asymmetrical anticline, the axis of which trends north-south approximately along the course of Ice River.

Formations Exposed in Ice River Valley

Age	Name	Thickness	Rock Types
Ordovician	Goodsir	6000'	Shale; slate; lms; cherty lms.
U. Cambrian	Ottertail	1550'	Limestone; some shale.
" "	Chancellor	1160'	Argillite; shale.

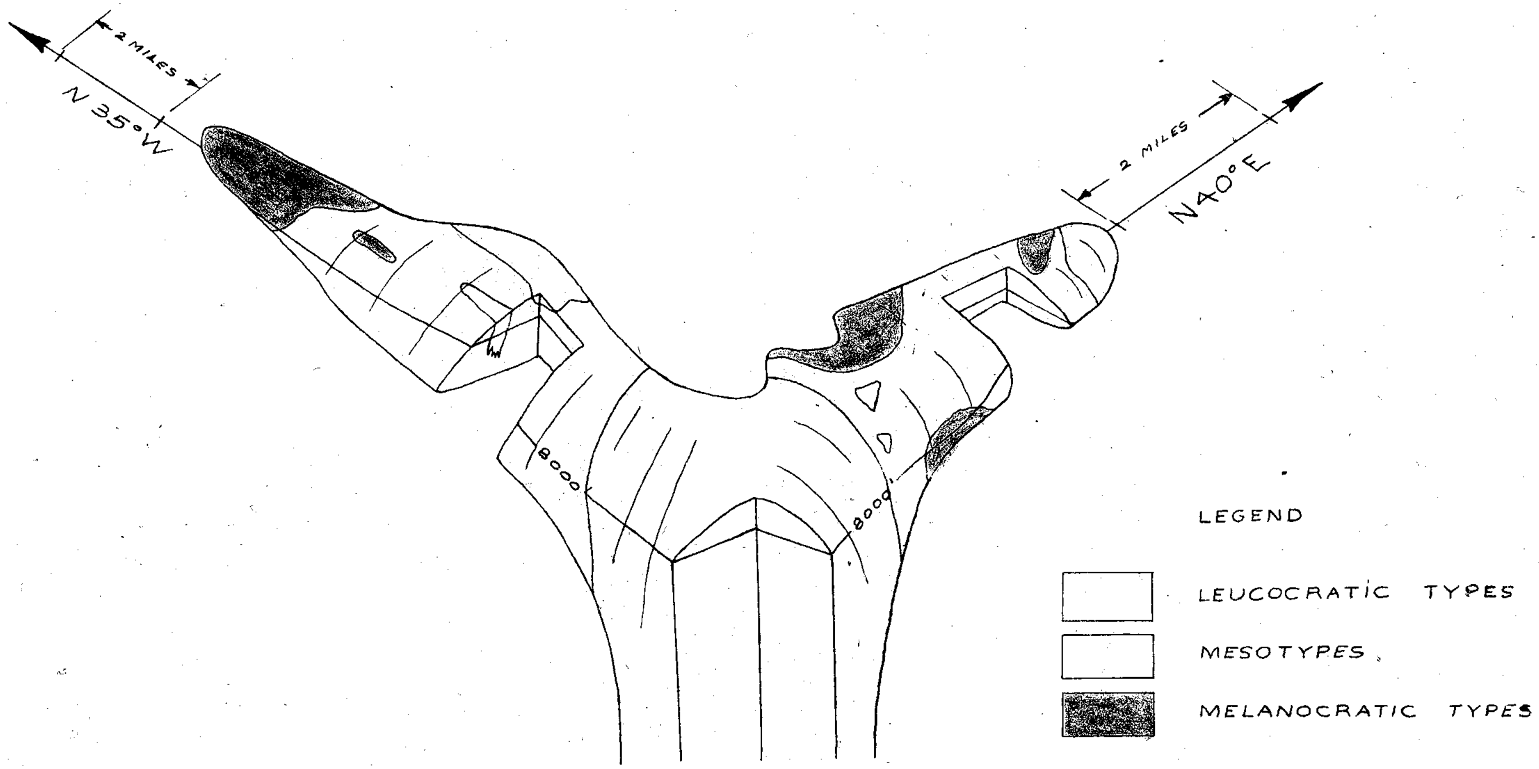
Igneous Geology

Structure

The alkaline Ice River intrusive complex, which is exposed in Ice River Valley, Moose Creek Valley and on the intervening ridge, is believed by Allan to form an asymmetrical laccolith with a stock-like feeder (see fig. 2, p. 5). From the stock, which is located in the southern part of Ice River Valley, a still-like extension projects northward along the east side of Chancellor Ridge for a distance of approximately seven miles. This extension ends abruptly in Ottertail limestone a few hundred yards south of Chancellor Peak. Another sill-like extension projects north-eastward from the stock and trends across Moose Creek Valley. Much of this extension has been removed by erosion

Fig. 2

IDEALIZED ISOMETRIC DRAWING
OF ICE RIVER COMPLEX — AFTER J.A. ALLAN (1914)



but a small, isolated erosional remnant of it is exposed on the east side of Moose Creek Valley near the headwaters of Moose Creek.

A rough layering is evident in the stock, the darker coloured rock types generally occuring lower than the lighter coloured types. In thin parts of the complex, layering is less conspicuous. However, layering was observed in the north-west extension on the north side of Garnet Mountain. Because of the steepness of the cliffs in the latter area, the layering could not be studied in detail.

Igneous Rock Types

Introduction:

Allan divided the rocks of the complex into three major groups based on mineral composition. Many diverse types exist in each group and all gradations are present which makes dividing lines only approximate.

Leucocratic Group:

Rocks of the leucocratic group compose about two-thirds of the complex. They form the stock and smaller outcrops are found on the eastern slopes of Garnet Mountain and Aquila Ridge; on Zinc Mountain which is located about one mile north-east of the main stock and at the extreme tip of the eastern extension.

Nepheline syenite is by far the most abundant rock type of this group. In general, rocks of this group are light in colour, coarse-grained and somewhat inequigranular. They are composed essentially of nepheline and potash feldspar with subordinate amounts of pyroxene and amphibole. Sodalite is generally present and becomes so abundant in some varieties that the rock is sodalite syenite. Although all nepheline syenites in the Ice River complex appear similar in hand specimen, a number of slightly different varieties have been determined microscopically. The reader is referred to Chapter II for a detailed description of nepheline syenite.

Leucocratic pegmaties cut all other igneous rocks. These are of three major types: acmite-orthoclase pegmatites; perthitic feldspar pegmatites and nepheline-aegirine-augite pegmatites. No detailed work on these rocks was done by the author.

Mesotype Group:

The two main mesotype rocks present are ijolite and urtite. Ijolite is by far the most common and is a coarse-grained, equigranular rock consisting essentially of nepheline, pyroxene and amphibole with the light and dark constituents being about equal in amounts. Ice River ijolite is a rather special type since barkevikite replaces, in part, the pyroxenes. Urtite, a rock generally of coarser grain than ijolite, consists essentially of nepheline, pyroxene and schorlomite. For a detailed description of a specimen of urtite the reader is referred to Chapter II.

Melanocratic Group:

Rocks of the melanocratic group occur in the thin edges of the laccolith. They are exposed in the northern end of the eastern extension; in two other localities in the eastern extension and between Garnet Mountain and Chancellor Peak. Members of this group include only types in which light coloured minerals are accessory or entirely lacking. By far the most common type is jacupirangite which is a coarse-grained rock consisting essentially of pyroxene, magnetite or ilmenite and sphene. Small outcrops of pyroxenite have also been reported.

Metamorphism and Metasomatism

Allan made a very brief study of contact metamorphism and metasomatism of shale and limestone along the roof of the north-west extension of the laccolith. In this area, a band of reddish hornfels ranging in thickness from a few feet to 350 feet occurs. In thin-section, Allan found this hornfels to consist mainly of quartz, feldspar, biotite and clinozoisite. The hornfels and the overlying limestone have sharp contacts and where no hornfels is present, the limestone has been recrystallized for several hundred of feet from the contact, and tremolite, diopside, garnet, epidote and wollastonite are found in it. He attributes variations in widths of the metamorphic and metasomatic bands largely to variations in concentrations of fluids which emanated from the magma.

The sedimentary rocks along the upper contact of the north-west extension are brecciated and inclusions of both hornfels and limestone occur within the igneous rock, particularly near the roof. The inclusions differ greatly in size and except for one, which outcrops on Aquila Ridge, do not exceed 100 feet in diameter.

Shearing forces were active at the close of the emplacement of the conplex, They resulted in shearing and brecciation of the surrounding sediments but had little effect on the competent igneous rocks.

Age of Intrusion

The age of the Ice River complex is believed by Allan to be post-Cretaceous. Evidence is supplied by the Cretaceous rocks of the Cascade Basin, located some 35 miles north-east of Ice River. In the Cascade Basin area, Cretaceous rocks have been folded and the age of the folding is believed to correspond to the formation of the Ice River anticline. Since the Ice River complex has been intruded into folded strata, the intrusion must be post-Cretaceous in age. Allan believes that the Ice River complex is of the same age as alkaline intrusive rocks of the Montana petrographic province which are known definitely to be post-Cretaceous in age.

CHAPTER II

GEOLOGY OF THE GARNET MOUNTAIN-AQUILA RIDGE AREA

Introduction

The accompanying geologic map and cross sections illustrate the structure and distribution of rock types in the Garnet Mountain-Aquila Ridge area.

The large inclusion previously mentioned is well exposed on Aquila Ridge and on the south side of Garnet Creek basin where it forms cliffs about 300 feet high. This inclusion parallels the upper contact of the laccolith and the overlying sedimentary rocks in attitude and is at most 1250 feet thick and slightly less than one mile in length. Except for the basal 80-100 feet, the inclusion is stained deep brown by limonite, a feature which makes it especially conspicuous from a distance.

Igneous Rocks

Nepheline-sodalite Syenite

Nepheline-sodalite syenite forms numerous small outcrops on the nose of Aquila Ridge. Hand specimens of this rock are light greenish, medium to coarse-grained, somewhat inequigranular and display a pitted surface due to the relatively rapid weathering of nepheline. Nepheline, K-feldspar, pyroxene, amphibole and sphene were recognized in hand specimen, the mafics making up about 15% of the rock. In all the following thin-section descriptions, mineral percentages are from visual estimates only.

In thin-section, nepheline-sodalite syenite is seen to be composed of:

Perthite	45%
nepheline	20%
aegirine-augite	15%
Na-Fe rich amphibole	5%
sodalite	5%
sphene	5%
cancrinite	3%
apatite } magnetite(?) }	2%

The texture is inequigranular and hypidiomorphic. Nepheline, perthite, pyroxene and amphibole occur as large subhedral crystals. Sphene forms euhedral crystals which range greatly in size, a few of the smaller crystals being enclosed in pyroxene. Apatite occurs as coarse euhedral crystals, some of which, along with a few grains of magnetite, are enclosed in sphene. Sodalite forms irregular interstitial masses and cancrinite occurs as irregular grains around nepheline, of which it is probably an alteration product. A small amount of sericite has been developed in the feldspars. From the relationships outlined above, the sequence of crystallization of the constituents appears to be: magnetite (?) and apatite; sphene; pyroxene and amphibole; nepheline and feldspar; sodalite.

Urtite

Several specimens of mesotype igneous rocks were collected about 100 yards west of the lower contact on Garnet Mountain. A type corresponding rather closely in mineral composition to urtite described by Allan (p. 147) is described below.

In hand specimen, this rock is dark green, coarse-grained and equigranular. Nepheline, pyroxene, biotite, schorlomite sphene, magnetite and ilmenite are recognizable in the hand specimen.

In thin section, the rock is seen to be composed of:

Nepheline	60%
augite and aegirine-augite	20%
schorlomite, magnetite, ilmenite	10%
biotite	5%
sphene	3%
apatite, calcite, cancrinite	2%

The texture is equigranular and hypidiomorphic. Nepheline occurs as fresh subhedral crystals and the pyroxenes form both subhedral crystals of aegirine-augite and subhedral zoned crystals with augite cores and aegirine-augite rims (plate IB). Biotite is closely associated with the pyroxenes. Schorlomite is deep red in thin-section and is closely associated with the iron oxides. The iron oxides form scalloped contacts with the pyroxenes suggesting partial replacement of the latter. Calcite occurs interstitial to the other minerals. Alteration consists of the development of cancrinite around nepheline crystals, minor development of muscovite along fractures in the nepheline and the formation of fine-grained iron oxides in cracks and around the edges of pyroxene crystals. The sequence of crystallization of the constituents was not determined.

Acmite-microcline Rock (plate II).

This rock, specimens of which were collected about 100 yards west of the lower contact on Garnet Mountain, consists of acicular and radiating groups of pyroxene crystals up to 1 inch long in a white, finely crystalline feldspar groundmass.

In thin-section, the rock is seen to be composed of:

Microcline	70%
acmite	20%
natrolite	5%
sodalite	5%

The acmite occurs as dark green, weakly pleochroic, euhedral crystals twinned on (100) and elongated along (010). Microcline forms small anhedral to subhedral crystals which have, in part, replaced acmite. A remarkable feature of the microcline is that only Carlsbad and Albite twinning are developed in it and the familiar "plaid" twinning is not seen. A detailed description of this and other minerals found in Ice River rocks is included in Chapter III. Natrolite occurs as irregular masses surrounding and replacing crystals of microcline. Sodalite is closely associated with the natrolite. From the relationships outlined above, the sequence of events in the formation of this rock was: crystallization of acmite; crystallization of microcline which partly replaced the acmite; introduction of natrolite and sodalite with very minor brecciation of and partial replacement of microcline.

This rock is included here only because it possesses an igneous appearance and texture. Its relationship to the enclosing urtite was not determined and it may be a metasomatised inclusion.

Metasomatised Limestone

Lower Contact, Garnet Mountain

Eleven specimens of limestone representing a stratigraphic thickness of approximately 7 feet and showing various degrees of alteration were collected near the lower contact of the intrusion on Garnet Mountain. The effects of metasomatism can be detected in hand specimen only within 4 feet of the contact.

The unaltered limestone is finely crystalline, light grey and thin-bedded, the bedding being exaggerated by surface weathering. Etching with dilute hydrochloric acid revealed about 10% dolomite and insoluble residues.

In thin-section, limestone 7 feet below the contact consists of fine-grained, subhedral crystals of carbonate and minor amounts of phlogopite, amphibole and fine-grained iron oxides. The amphibole occurs as minute acicular crystals randomly distributed throughout the rock. The phlogopite, iron oxides and some amphibole form narrow bands and lenses parallel to the bedding.

4 feet below the contact, the limestone is seen to be composed of:

Carbonates	80%
phlogopite	10%
microcline	5%
amphibole, iron oxides, sphene	5%

The amphibole appears to be of two varieties: tremolite and a colourless variety with high dispersion and $X_{\wedge}c$ of 39^{o}. Only one fairly large crystal of the latter was found and the optical properties could not be accurately determined even with the aid of the universal stage. The phlogopite, microcline and amphiboles form irregular vein-like masses and "knots" in the carbonates. The microcline occurs as small subhedral crystals largely confined to these "knots". It shows only Carlsbad-albite twinning as was evident in the acmite-microcline rock described above. A few irregular grains of sphene and some amphibole also occur randomly distributed throughout the rock.

Within 3 feet of the contact, the bedding in the limestone has become completely destroyed and the rock is coarsely crystalline (calcite grains up to 1/8 inch) with irregular "knots" of fine-grained minerals scattered throughout it. The most noticeable mineralogical change is the disappearance of amphibole and the formation of small acicular crystals of acmite. The acmite is largely confined to the "knots" where it forms groups of crystals oriented parallel to the borders of the "knots". Small irregular groups of acmite crystals also occur throughout the rock. The "knots" and irregular veinlets are composed of phlogopite, acmite, fine-greained iron oxides (chiefly limonite) and possibly other fine-grained minerals. Iron oxides, which are more abundant than in limestone 4 feet from the contact, also occur as dust-like inclusions throughout the carbonate.

Within 1 foot of the contact, the rock changes markedly. In hand specimen it becomes a dark reddish-green, hematite-stained skarn in which pyroxene, calcite and feldspar are recognizable. In thin-section, the rock is seen to be composed of:

Microcline	45%
acmite	35%
natrolite	10%
iron oxides (chiefly hematite)	7%
calcite } chlorite }	3%

The acmite occurs as small needles and subhedral crystals up to 3 mm. long, many of which are slightly brecciated. This mineral is only very weakly pleochroic and the pleochroism varies slightly even within the same crystal. Microcline, which again shows only Carlsbad-albite twinning occurs as anhedral to subhedral crystals commonly highly brecciated. The breccia fragments are generally surrounded by calcite and natrolite.

Natrolite occurs as feathery masses, some of which are replaced pseudomorphously by calcite. The iron oxides occur in or closely associated with natrolite, and minute black grains of an unidentified mineral, visible only under high power, occur throughout the natrolite (plate IIIA). Hematite dust is concentrated around these black grains and breccia fragments of microcline enclosed in natrolite also have hematite dust concentrated around them. A few small pyrite crystals occur along grain boundaries and fill fractures. Chlorite occurs as small nodular masses of minute crystals forming veinlets cutting acmite and also occurs as "knots" of tiny crystals along crystal borders. The chlorite shows green to reddish pleochroism and its X-ray diffraction pattern agrees rather closely with penninite from Rimpfischwange, Zermatt, Valais, Switzerland (A.S.T.M. No. 2-0102).

The amount of feldspar and iron oxides differs considerably in rocks close to this contact. A specimen taken only a few feet along strike from the skarn described above consists almost entirely of microcline with only subordinate amounts of natrolite, carbonate, acmite and iron oxides. In hand-specimen, this rock is a dark grey, fine-grained skarn not showing the hematite staining or acmite of the rock described above.

Within a few inches of the contact, the skarn is a light reddish-green, rather coarse-grained rock in which brecciated crystals of pyroxene up to $\frac{1}{4}$ inch long occur in a matrix of zeolite and K-feldspar. In thin-section, this rock is seen to be a coarse-grained aggregate of:

Natrolite	60%
microcline	20%
acmite	15%

iron oxides	5%
carbonate	
biotite	
chlorite	
pyrite	
pyrochlore	
sericite	

A few minute black specks surrounded by hematite dust similar to that described in skarn 1 foot from the contact occur throughout the natrolite. Natrolite, which forms the ground mass, encloses and partly replaces breccia fragments of acmite, microcline and carbonate. The iron oxides and fine-grained black mineral surrounded by hematite are concentrated chiefly around microcline breccia fragments. Pyrochlore occurs as a few, minute, euhedral crystals surrounded by hematite dust and partly enclosing the fine-grained black mineral (plate IVA). A few minute veinlets of chlorite cut acmite crystals and a few cubes and irregular masses of pyrite are closely associated with biotite. Alteration consists of minor sericitization of the microcline.

A summary of the mineralogical changes in the altered limestone at the lower contact on Garnet Mountain is given in table 1, p. 18.

Radioactivity was detected in some of the skarn rocks described above. It will be discussed in detail in chapter III.

Limestone Inclusions in Igneous Rocks

Garnet Mountain Inclusions

Two inclusions of limestone (see section A-B), each about 10 feet thick, were examined. These inclusions consist of coarse calcite (crystals up to $\frac{1}{4}$ inch) stained deep brown by limonite. A few small veinlets of nearly black chlorite cut these rocks. Radioactivity, sufficient to make a small portable geiger

Table 1

Mineral Assemblages in Metasomatised Limestone at Various Distances from the Igneous Rock; Lower Contact, Garnet Mountain

7 feet	4 feet	3 feet	1 foot	Contact
carbonates (95%)	carbonates (80%)	carbonates (75%)	carbonates (1%)	carbonates (2%)
amphiboles	amphiboles	-	-	-
phlogopite (5%)	phlogopite (10%)	phlogopite (5%)	-	-
iron oxides	iron oxides (5%)	iron oxides (20%)	iron oxides (7%)	iron oxides (2%)
	microcline (5%)	-	microcline (45%)	microcline (20%)
	sphene	-	-	-
		acmite (1%)	acmite (35%)	acmite (15%)
			natrolite (10%)	natrolite (60%)
			pyrite	pyrite
			radioactive constituents	radioactive constituents
			chlorite (2%)	chlorite
				biotite (1%)
				sericite
				pyrochlore

counter count twice background, was detected in both inclusions.

The distribution of minerals within the inclusions appears to be quite erratic. Two thin-sections were made of the altered limestone of the most westerly inclusion shown on section A-B. In one, coarse, euhedral crystals of calcite are replaced along crystal boundaries and cleavage planes by hematite. A few, subhedral, colourless, altered crystals of an unidentified mineral (1) also occur in this altered limestone.

The second thin-section, made from limestone collected from the same inclusion only a few feet from the above showed the rock here to be composed of calcite (45%), chlorite (40%) and 15% of iron oxides and pyrite. The chlorite occurs as irregular masses of tiny botryoidal clusters of crystals which vein and replace calcite. Fine-grained pyrite and iron oxides occur as veins and irregular disseminations in and especially along the borders of the chlorite masses.

No thin-sections were made of specimens of the other inclusion on Garnet Mountain.

Main Aquila Ridge Inclusion

Numerous specimens of altered limestone were collected from the large inclusion outcropping on Aquila Ridge. The position of each specimen is shown on section C-D.

The basal 80-100 feet of this inclusion was found to be radioactive throughout and it was found that this zone persisted southward for at least ¼ mile. Radioactivity was also detected in the upper few feet of the inclusion but its extent was not determined. In hand specimen, radioactive rocks of this inclusion differ from non-radioactive rocks in that the former lack the limonitic staining characteristic of the latter.

Specimen 1: Non-radioactive rock collected from near the centre of the inclusion was found, in thin-section, to consist of:

Hematite and limonite	55%
calcite	40%
chlorite	5%
pyrochlore	½%
unidentified mineral (2)	-

The calcite is replaced along cleavage planes and along grain boundaries by fine-grained iron oxides, many of the calcite crystals being entirely replaced pseudomorphously with the retention of the cleavage. Pyrochlore occurs as small, euhedral, somewhat fractured crystals generally associated with iron oxides. The chlorite forms small botryoidal masses as it does in altered limestone from Garnet Mountain. A few minute veinlets of chlorite and calcite cut all other minerals including pyrochlore.

Specimen 2: Non-radioactive rock collected immediately above the basal radioactive zone was found, in thin section, to consist of:

Apatite	70%
calcite	10%
iron oxides	10%
acmite	5%
chlorite	5%
pyrochlore	½%

The apatite forms irregular masses of small euhedral crystals cyclically twinned probably by reflection in a plane parallel to the c-axis (plate IA). The acmite occurs as small subhedral crystals generally concentrated in the apatite masses and the pyrochlore occurs as subhedral to euhedral crystals also confined to the apatite masses.

Specimen 3: Radioactive rock collected from the upper radioactive zone was found, in thin-section, to consist of:

Apatite	75%
calcite and iron oxides	20%
chlorite	5%
pyrochlore	½%
pyrite	-
unidentified mineral (2)	-

The texture of this rock is very similar to the apatite-rich rock described above except that the calcite crystals in this rock are somewhat brecciated.

Specimens from the Basal Radioactive Zone: Several thin-sections were cut from specimens of the main radioactive zone. In thin-section, altered limestone from this zone was found to consist of:

Calcite	55%
apatite	30%
chlorite	10%
iron oxides and pyrite	2%
altered rutile(?)	2%
pyrochlore	1%

The textures and mineral relationships are very similar to those described above. The most noticeable difference between this rock and others of the inclusion is the greater abundance of pyrochlore and lesser quantity of iron oxides. The pyrochlore forms brecciated euhedral crystals up to about .2 mm. in width (plate IIIB) and the pyrite occurs as anhedral to subhedral crystals largely confined to the apatite masses. Small euhedral crystals of a brownish mineral, thought possibly to be rutile largely replaced by iron oxides, occurs confined mainly to the chlorite patches.

A detailed description of the pyrochlore, other radioactive constituents and several other minerals found in the above rocks is given in Chapter III.

CHAPTER III

MINERALOGY

The following minerals were identified by the author in rocks from the Ice River area:

Acmite	ilmenite
aegirine-augite	pyrochlore
augite	apatite
tremolite	nepheline
hornblende (Na-Fe rich)	natrolite
unknown amphibole	sodalite
microcline	garnet (schorlomite)
perthite	sphene
chlorite	cancrinite
phlogopite	carbonates
biotite	pyrite
sericite	rutile
hematite	unidentified radioactive mineral
limonite	unknown (1)
magnetite	unknown (2)

Pyroxenes

acmite: See fig. 3 for universal stage determination.

light green
weakly pleochroic
$n_x = 1.76$ $n_z = 1.78$
$2V = 68^{\circ}$
opt. (+)
$Z_{\wedge}c = 87^{\circ}$
S.G. (average of 5 readings) = 3.38

Except for the weak pleochroism, the properties listed above agree closely with those given in Rogers and Kerr (1942, p. 270) for acmite. Washington and Merwin (1927) have described acmite from the Islet of Rockall and from Rundemyr, Norway showing weak pleochroism. Spectrographic analyses showed both to be comparatively high in zirconium and certain rare earths. Qualitative spectrographic analysis carried out by the author on Ice River material showed:

Strong lines: Mg and the primary constituents Na, Fe and Si.
Moderate lines: V and Zn.
Weak lines: B, Cr, Cu, Ti, Mn and Zr.

Since Cu and Mg occur as impurities in the carbon electrodes, it is not certain that they are present. No rare earths were detected.

From the above analyses, it appears therefore that Ice River acmite is somewhat more deficient in Zr than specimens examined by Washington and Merwin. However, the fact that certain uncommon elements were detected in Ice River acmite tends to support their hypothesis that impurities may cause anomalous optical properties in acmite.

aegirine-augite and augite: In urtite, there minerals occur as zoned crystals, usually with augite forming an inner core and aegirine-augite, the outer rim (plate IB).

aegirine-augite	augite
pale green	colourless
pleochroism: X>Y<Z: grass green; yellowish green: brownish green	
$X_{\wedge}c = 23^{\circ}$	$Z_{\wedge}c = 45^{\circ}$

The above properties agree closely with those given for aegirine-augite in Winchell and Winchell (1951, pp. 416-417) and for augite in Rogers and Kerr (1942, p. 264).

Amphiboles

tremolite: colourless
$2V = 78^{\circ}$
opt. (-)
$Z_{\wedge}c = 17^{\circ}$

The above properties, determined on the universal stage, agree closely with those given for tremolite in Rogers and Kerr (1942, p. 282).

hornblende (Na-Fe-rich):

dark greenish brown
strongly pleochroic: $X<Y<Z$:
light brown:dark brown:brownish green.
2V ?
$Z_{\wedge}c = 13^{\circ}$ (?) approximately
optic plane parallel to a-c

The optic orientation and pleochroism indicate that this mineral is not a member of the soda-hornblende group. It is suggested that this variety is a common hornblende containing soda and an excess of iron as described in Winchell and Winchell (1951, p. 435).

unknown amphibole: colourless
high dispersion
$X_{\wedge}c = 39^{\circ}$

The few properties that the author was able to determine agree with no amphibole described in modern texts, the only known species approximating it being an asbestiform amphibole described by Wahlstrom (1940) from Boulder County, Colorado which has a $Z_{\wedge}c = 44^{\circ}$ and is pleochroic light yellow to dark yellow. The latter is close to arfvedsonite in composition.

Microcline

See fig. 4 for universal stage determination.
$n<1.54$
$2V = 84^{\circ}$
opt. (-)
twinned according to the Carlsbad
and Albite laws only (plate IIA and IIB)

The identity of this species was confirmed by X-ray diffraction powder photographs. Microcline, displaying only Carlsbad and Albite twinning is exceedingly rare. However, it is known from Quincy, Mass. where it occurs in vugs in aegirine-riebeckite bearing pegmatites (Warren and Palache, 1911).

Apatite

Optic properties as in modern texts. Confirmed by X-ray powder diffraction photographs. A remarkable feature of the Ice River apatite is its cyclic twinning (plate IA). Each twin generally consists of 3 interpenetrating members which resemble, in appearance, cyclic twinning in cordierite.

Natrolite
colourless
birefringence = .01
low relief
parallel extinction
length slow
perfect cleavage parallel to c axis
$2V = 15^{\circ} - 30^{\circ}$
opt. (+)

The identity of numerous specimens of natrolite from various Ice River rocks was confirmed by X-ray powder diffraction photographs (plate V). This mineral occurs both as feathery and irregular masses and as euhedral, orthorhombic crystals. The 2V, which varies slightly in natrolite from various rocks, is abnormally low for natrolite. However, the optical properties agree closely with those given for natolite in Winchell and Winchell (1951, p. 340) and the X-ray diffraction pattern with that of natrolite from Aussig, Bohemia.

Garnet

In hand specimen, the garnet is pitch black in colour and in thin-section, a deep red. Chemical analyses carried out by Allan (1914, p. 177) on similar garnet revealed up to 22% TiO_2 thus indicating the species schorlomite.

Rutile

A brownish mineral, occuring as small, euhedral crystals largely confined to patches of chlorite in altered limestone, was determined as rutile by X-ray powder diffraction photographs. However, in thin-section, the relief is obnormally low for rutile. A possible explanation is that the original rutile has largely been pseudomorphously replaced by fine-grained limonite and possibly some chlorite with the retention of sufficient rutile to enable a fairly good diffraction pattern to be obtained.

Unidentified mineral (1)

A few highly altered crystals of an undetermined mineral occur in limestone of the lowest inclusion on Garnet Mountain.

colourless
birefringence = .008 approximately
n>1.54
parallel extinction (?)
length fast (?)
biaxial; large 2V

Unidentified mineral (2)

This mineral occurs as minute, euhedral, possibly hexagonal crystals in apatite-rich bands in the upper radioactive zone on Aquila Ridge.

colourless
birefringence = .025 approximately
n>1.65 (apatite)<1.76 (acmite)
2 poor cleavages parallel to the c axis
cleavages approximately at 90° in basal sections
uniaxial (+)

Pyrochlore

In hand specimen, this mineral occurs as dead white to light yellow, vitreous octahedrons and fragments up to .2 mm. in diameter. In thin-section, it is colourless, unaltered, of very high relief and isotropic (plates IIIB and IVA). It's identity was determined by X-ray powder diffraction photographs, data for which is given with plate VI. A semi-quantitative spectrographic analysis carried out by the B.C. Dept. of Mines at Victoria gave the following results:

Si: less than 10%
Al: 3-30%
Mg: 0.2-2%
Ca: greater than 5%
Fe: 0.3-3%
Ti: greater than 1%
Na: greater than 1%
Cb: greater than 10%
Sr, Cr, Ba, Cu, Mn: trace

Qualitative spectrographic analysis carried out by the author on similar material yielded a trace of Ta, Y, Ce and K in addition to the above. From the above analyses, it is evident that the variety is very near the pyrochlore end of the pyrochlore-microlite series.

Pyrochlore-bearing rock was crushed, screened and a heavy tip was concentrated by super-panning. The tip was exposed on Kodak Nuclear Track Plates for several weeks and upon development, the pyrochlore was seen to display weak and sparse tracks which indicates a very small percentage of radioactive constituents. By comparing the density of tracks against the colour, it was found that the darker the pyrochlore, the greater the amount of contained radioactive material.

Unidentified radioactive mineral

Chemical analysis of radioactive skarn from the main inclusion on Aquila Ridge carried out by J.R. Williams and Sons, Provincial Assayers at Vancouver, gave 0.1% U_3O_8. A bulk semi-quantitative spectrographic analysis by the B.C. Dept. of Mines on weakly radioactive skarn gave the following results:

Si: greater than 10%
Al: 0.5-5%
Mg: 0.2-2%
Ca: greater than 5%
Fe: 1-10%

Mn: 0.3-3%
V: 0.007-0.07%
Ni: 0.003-0.03%
Co: 0.2-2%
Sr: 0.3-3%
P: greater than 1%
As: 0.05-0.5%
Cb: 0.03-0.3%
Th: 0.03-0.3%
Pb, Cu, Ti, Y, Yt, Ce, Na, La, Cr, Ba: trace

As the lower limit of detection of uranium by this method is 0.1%, this element was not detected in the sample analysed.

The 1% (approximate) of weakly uraniferous pyrochlore contained in most radioactive skarn is insuffieient to account for approximately 0.1% U_3O_8. Also, the best grade material obtained from the lower contact on Garnet Mountain (about twice background using the hand counter) is deficient in pyrochlore whereas material from the same locality giving a lower count contains a small amount of pyrochlore. Therefore the bulk of the radioactive material must be contained in another mineral or minerals.

In the radioactive material from Garnet Mountain, taken about 1 foot below the contact, minute black grains in natrolite surrounded by hematite dust are visible under high power (plate IIIA). In the same rock, a few pleochroic haloes are visible in biotite but their nucleii are not visible. A 200 gm. sample of this material was crushed, screened and super-panned. A tip of pyrite and minor acmite, a middling of almost pure acmite and a tail consisting of hematite-stained natrolite, microcline and calcite was obtained. The amount of tip obtained was too small for an accurate radiometric determination of its radioactive constituents. However, the middling gave no count above back-ground whereas the tail gave a count almost as high as the bulk sample. Hematite-stained natrolite was then isolated under the binocular microscope and an X-ray powder diffraction photograph made. Only a natrolite pattern was obtained and from this it is concluded that either the contained black grains are too few and too small to give a pattern or the contained mineral is metamict. No larger black grains were visible in any of the fractions.

The heavy tip obtained by super-panning material from the main radioactive zone (see under pyrochlore) contained approximately 50% each of pyrochlore and pyrite plus a small amount of impurities. The pyrochlore was easily identified on the track plates. A few opaque grains, some of which were attached to pyrochlore (plate IVA) were surrounded by a dense pattern of tracks. These were isolated under the medium power of the petrographic microscope and re-examined under the binocular microscope. They were found to be either pyrite or pyrochlore containing small black specks. Only a few very small grains were obtained although numerous track plates were prepared and attempts to obtain X-ray powder diffraction photographs of the contained radioactive mineral resulted only in weak patterns of either pyrite or pyrochlore.

A small amount of the pyrite-pyrochlore tip was mounted in bakelite and super-polished. Under the reflecting microscope, the pyrite was seen to be cut by irregular veinlets of hematite. However, a few minute crystals, some of them perfect cubes, were observed (plate IVB). These did not show the deep red internal reflection characteristic of hematite. Etching with hot 1:1 HCl did not tarnish these grains which seems to eliminate the possibility of their being magnetite. The grains, unfortunately, were too small to be isolated for X-ray determination. Numerous grains of pyrite were picked from the heavy tip and fused with LiF. Upon exposure to ultraviolet light, some of the beads thus obtained showed a weak greenish fluorescence, thus indicating the presence of uranium.

A 447.3 gm. sample of the radioactive grey altered limestone from Aquila Ridge, which showed little hematite staining and no natrolite was crushed and screened to 6 fractions. Each fraction was super-panned and a tip, middling and tail obtained. The resulting fractions were then radiometrically assayed using a stationary geiger counter. The assay results are recorded in table 2, p. 32. From table 2, it appears that the radioactivity is concentrated in the tip and middling whereas in the specimens from Garnet Mountain, it is concentrated in the tail.

From the above observations, it appears that at least one other radioactive mineral besides pyrochlore is present in contact limestones of the Garnet Mountain-Aquila Ridge area. Because the grains are too small, this mineral or minerals was unidentified. However, a few general statements can be made. In rocks high in natrolite, the radioactivity is concentrated in the natrolite and hematite is closely associated with the radioactive minerals. In rocks containing no natrolite and little hematite, such as that of the radioactive zone on Aquila Ridge, the radioactive mineral is concentrated in pyrite. The etch reactions, colour and crystal outline as seen in polished section and the density of tracks on nuclear track plates suggest uraninite as the main radioactive mineral. The writer is at a loss to explain the presence of thorium in the spectrographic analysis. A possible explanation is that it is contained in uraninite which is known to carry up to 14% ThO_2 in some deposits (Palache, Berman and Frondell, p. 612).

Table 2

Distribution of Radioactivity in Aquila Ridge Radioactive Zone

Radiometric determinations.
Wt. of sample: 447.3 gms.
Heads: 18 counts/min. .043%

10 counts/min. .02%
100 counts/min. .18%

Size	Wt.(gms.)	Counts/min.	Fraction	Wt.(gms.)	Cts./min.
			tail	33.6	14
48	43.9	19	middling	5.1	33
			tip	.5	--
			tail	47.6	14
65	60.1	18	middling	9.0	31
			tip	.5	--
			tail	47.6	9
100	66.8	14	middling	11.5	21
			tip	.8	--
			tail	29.8	4
150	38.5	12	middling	4.6	40
			tip	.5	--
			tail	39.9	9
200	47.4	17	middling	2.1	97
			tip	.4	--
			-		
(-)200	190.6	17	-	--	--
			-		

Combined tips: 2.7 gms. 82 counts/min. (approx. = .16%).

18 gm. sample used where possible. Middling and tail assayers corrected to 18 gm. values.

Fig. 3

ACMITE

Y 358 $\overrightarrow{7\frac{1}{2}}$

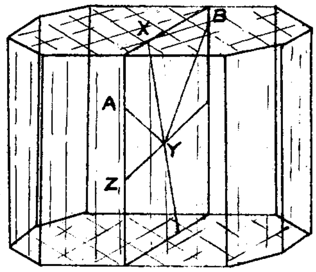
Z 265 $\overrightarrow{6}$

optic axis 30↑

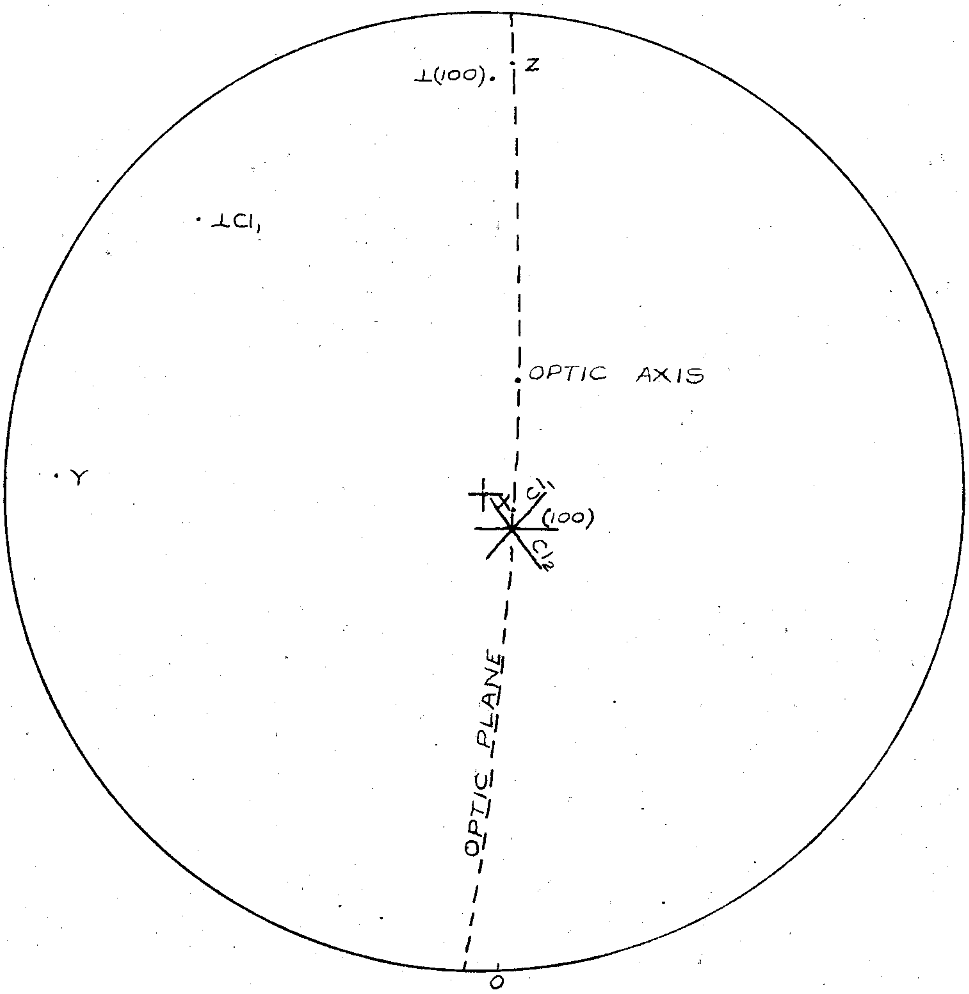
Cl_1 44 13↓

Cl_2 309 0

(100) 357 10↓



Therefore: $Z_{\wedge}c=87^{\circ}$; $V_z=56$; $2V_z=112^{\circ}$; $2V_x=\underline{\underline{68^{\circ}}}$



Nb: All values corrected for differences in refractive indices between mineral and hemispheres using Federow's diagram.

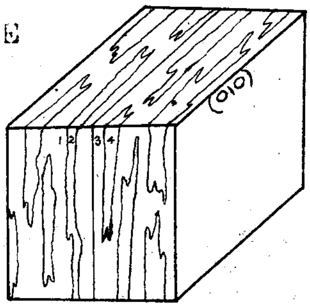
Fig. 4

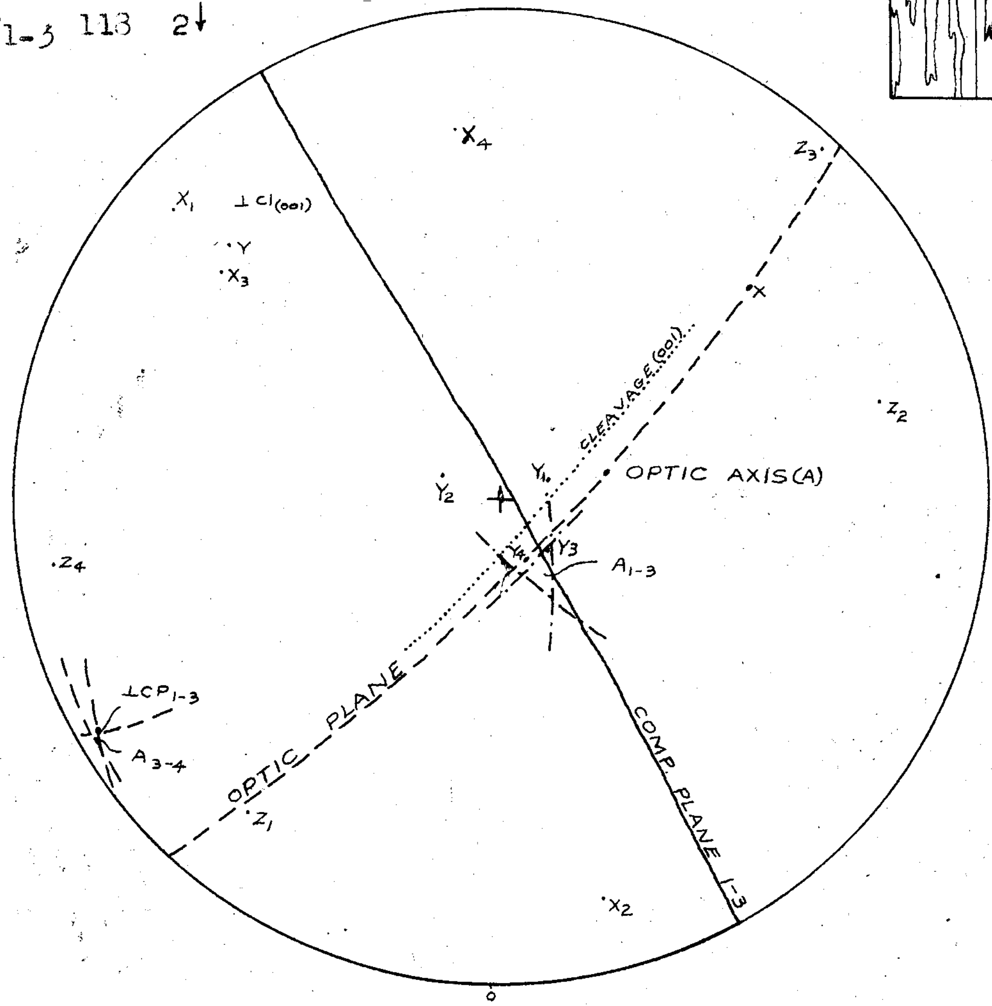
CARLSBAD - ALBITE TWINNING IN MICROCLINE

Combined twins			Single twin		
Z_1	49	$\overrightarrow{11}$	Y	314	$\overrightarrow{15}$
X_1	316	$\overrightarrow{5}$	X	39	$\overleftarrow{24}$
Z_2	15	$\overleftarrow{13}$	A	22	↑
X_2	102	$\overrightarrow{9}$	$Cl_{(001)}$	46	12↓
Z_3	46	$\overleftarrow{1}$			
X_3	318	$\overrightarrow{18}$			
Z_4	6	$\overrightarrow{3}$			
X_4	95	$\overleftarrow{16}$			
CP_{1-3}	113	2↓			

$X_1 \wedge CP = 71^\circ$ } Therefore MICROCLINE
$Y_1 \wedge CP = 81^\circ$ }

$A_{1-3} \wedge \perp Cl_{(001)} = 77^\circ$ (?)





A_{1-3} - Parallel or complex twin (Carlsbad)

A_{3-4} - Normal twin (Albite) 2V (-) $\underline{\underline{84^\circ}}$

CHAPTER IV

THEORETICAL CONSIDERATIONS

Theories on the Origin of Undersaturated Alkaline Igneous Rocks

Several theories have been brought forward to explain the origin of undersaturated alkaline igneous rocks. Brief summaries of a few of the more important of these theories are given below.

Bowen, in 1915, postulated that a nepheline syenite magma could be produced by the prolonged fractional crystallization of a basaltic magma. During an early stage in the differentiation of basaltic magma, calcic plagioclase and pyroxenes are believed to form which deplete the magma in calcium, some magnesium and iron and enrich it in alkaline constituents and volatiles. As this alkaline residuum is evolved, certain reactions are believed to take place which involve the breakdown of complex silicate molecules to simpler molecules. Two of the more important reactions, believed to be aided by a concentration of water and other volatiles, are as follows:

$$NaAlSi_3O_8 \longrightarrow NaAlSiO_4 + 2SiO_2$$

$$KAlSi_3O_8 \longrightarrow KAlSiO_4 + 2SiO_2$$

For a certain concentration of $NaAlSi_3O_8$ and $KAlSi_3O_8$, there is a corresponding concentration of $NaAlSiO_4$ and $KAlSiO_4$ and the amounts of each of these four constituents increases with increasing differentiation. At a certain stage in this process, silica becomes so concentrated that it begins to crystallize as quartz.[1] $KAlSiO_4$, $HAlSiO_4$, certain complex ferromagnesian

1 Bowen believes that the molecules which separate out are not necessarily those which are most concentrated but are those least soluble. For example, silica is less soluble than $NaAlSiO_4$.

molecules, and a limited amount of $NaAlSiO_4$ separate out to form biotite. Some feldspar also crystallizes at this stage and the result is biotite granite.

It is easily seen that a magma rich in $NaAlSiO_4$, other soda compounds, certain soluble potash compounds and volatiles might be formed by the above processes. This soda-rich magma may be removed from the underlying granite by filter pressing or it may crystallize in place giving rise to a layered body which is silica-rich near the base and silica-deficient near the top.

As evidence for his hypothesis, Bowen has pointed to the post-Cretaceous undersaturated intrusives of the Black Hills, South Dakota, the nepheline syenites of the Bancroft area,Ontario and many other localities where both silica-rich and under-saturated igneous rocks occur closely associated.

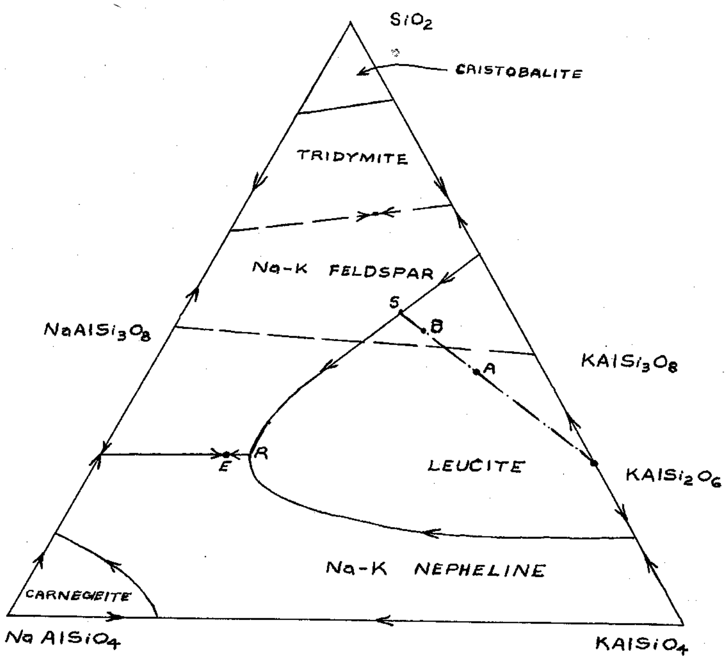
Bowen believes that volatiles are expelled from the granitic magma and become concentrated in the late soda-rich differentiate. He thinks volatile-bearing compounds are formed by what may be termed a decomposition of the silicates. This decomposition is the result of the action of H_2O, CO_2, Cl, F, etc. on silicates with the formation of soluble hydrates, carbonates, chlorides, etc. The latter are precipitated at a very late stage in and around the nepheline syenite to form such minerals as sodalite and cancrinite.

Bowen postulates that rare elements are eliminated from the granitic magma as ions because of their geochemical incompatibility with common silicates. These rare elements are deposited at a late stage in the solidification of the nepheline syenite magma.

In 1928, Bowen pointed out several other reactions which could produce silica-deficient magmas. These reactions will not be discussed here.

The nepheline-kaliophilite-silica system was investigated by Shairer and Bowen in 1935. The phase diagram for this system is given in fig. 5.

fig. 5



Phase Diagram for the System Nepheline-Kaliophilite-Silica

Rocks forming from melts of composition below the albite-orthoclase join will obviously be silica-deficient. A part of the system that requires some explanation is that existing in the leucite field. Let us consider a melt of composition A. Leucite begins to crystallize on cooling and the composition of the melt moves towards S. At S, leucite reacts with the melt and K-Na-feldspar crystallizes, the melt meanwhile following the curve SR. At R, leucite continues to dissolve and K-Na-feldspar and nepheline crystallize simultaneously. When all of the leucite is used up, K-Na-feldspar and nepheline separate together and the melt moves towards E until entirely used up. The final product is nepheline syenite. Bowen believes that such reactions explain the existence of pseudoleucite, ie., finely crystalline K-Na-feldspar and nepheline pseudomorphous after leucite.

Melts of composition B normally yield quartz-bearing rocks. However, if leucite crystals are concentrated during the early stages of cooling and the siliceous melt is largely eliminated by some process such as filter pressing, the remaining mixture may be so enriched in leucite as to be deficient in silica. During its cooling this mixture would have the same history as a magma of composition A giving rise to an under-saturated rock. A necessary result of this process would be the injection nearby of siliceous rocks representing the expelled fraction.

The mechanisms described above may not operate under very deep seated conditions. Bowen and Tuttle (1950) have shown that if water reaches a relatively high concentration under a pressure of approximately 2600 atm., the leucite field may be so restricted as to be excluded from the albite-orthoclase-silica triangle. Under these conditions, leucite would not precipitate from a melt of any composition lying in the albite-orthoclase-silica triangle.

Daly (1933) postulated dissolution of limestone by sub-alkaline magmas with consequent formation of calc-silicates and depletion of the original magma in silica, as the mode of origin of undersaturated alkaline igneous rocks. He believes that reactions such as the following go on when limestone is assimilated by a granitic magma.

$$2NaAlSi_3O_8 + 5CaCO_3 \longrightarrow Na_2SiO_3 + Ca_3Al_2Si_3O_{12} + 2CaSiO_3 + 5CO_2$$

$$2NaAlSi_3O_8 + 6CaCO_3 \longrightarrow Na_2CO_3 + Ca_3Al_2Si_3O_{12} + 3CaSiO_3 + 5CO_2$$

Garnet and other minerals so formed are believed to settle out whereas Na_2SiO_3 and Na_2CO_3 rise toward the top of the magma chamber where they react with albite and anorthite molecules to produce nepheline. The chemistry of the latter reactions is thought to be as follows:

$$NaAlSi_3O_8 + 2Na_2CO_3 \longrightarrow NaAlSiO_4 + 2Na_2SiO_3 + 2CO_2$$

$$CaAl_2Si_2O_8 + Na_2SiO_3 \longrightarrow 2NaAlSiO_4 + CaSiO_3$$

and, at lower temperatures:

$$CaAl_2Si_2O_8 + Na_2CO_3 \longrightarrow 2NaAlSiO_4 + CaCO_3$$

Daly, like Bowen, advocated a concentration of H_2O, CO_2 and other volatiles in undersaturated magmas. Daly believed that rare elements combine with certain volatiles to form soluble compounds. These soluble compounds do not crystallize until a very late stage and thus delay the final freezing of the magma.

Gummer and Burr (1943) and Baragar (1954), after studying nepheline gneisses in the Bancroft area, Ontario and at York River, Ontario, respectively, concluded that these rocks, which are interbanded with Grenville-like paragneisses and crystalline limestones, are the result of replacement of metamorphosed sedimentary rocks. Gradations from normal siliceous gneisses through nepheline-poor to nepheline-rich gneisses were observed at both localities. Gummer and Burr (1943) believe that these rocks may have resulted from granitic or syenitic liquids reacting with limestone to form nepheline. Evidence for such reactions is offered by calcite and other calcic minerals which are found in these rocks.

Origin of the Ice River Complex

If Bowen's original theory is correct, biotite granite should exist at Ice River. Although no biotite granite is exposed in the area, such granite may exist beneath the stock.

Let us briefly consider the nepheline-kaliophilite-silica system (fig, 5) in reference to the formation of the Ice River complex. Free silica has not been detected in any of the Ice River rocks which suggests that the composition of the soda-rich residuum was in the field below the albite-orthoclase join. However, as previously stated, silica-deficient residuums can be formed in the leucite field above the albite-orthoclase join by the squeezing off of interstitial silica. As no silica-rich rocks were found, this hypothesis appears inapplicable at Ice River. It also appears that the composition of the residuum did not lie within the leucite field as no pseudo-leucites have been found in any Ice River igneous rocks. As previously stated, the development of leucite is considerably restricted under conditions of very high pressure. Very high pressures did not likely exist during the emplacement of the Ice River complex as the maximum rock cover existing at that time probably did not exceed 2 miles (2 miles = 600-800 atm.).

The replacement theory as postulated by Gummer and Burr (1943) and Baragar (1954) appears untenable for the formation of the Ice River complex for several reasons. Discordant and brecciated contacts of igneous and sedimentary rocks, the presence of inclusions of country rock in the complex and the bowing up of overlying strata indicate an igneous origin. However, the author is at a loss to explain the apparent layering in igneous rocks at Garnet Mountain which some geologists might interpret as a replacement phenomenom.

In accordance with Daly's limestone syntexis theory, Allan (1914) believes that the addition of $CaCO_3$ has resulted in the desilication of an original sub-alkaline magma at Ice River with the resultant formation of silica-deficient alkaline assemblages. Daly's theory appears to apply at Ice River for two reasons. First, in order to attain its position, the magma would have to pass through approximately 13,000 feet of Cambrian limestone and limy sediments. Secondly, aegirine-augite and calcic plagioclase which were detected by Allan in the deeper portions of the exposed igneous rocks and the existence of such calcic minerals as calcite, schorlomite, perovskite and cancrinite veins throughout the complex points to an addition of $CaCO_3$.

Allan believes that the Ice River complex represents a single intrusion and that processes of differentiation have resulted in the diverse types. He states:

> "The hypothesis offered for the explanation of the diverse types within this complex, which are transitional into one another, is a combination of the result of separation by gravitative adjustment, and a rapid cooling of a portion of the original heterogeneous magma in the thinner and cooler portions of the chamber. There has been a sinking of the heavier minerals and a rising of the lighter ones".

That darker coloured rocks solidified first is reinforced by the fact that fragments of darker material are enclosed in lighter coloured material near the contacts of the two and fractures in dark rocks are filled with lighter coloured material. Patches of darker rock types occur near the roof of the magma chamber in a few places in the thinner portions of the complex. Allan believes that the magma did not have time to differentiate completely in these thinner portions.

As pointed out in previous chapters, mineralizers and rare elements are abundant in the rocks at Ice River. The role that these mineralizers (chiefly F, Cl and probably H_2O) have played in the formation of the Ice River alkaline rocks or in the extraction of rare elements, remains a matter of conjecture. However, the fact that mineralizers and rare elements are closely associated suggests to the author that they were probably concentrated and deposited together.

Rare Elements in Igneous Rocks

The relative abundance of columbium and tantalum in various igneous rock types has been compiled by Rankama and Sahama (1949) (Table 3).

Table 3

Average Cb and Ta Content and Cb-Ta Ratios in Igneous Rocks

Rock Type	Cb(gms./ton)	Ta(gms./ton)	Cb:Ta Ratio
monomineralic rocks	0.3	0.7	0.4
ultrabasic rocks	16.0	1.0	16.0
eclogites	3.0	0.7	4.3
gabbros	19.0	1.1	17.3
diorites	3.6	0.7	5.1
granites	20.0	4.2	4.8
syenites	30.0	2.0	15.0
nepheline syenites	310.0	0.8	387.5
basic alkalic rocks	10.0	1.2	8.3

In the above table it is seen that columbium becomes concentrated in far greater amounts than tantalum in nepheline syenites. This seems to hold true at Ice River for the pyrochlore is relatively richer in columbium than tantalum. Deposits of pyrochlore-microlite at Lake Nipissing, Ontario (Rowe, 1954) in which the source rock is diorite, have a tantalum content of almost 30%.

Rankama and Sahama (1949) have also shown that the content of columbium in alkaline igneous rocks is proportional to be content of zirconium in the ratio of about 1:10. Although the Ice River rocks are deficient in zircon, zirconium is present in the acmite and since the acmite forms a major constituent of many of the rocks in the area, this 1:10 proportion may well hold true.

Radioactive elements become concentrated in late magmatic differentiates as illustrated by tables 4 and 5.

Table 4
(Rankama and Sahama, 1949)

Abundance of Uranium in Igneous Rocks

Rock Type	Uranium (gms./ton)
ultrabasic igneous rocks	.96
basalts	.83
diabases	.83
intermediate igneous rocks	2.61
granitic rocks	3.96

Table 5
(Washington, 1909)

Concentrations of Rare Elements in Magmas

Alkaline Rocks		Sub-alkaline Rocks		
Na-rich	K-rich	Fe-rich	Mg-rich	Ca-rich
Li	Ba	Ti	Cr	Cr(?)
Be		Va	Pt	P(?)
Ce		Mn		
Yt		Ni		
Zr		Co		
U				
Th				

S
F
Cl
Sn(?)

More recent analyses using improved methods carried out by Evans and Goodman (1941) and Senftle and Keevil (1947) have also demonstrated the increased concentration of radioactive elements in late differentiates.

Metasomatism by Undersaturated Alkaline Igneous Rocks

An intense search of the literature revealed that little work has been done on contact metamorphism or metasomatism by undersaturated alkaline igneous rocks. This is possibly due to the fact that these rocks do not often generate extensive metamorphic aureoles or skarn zones especially in areas where they are bounded by gneisses.

Callisen (1943), in describing alkaline rocks at Ivigtut, Greenland, noted that the contact effects on the enclosing gneisses was merely conversion of certain dark coloured minerals to crocidolite and phlogopite. He also reported minor impregnations of fluorite, carbonate and phosphates in the gneisses.

A description of metasomatism was given by Chayes (1942) who noted tremolite, spinel, phlogopite, diopside and apatite developed in limestones contacting alkaline rocks in the Bancroft area, Ontario.

Metasomatism of Ice River limestone consisted of an introduction of sodium to form such minerals as acmite, natrolite and soda-rich amphiboles; potassium to form microcline and phlogopite; iron to form iron oxides, pyroxenes and amphiboles; fluorine and phosphorous to form apatite and the rare elements columbium, tantalum, zirconium, yttrium, cerium, etc. to form pyrochlore, uraninite(?), and other uncommon minerals.

PLATE I

A. Cyclic twinning in apatite (x 400).

B. Aegirine-augite, augite zoning in urtite (x 150).

PLATE I

A

B

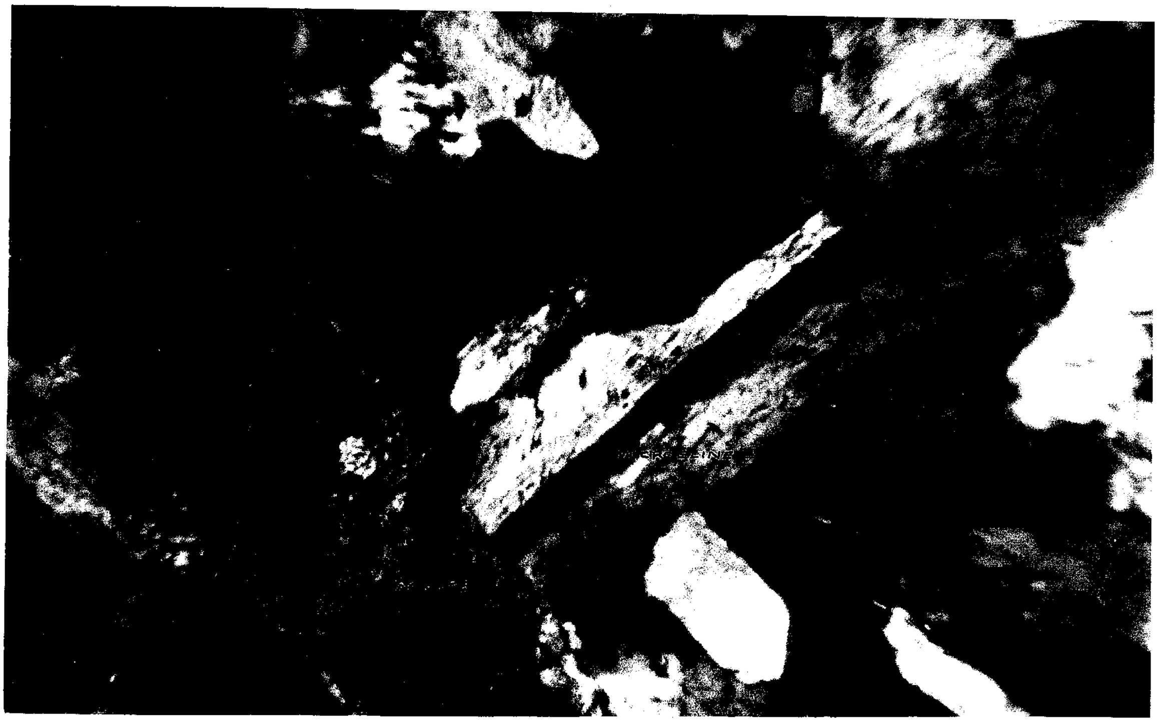
PLATE II

A. Albite twinning in microcline (x 400).

B. Carlsbad-albite twinning in microcline.
Acmite-microcline rock (x 150).

PLATE II

A



B

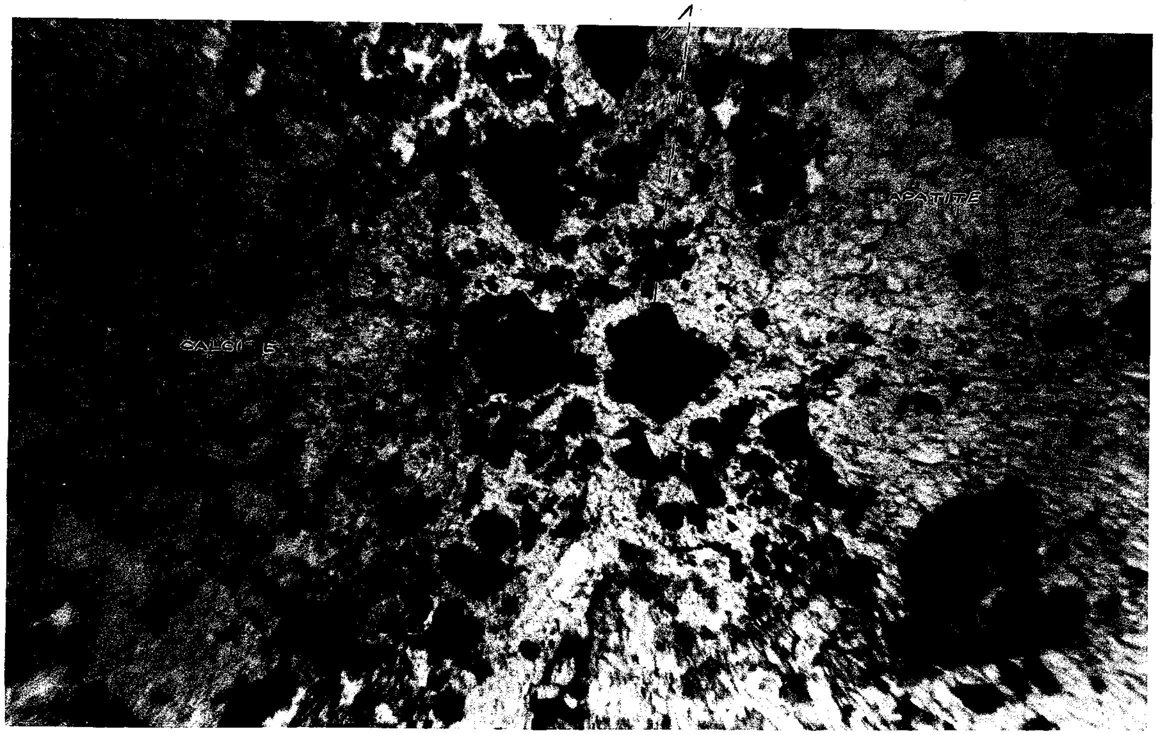
PLATE III

A. Minute radioactive (?) grains in hematite-stained natrolite. Metasomatised Garnet Mountain limestone (x 400).

B. Pyrochlore in apatite. Main Aquila Ridge radioactive skarn zone (x 150).

PLATE III

A



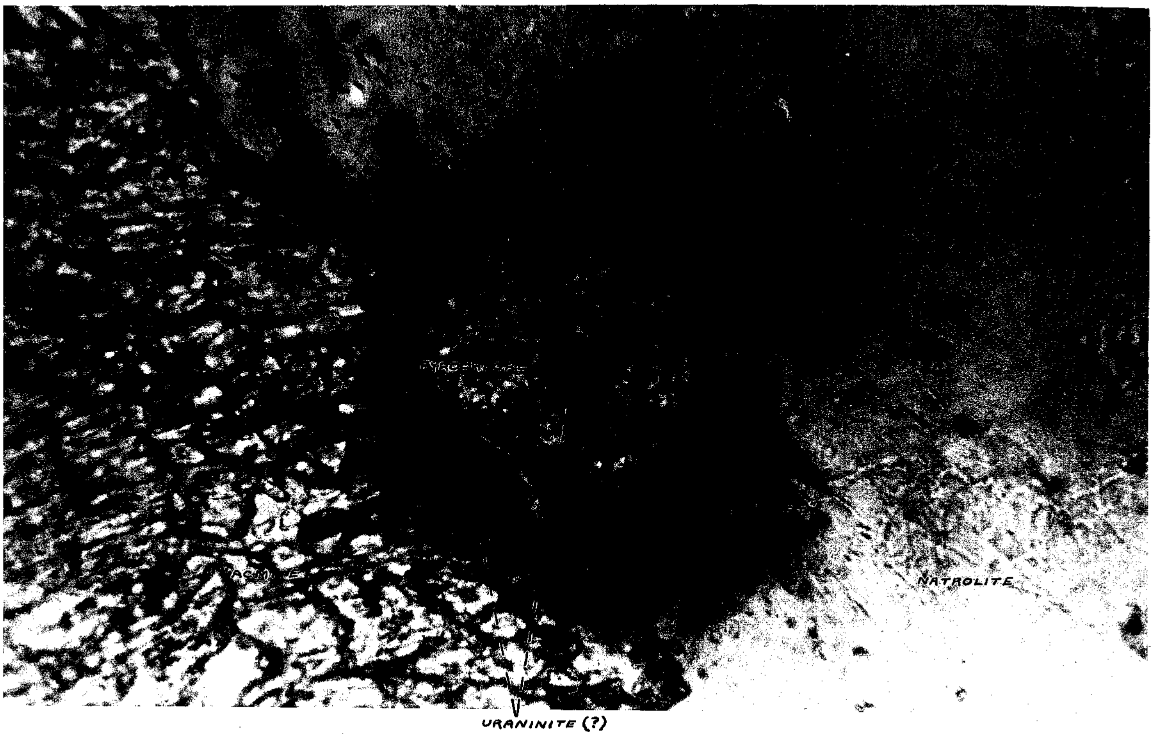
B

PLATE IV

A. Pyrochlore and uraninite (?) surrounded by hematite "dust" in natrolite (x 400).

B. Uraninite (?) in super-polished pyrite (x 200).

PLATE IV



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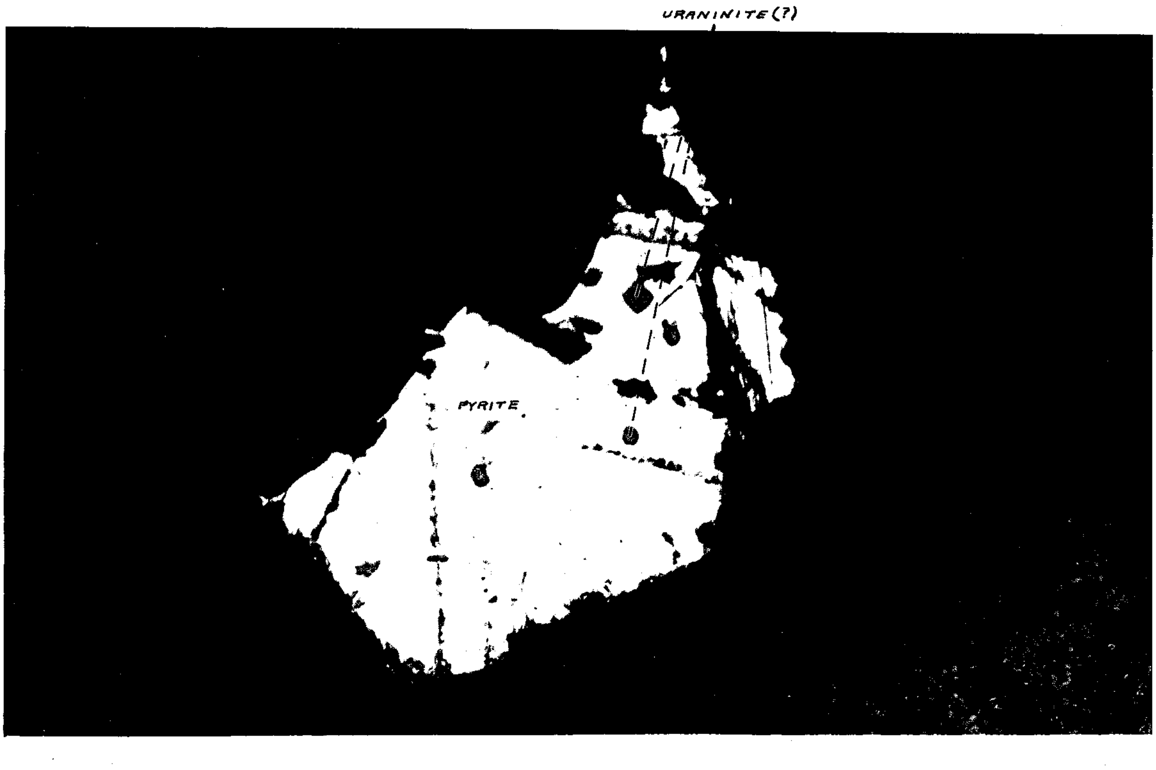

B

PLATE V

Natrolite, Ice River, B.C. Fe/MnO

I	e	D	I	e	D	I	e	D
2	7.75	7.18	1	21.05	2.70	1	36.35	1.634
7	8.45	6.59	2	22.15	2.57	1	36.95	1.611
5	9.35	5.96	2	23.35	2.44	½	37.85	1.579
1	10.75	5.19	2	23.65	2.41	1	38.95	1.541
1	11.45	4.88	1	24.55	2.33	½	39.85	1.512
4	12.15	4.64	½	25.45	2.25	3	41.25	1.469
5	12.65	4.42	2	26.35	2.18	1	42.85	1.424
4	13.55	4.13	½	28.05	2.06	1	44.15	1.391
½	14.55	3.86	½	29.15	1.989	½	44.95	1.371
2	16.05	3.50	1	30.85	1.889	1	45.95	1.348
10	17.85	3.16	3	32.35	1.810	½	46.95	1.326
1	19.05	2.95	1	34.05	1.730	1	47.65	1.311
10	19.75	2.87	1	34.45	1.712	3	52.55	1.220

All values adjusted for film shrinkage.

PLATE VI

Pyrochlore, Ice River, B.C. Cu/NiO. a (calc.): 10.408 Å

I	e	d (meas.)	hkl	d (calc.)
3	7.35	6.04	(111)	6.01
3	14.15	3.15	(113)	3.14
10	14.40	3.01	(222)	3.01
2	17.20	2.60	(004)	2.60
1	22.65	2.00	{(115) (333)}	2.00
8	24.70	1.844	(044)	1.840
1	26.03	1.757	(135)	1.759
8	29.45	1.568	(226)	1.569
2	30.85	1.503	(444)	1.502
1	31.86	1.460	{(117) (155)}	1.457
2	34.66	1.355	{(137) (355)}	1.355
2	36.40	1.299	(008)	1.301
4	40.30	1.192	(266)	1.194
3	41.60	1.161	(048)	1.164
½	42.40	1.143	{(119) (357)}	1.143
½	45.15	1.087	(139)	1.091
2	46.75	1.058	(448)	1.062
2	50.30	1.002	(666)	1.002
4	61.30	.879	{(26,10) (668)}	.880
3	62.75	.867	{(00,12) (488)}	.867
2	69.65	.822	(04,12)	.823

All values adjusted for film shrinkage.

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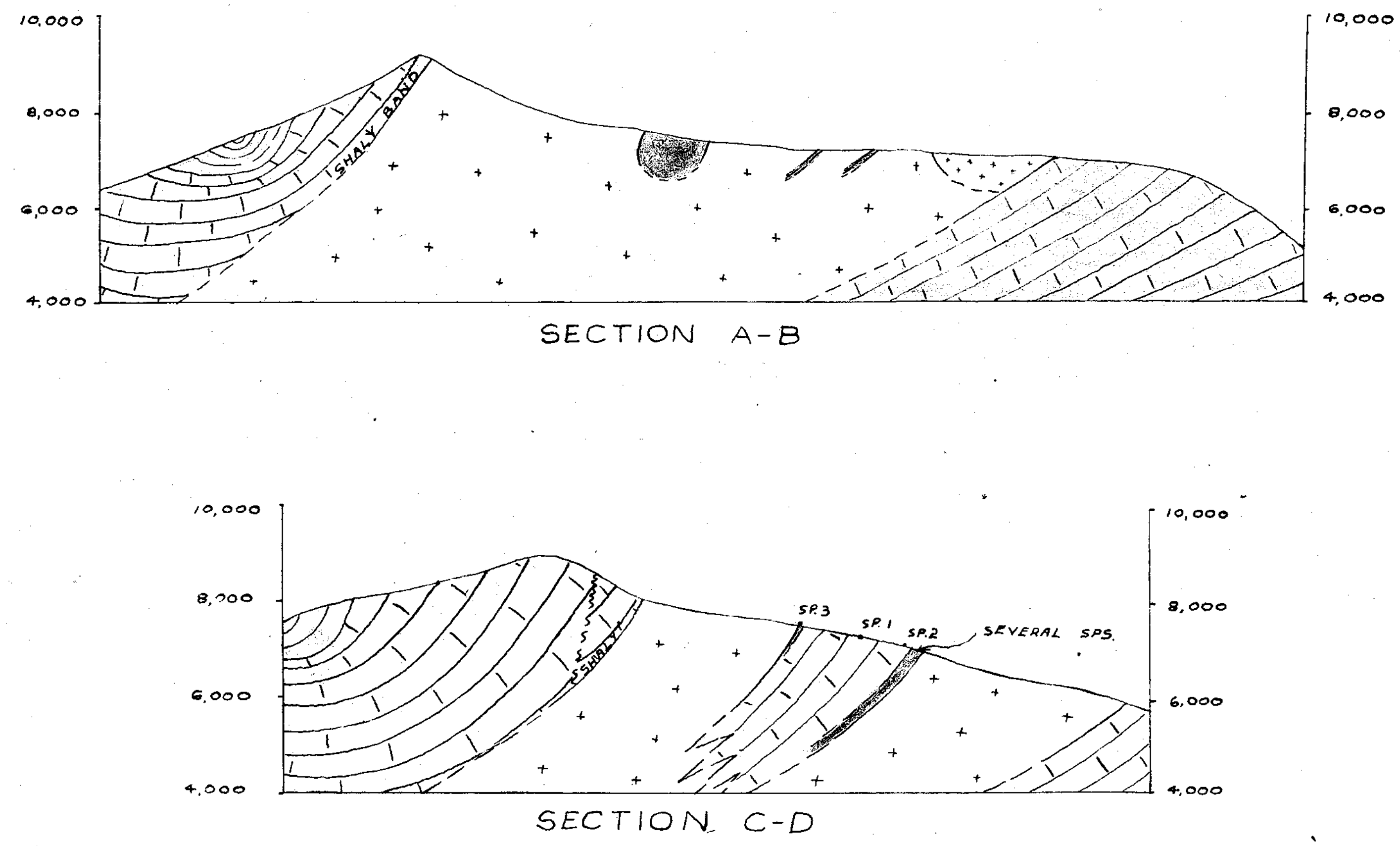

GEOLOGY OF GARNET MTN.- AQUILA RIDGE AREA

LEGEND

- ALLUVIUM
- GLACIAL
- UNDERSATURATED ALKALINE IGNEOUS ROCKS
  - LEUCOCRATIC TYPES
  - MESOTYPES
  - MELANOCRATIC TYPES
- UPPER CAMBRIAN
  - GOODSIR FM. — Shale; slate; lms.
  - OTTERTAIL FM. — Lms.
  - CHANCELLOR FM. — Argillite.
- RADIOACTIVE SKARN

CONTOUR INTERVAL = 1000' SCALE 1" = 2000'

AFTER J.A. ALLAN (1914)