THE SEAGULL CREEK BATHOLITH AND ITS METAMORPHIC AUREOLE

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED 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 APPLIED SCIENCE.

Members of the Department of
GEOLOGY AND GEOGRAPHY

THE UNIVERSITY OF BRITISH COLUMBIA
April, 1952

Abstract

The main features of the Seagull creek batholith are described. The most noteworthy of these is the abundance of boron in the granites themselves and in the contact aureole. This has led to the formation of miarolitic cavities containing tourmaline, to the formation of tourmaline and axinite veins and disseminations in the surrounding rocks, and to the formation of magnesium iron borates in a contact metamorphic iron deposit.

Laboratory studies and reference to literature on similar rocks have led to the following conclusions:

1. Boron was a major constituent of the final residual liquid of the Seagull creek magma.

2. Segregations, either gaseous or liquid, from this final liquid caused the formation of miarolitic cavities in the granite.

3. Fine grained and aplitic phases of the Seagull creek granite are younger than the coarser grained phase.

4. The rocks are similar in many respects to those of Cornwall, Seward peninsula, Alaska, and other tin bearing regions.

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CHAPTER 1
INTRODUCTION

General Statement

This report is based on field work carried out in the summer of 1951 for the Geological Survey of Canada under W.H. Poole, party chief. Mapping, on a scale of four miles to one inch, was commenced on the Wolf Lake sheet, a 5000-square mile quadrangle bounded by the 60th and 61st parallels and the 130th and 132nd meridians.

The area described in this report is in the south-central part of the sheet. Its most prominent feature is the Seagull creek batholith, noteworthy for its variations in texture, for its abundant miarolitic cavities, for the high content of boron within the batholith and in the metamorphic aureole, and for an unusual mineral assemblage in a related contact metamorphic deposit.

These were the subject of considerable laboratory investigation and the results form the body of this report.

Grateful acknowledgement is made to W.H. Poole of the Geological Survey of Canada for permission to use material collected during the 1951 field season. Thanks are also due to Drs. H.C. Gunning, W.H. White, R.M. Thompson, and K.C. McTaggart, of the Department of Geology and Geography of the University of British Columbia, for advice on the preparation of the report and aid in determining the minerals, and to Mr. J.A. Donnan, Laboratory Technician, who assisted in the preparation of thin-sections and polished sections.

Location

The Seagull creek area lies between latitudes 60° and 60°15' North and longitudes 131° and 131°30' West. The Alaska highway cuts across the southeastern corner of the area from mileage 726 to 733.5 measured from Dawson Creek. Swift river Control Station at mile post 733 is the only settlement in the area. An emergency airstrip is located two miles north of the highway at mile post 722, just east of the area.

The highway is served by British Yukon Navigation buses that run twice weekly between Whitehorse and Dawson Creek.

Physical Features

The area marks the northern extension of the Cassiar mountain ranges which have a core of granitic rocks, the Cassiar batholith (Bostock, 1948). It is essentially a dissected plateau with an elevation of over 5,000 feet in which the river valleys are entrenched about 3,000 feet below the plateau surface.

Glacial erratics up to 6,500 feet elevation indicate that the entire region has been glaciated. U-shaped valleys and heavily drift-covered valley floors are the rule.

Drainage

The area is drained by tributaries of the Teslin river, the main ones being the Smart, the Swift and the Morley rivers. The Rancheria river, a tributary of the Liard, rises near the northern edge of the area and flows in part through the same valley as the Swift river. Seagull creek, a tributary of the Swift river, rises in the centre of the area and flows almost due south to join the Swift at mile post 733 on the Alaska highway.

Climate

The climate during the 1951 field season was mild and dry. Field work was carried on from June 15 to September 7, during which time very little rain fell. Night frosts were common after August 15.

Vegetation

Timber line is about 4,500 feet, below which small conifers and dwarf birch are the most abundant vegetation. Horse feed is plentiful, and except in burned over country, trails do not have to be cut.

CHAPTER 2

GENERAL GEOLOGY OF THE AREA

Regional Setting

Cassiar batholithic rocks, trending northwest, form the core of the area. They occupy a narrow belt several hundred miles long and are probably a continuation of the Omineca batholithic rocks to the southeast. Paleozoic sedimentary rocks, metamorphosed near the granitic rocks, lie along the flanks of this belt. Mesozoic volcanic rocks overlie these sedimentary rocks on the west, from Teslin lake north. Tertiary basalt outcrops locally in some of the main river valleys. Intrusions of ultra-basic rocks, probably older than the Cassiar batholiths, occur in belts along their eastern and western flanks.

Sedimentary and Regionally Metamorphosed Rocks

The oldest rocks in the area are believed to be those in contact with the main Cassiar batholith and consist of, from the contact westwards, quartz-feldspar-biotite gneiss, quartz-biotite schist, quartz-sericite schist, and quartz-chlorite schist. These rocks were mapped by Lord (1944) as a separate group because of their higher degree of metamorphism than the rocks to the west, and because of a possibility that the chlorite schists may have been derived from older volcanic rocks. No evidence was seen in 1951 to support this possibility.

In apparent structural conformity above these rocks lie, in ascending order, quartzitic conglomerate, argillaceous quartzite, encrinal limestone, argillaceous quartzite, coral limestone, and finally black chert, the youngest sedimentary rock of the area.

It is possible to make only the roughest of estimates of the thicknesses of these rocks. At most of the outcrops, especially those poorly exposed, it was impossible to determine the bedding with certainty. The quartzite gives the most reliable attitudes, for the bedding is usually obliterated in the schists and gneisses, and the limestone is so complexly folded that attitudes in it are of little use.

Two fossiliferous beds were mapped. One is encrinal limestone of unknown age. The other is mainly coral limestone of Upper Mississippian age[1]. These beds are each about 200 feet thick in a sedimentary succession of 5,000 to 10,000 feet.

Intrusive Rocks

Cassiar Batholith

A large body of intrusive rocks, mapped by Lord

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1. Dr. Peter Harker, via W.H. Poole, personal communication.

(1944) as a possible extension of the Cassiar batholith, lies to the east of the map area and cuts across the northeast corner. The principal rock, according to Lord, is a biotite-quartz monzonite. Thin-sections of this rock were not studied, but hand specimens collected in 1951 contain approximately:

Pink feldspar (orthoclase and/or microcline)	30%
White feldspar (plagioclase)	30%
Quartz	30%
Biotite and Muscovite	10%

Pegmatitic phases are richer in potash feldspar and muscovite than the quartz monzonite, and contain black tourmaline and small red garnets.

Swift River Diorite and Granodiorite

Two dome-shaped mountains on opposite sides of Swift river near Camp 11 are composed chiefly of granodiorite with a dioritic envelope. The exposed parts of the intrusive are about a mile square. The compositions of the two phases, estimated from hand specimens, are:

Diorite	
Feldspar, largely altered to sericite	40%
Hornblende	50%
Biotite and Chlorite	8%
Quartz	2%
Granodiorite (or Quartz Diorite)	
Feldspar	50%
Hornblende	30%
Biotite	10%
Quartz	10%

Seagull Creek Batholith

The Seagull creek batholith, at least ten miles long and up to seven miles wide, is exposed in the central part of the area. Small exposures of similar rock lie to the north and northeast of the main body. The batholith is composed principally of coarse-grained massive granite, deeply weathered in a few places, but otherwise hard and fresh looking. Its average composition, from hand specimens and thin-sections, is

Quartz	40%
Potash feldspar	35%
Plagioclase (An_{25})	15%
Biotite	10%

The texture, structure, and other features will be described in Chapter 3.

Minor Intrusives

Several dykes and sills were mapped. Their composition ranges from peridotite, through andesite, to rhyolite. Most of them are associated with the main Cassiar batholith but two, cutting amphibolite near Camp 18, are apparently associated with the Seagull creek batholith. One is an altered peridotite, composed of olivine, enstatite, serpentine and chrysotile asbestos, with minor magnetite. The other is rhyolite with glassy borders. The rhyolite dyke, about four feet wide, is composed of a white porcelain-like interior and green obsidian margins a few inches thick. A thin-section of the obsidian (No. 108) shows shreds of two minerals occurring as phenocrysts. One is colourless and lathlike with inclined extinction (probably plagioclase). The other is pale green, with low birefringence, straight extinction, and is probably biaxial. It may be chlorite replacing biotite as it appears to have higher relief and birefringence than pure chlorite. A thin-section of the interior part (No. 109) contains phenocrysts of quartz, plagioclase, biotite partially altered to chlorite, and a small grain of sphene. The ground mass in both specimens is extremely fine grained.

Contact Metamorphic Rocks

Contact metamorphic rocks outcrop in an irregular aureole surrounding the Seagull creek batholith and the Swift river granodiorite. Hornfels, amphibolite, and crystalline limestone are the most abundant rock types. A contact metamorphic iron deposit lies within the aureole on the south fork of Swift river. The rocks and this deposit will be described in Chapter 3.

Structure

Lord (1944, p. 15) states that the sedimentary rocks of this area probably occupy a major syncline that trends northwesterly. "The strata within the central part of this major syncline trend in many directions and probably form several smaller folds, the axes of which possibly trend about north-northwest and lie several miles apart."

On the British Columbia-Yukon boundary, just east of Partridge creek, approximately in the centre of the outcrops mapped by Lord as "Group B", a major synclinal axis was observed. The rocks for miles on both sides dip generally gently toward this axis, but are, as Lord states, somewhat contorted near the axis.

A great deal more work is necessary before the rocks on the opposite limbs can be safely correlated. Fossil horizons are probably numerous, however, and careful detailed collections and stratigraphic studies may provide the answer.

CHAPTER 3

THE SEAGULL CREEK BATHOLITH AND ITS METAMORPHIC AUREOLE

The Seagull Creek Batholith

The granite of the Seagull creek batholith exhibits two distinct textural phases, one coarse to almost pegmatitic, the other fine to, in some cases, aplitic. The coarse granite forms about 90% of the batholith outcrops. It is remarkably uniform, specimens from widely separated localities being practically identical in colour, texture and composition. The feldspar crystals, about 5 mm. diameter, are cream coloured, and show abundant carlsbad twinning. The quartz grains are anhedral, generally smaller than the feldspar crystals, and have a frosted appearance. Except in the instances mentioned below they are colourless, white or light grey.

The fine-textured phase of the granite is composed of the same minerals as the coarse but the average grain size is less than 1 mm., except for occasional phenocrysts of quartz and feldspar up to 5 mm. diameter. Most of the fine-textured granite forms large irregular bodies but some of it occurs in dykes ranging in width from a few inches to tens of feet. These dykes are probably true aplites. The rock has a sugary texture, and is composed of light grey feldspar, colourless quartz, and a little biotite. The fine-grained granite is sporadically distributed, but seems to be more abundant near the margins of the batholith. Large masses of it outcrop in the canyon of the south fork of Swift river (Specimen 51), and just to the north of the large xenolith (see map) south of Camp 18 (Specimen 119). Its composition, estimated from hand specimens, and thin-section 119, is:

Quartz	50%
Potash Feldspar	35%
Plagioclase (An_8)	10%
Biotite	4%
Fluorite	
Topaz (?)	1%
Iron ores	

Aplite dykes outcrop on the ridge near the north boundary of the main exposure of the batholith (Specimen 61), and near the eastern boundary (Specimens 69, 70). Their average composition, from thin-sections, is:

Quartz	60%
Potash Feldspar	25%
Plagioclase (An_8)	10%
Biotite	5%
Tourmaline	
Fluorite	
Sphene	<1%
Apatite	
Iron ores	

Two inclusions of quartzite were mapped, in both cases near the margin of the main exposure (see map). The bedding has been preserved and the rock shows no signs of alteration other than bleaching. The large amphibolite xenolith, mentioned previously, will be described later in this Chapter.

The Seagull creek batholith is characterized by an abundance of miarolitic cavities. Their distribution is sporadic. They are most abundant in a cirque near the centre of the batholith (Specimen 62) where for several hundred feet of exposure they are only a few feet apart and where almost every boulder on the talus slope below the outcrop contains one or more cavities (see Fig. 1). They are also abundant near the eastern boundary of the main exposure near the aplite dykes mentioned previously. Very few were seen in the canyon of the south fork of Swift river.

The average size of the miarolitic cavities is about four inches in diameter, but some were seen up to a foot across. Their shapes range from spherical to elongate (Fig. 1). Generally speaking the larger ones tend to a less-perfect spherical form, possibly due to the fusion of two or more of them during their formation.

The miarolitic cavities are lined with crystals of quartz and tourmaline, and locally fluorite. The quartz crystals, about an inch in length, are, in contrast to those of the surrounding granite, smoky rather than colourless or white. Rhombohedral terminations were noted in many specimens. Black tourmaline, in prismatic crystals about an inch long, has grown radially inwards from the walls of the cavities. The bases of both the quartz and tourmaline crystals are intergrown with the quartz and feldspar of the surrounding granite. Each of the cavities is surrounded by a dark grey zone up to six inches thick carrying abundant tourmaline. Biotite is lacking in such zones and feldspar shows replacement by tourmaline. A partly replaced plagioclase crystal in a thin-section of this material has a composition of An_8 (Specimen 62). Fluorite and minor topaz (?) were seen in the thin-section.

In the aplite dykes, and to a lesser extent in the coarser-grained granite, dark grey spherical masses with no central cavity occur (see Fig. 1), which contain the same mineral assemblage as the zones around the cavities.[1] These masses range in size from one inch to six inches diameter. The dark grey colour is here also due to tourmaline which constitutes about 10% of the mass. The light grey fine-grained granite also contains tourmaline but commonly only one or two percent. Some biotite is present, corroded and partially replaced by tourmaline. Micro-granophyric intergrowths are common in all of the fine-grained granite.

The tourmaline of the granite is probably close to schorlite in composition (see spectrographic analyses in Chapter 5). In thin-section most of it is strongly pleochroic, from pale blue to dark greenish-blue, but some from pale yellow to greenish-yellow. The refractive indices, measured with monochromatic light and an oil of known refractive index, are e = 1.638, w = 1.665. These

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1. Aplites containing similar masses of tourmaline are called "puddingstone" by Flett (Ussher, et al, 1909).

fit data for schorlite, given by Winchell (1951).

At one locality (Specimen 104a) the granite has a rust coloured weathered surface. Investigation revealed an abundance of tiny irregular vugs containing microscopic crystals of arsenopyrite. Disseminated interstitial tourmaline is also abundant in this rock.

There can be little doubt that the fine-textured granite is younger than the coarse. The field relationships, as illustrated in Fig. 1, show the cross-cutting relationship of the aplites to the coarse-grained granites. Contributing evidence, brought out by laboratory study, is that the tourmaline and fluorite content is much higher in the fine-textured phase than in the coarse, and that the composition of the plagioclase is more sodic in the fine. Ghosh (1934), discussing the relationships of fine- and coarse-textured phases of the Carnmenellis granite, concludes that the fine-textured granite cuts the coarse. He envisages a semisolid cover of the earlier phase being cracked by the force of intrusion of the later phase, the fissures being immediately sealed by injections of magma.

Fine-grained granites that occur as dykes in the Dartmoor granite are described by Flett (Reid, et al, 1912). "They are later than the coarse granites but belong undoubtedly to the same magma. Usually pale grey in colour they range in texture from cryptocrystalline to fairly coarse-grained. As a rule they contain less biotite and more tourmaline than the coarse granite. On the whole they are more acid in character than the main granite and contain less oligoclase and more alkali feldspar."

Origin of the Miarolitic Cavities

The following definition is given by Johannsen (1939) of the word miarolitic. "Miarolitic (after an Italian word miarolo, a local name for a variety of granite) - used by Rosenbusch as a term to describe the texture of certain granites between whose constituents there are small angular cavities into which small crystals of the different constituents project." The word may be originally from the Greek, miaros=stained, and lithos= stone.

Miarolitic cavities are common in some granites but the size and type occurring in the Seagull creek granite are rather unusual.

Of the geological reports on areas adjacent to the Wolf lake area only two mention miarolitic cavities. Watson and Mathews (1944, p. 26) mapped a small stock of graphic and miarolitic granite in the Tuya-Teslin area, B.C., composed of pink feldspar and quartz and containing "miarolitic cavities which range from $\frac{1}{2}$ to $\frac{3}{4}$" in diameter .... lined with well formed crystals of quartz, feldspar and in some cases fluorite."

Fyles (1950, p. 53) states that certain smoky-quartz granites in the Whitehorse area contain miarolitic cavities from 1 inch diameter to microscopic filled by black quartz, orange feldspar, fluorite and locally an unknown green mineral.

Further afield Watson (1902, p. 186), describing tourmaline "bunches" in the Stone mountain granite of Georgia, notes an "abundant occurrence of small areas of aggregated black tourmaline crystals. Hardly a block of quarried stone does not show a few areas. The mineral is not a characterizing accessory but more after the order of segregations in biotite-bearing muscovite granite ... [It] rarely occurs in isolated or single crystals in the granite proper but nearly always as radiating and roughly parallel groups which occupy the centres of perfectly white areas of quartz and feldspar from which ... muscovite and biotite have been excluded."

These white areas "vary in size from a fraction to several inches diameter, in shape from oblong, irregularly rectangular to complete spherical or circular outlines." The tourmaline occurs in "slender prismatic forms varying from a fraction to several millimeters in cross section without terminal faces ... [is] jet black in colour and in every case examined considerably fractured."

Watson noted "no tendency to grading or merging of the colour of the white mass into the granite" and saw "no difference in texture and size of component grains from that of granite." In thin-sections he observed that "in some cases tourmaline is confined to feldspar individuals, in others it cuts well into quartz and feldspar grains in such a way as to clearly indicate its subsequent formation."

His conclusion was "the tourmaline areas have resulted from fumeroles highly charged with boric acid, acting on feldspar and mica."

The textural and age relationships of tourmaline to other minerals in the Bodmin and St. Austell granites has been studied by Ussher, et al (1909). Tourmaline in the granite started crystallizing at the same time as biotite and continued till orthoclase and quartz separated out. "It is not uncommon to find shapeless masses of tourmaline enclosing idiomorphic crystals of quartz, orthoclase and albite." Zonal bands in tourmaline indicate idiomorphic crystals at the start of crystallization when a considerable part of the rock was still liquid. The outer zones become progressively more and more irregular. In schorl rocks tourmaline replaces biotite but part of the tourmaline in granites is primary.

Gallagher (1937) describes the miarolitic cavities in the magnetite deposits at Lyon mountain, New York. The cavities are sporadically distributed. Their average size is 1' x 3' x 4' but some are large enough for a man to crawl in, and small ones are uncommon. They are lined with crystals up to 1 foot long, the bases of which merge imperceptibly into the enclosing wall rock structure without any line of demarcation. The cavities are composed of orthoclase, albite (Ab_{97}), quartz - rarely in good crystals, clear and smoky with frosted surfaces -, and hastingsite, in crystals up to 1 foot long with the average a few centimeters, and asbestiform amphibole, a white, wet, mushy mass filled with grains of other minerals.

In discussing the origin of these cavities Gallagher mentions the fact that the cavities must have formed under high pressure because when a drill hole penetrates a cavity, water shoots 20 to 35 feet out of the hole. He does not think they are solution cavities because there is no means of exit or entry of solutions. The cavities do not truncate structures in the enclosing rock. Gneissic structures bend around the cavities.

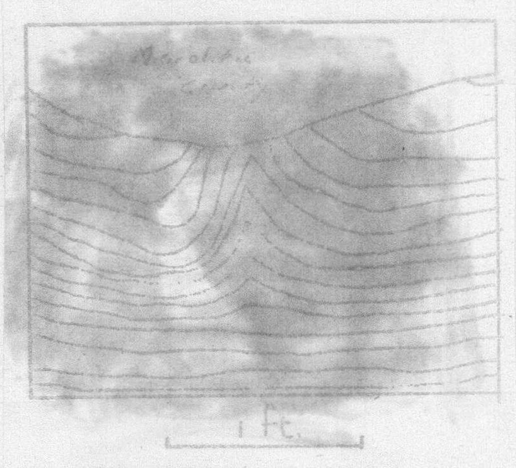

Figure 2

Gallagher's diagram (Fig. 2) shows banding bending inward towards a cavity. At a time when the gneiss was still a mobile mass some material, probably gas, moved laterally under the influence of differential force and merged with the material filling the cavity. This case suggests (to Gallagher):

1. The material filling the cavity was a gas.
2. The gas was mobile within the magma in masses like

bubbles.

3. There was a tendency for gas to collect in major bubbles.

4. The gneissic structure was in existence before the magma solidified.

5. The gas pressure was sufficient to hold the cavities open against load pressure from above and against forces of intrusion.

6. The stability of gas in the magma was low.

7. Its power to react chemically with other constituents of the magma must have been low.

Since gneissic structures were not observed in the Seagull creek batholith, Gallagher's inferences cannot be applied here. However, certain similarities between the two occurrences are seen, namely, the distribution of the cavities, their mode of occurrence and the relationship of the crystals lining the interior to those of the enclosing rock.

At least three modes of origin are possible for the cavities. 1. They may have been left by removal of inclusions. 2. They may be the result of solution of the granite by fluids from an outside source. 3. They may be the sites of pockets of fluid resulting from the crystallization of the magma.

The greatest difficulty in the first hypothesis is accounting for the removal of the inclusions. The xenoliths of the Seagull creek batholith, although in some cases considerably altered by metasomatism, do not appear to have been dissolved away or otherwise removed after the consolidation of the granite.

Fluids from an outside source would be guided through fractures in the rock and the distribution of the cavities would thus be related to these fractures. However, the joints and larger fractures of the granite seem to bear no relation to the cavities and are, in general, not filled with tourmaline. Furthermore, it is unlikely that certain crystals of quartz, feldspar, and tourmaline would be left intact while others immediately adjoining them would be completely removed.

The last hypothesis is the most likely, and the conclusion is therefore reached that these cavities are true miarolitic cavities. The following evidence is offered in support of this conclusion. Most of the cavities are spherical or ovoid, suggesting formation from a globule of liquid or a bubble of gas. The crystals lining the cavities are more nearly euhedral than those of the walls, suggesting growth in an environment that did not restrict their crystal shape (e.g. open space). The bases of the crystals lining the cavities merge with those of the surrounding granite, suggesting that they and the minerals of the normal granite formed simultaneously. There are apparently no channelways connecting the cavities to provide entry and exit of material.

In order to test this hypothesis it might be advisable to attempt a reconstruction of the history of formation of the cavities. One of the most acceptable theories, supported by laboratory investigations (Smith, 1948), is that a crystallizing granitic magma commonly yields a residual liquid rich in alkalies, silica, water, and other volatile constituents. To form the minerals lining the cavities this liquid, in the case of the Seagull creek batholith, must have contained boron, fluorine, silica, and water, and probably contained alumina, and iron, although it is conceivable that they could be derived from the earlier formed crystals.

The process starts with the crystallization of minerals from the magma. An interstitial magmatic liquid will remain. As crystallization proceeds this liquid probably becomes more dilute. By the process of diffusion, aided by the surface tension of the liquid, or perhaps by the formation of an aqueous immiscible phase of the liquid constituents (Smith, 1948, p. 544), this liquid is concentrated into spherical drops or globules either saturating the crystal mush or excluding the crystals from the interior of the drops. The size of the drops would decrease as crystallization proceeds. A point would eventually be reached where the surrounding crystals would no longer encroach on the drop because of the increased rigidity of the crystal framework. The final crystals to be formed would then grow under conditions of lower confining pressure and could take on their normal crystal forms.

In the case of the spherical clots of tourmaline-rich fine-grained granite with no central cavity, the process would for some reason not be carried far enough to form cavities. An answer should be sought in the different conditions of formation of the aplitic granite, namely, faster cooling, lower confining pressure, and more acidic magma. The concentration of spherulites in lavas at a point where the volatile content is high, and the formation of orbicular structures in granite, may be due to similar causes.

It is not known whether it would be necessary for the residual liquid to boil to cause the formation of a cavity. If so then the spherical clots may be explained more simply by the inference that in them the liquid never reached the boiling point.

The Metamorphic Aureole

Description of the Aureole

The contact metamorphic aureole encloses the outcrops of the Seagull creek batholith in an irregular envelope ranging in thickness from a few feet to several thousand. The aureole was not carefully mapped but was crossed on ridges by several traverses and a rough idea of its extent was obtained (see accompanying map). The best exposures are on the ridge north of the batholith, near Camp 18, and at a xenolith on the mountain top south of Camp 18. The metamorphic effects differ according to the type of rock. Hornfels, amphibolite, and crystalline limestone have been formed from calcareous sedimentary rocks. Quartzite has been much less altered although tourmaline and axinite have formed in it by metasomatism. A contact metamorphic deposit of magnetite and pyrrhotite occurs within the aureole a few hundred feet south of the granite outcrops in the canyon of the south fork of Swift river.

Description of the Rock Types

Hornfels outcrops on the ridge northeast of Camp 18 and along the bank of the south fork of Swift river near the contact metamorphic deposit. The rock at both localities is green, hard, dense hornfels. Thin-sections show their compositions to be practically identical. They are composed of diopside and intergrown plagioclase (An_{50}) with a little hornblende and calcite.

Amphibolite outcrops in a xenolith south of Camp 18. The principal rock is a medium-grained dark-green amphibolite composed of hornblende, feldspar, diopside, and biotite, but there are numerous local variations in texture and composition. Crystalline limestone and bands of hornfels are associated with the amphibolites but the structures are complex and were not solved in the time available at the outcrops.

Mineralogy of the Aureole

A wide variety of minerals occurs within the aureole but description will be restricted to the metasomatic minerals containing boron and fluorine. These are tourmaline, fluorite, axinite, clinohumite, ludwigite, and an unknown borate. (See Table 1)

Tourmaline occurs in at least four ways in the contact aureole. 1. Interstitially and as cavity fillings in amphibolite. 2. In veins. 3. As replacements in limestone. 4. In quartzitic sedimentary rock, (a) as detrital grains(?), (b) produced by replacement.

The tourmaline of the amphibolite occurs as crystal aggregates as much as two inches across, as well as interstitially. The tourmaline of such an aggregate (Specimen 118) is seen in thin-section to be strongly and irregularly zoned with sharp angular boundaries. It is pleochroic from pale blue-green to deep green, from pale olive-green to almost black, and from pale tan to very dark tan. As mentioned by Flett (Ussher et al, 1909) and by Harker (1950) the pleochroic colours are a guide to the composition, blue representing soda-rich varieties, brown, magnesium-rich types. Since the colours of this tourmaline are not as blue as those of the tourmaline in the granite, this type is probably not as rich in alkalies and richer in magnesium than the granitic tourmaline. (See Chapter 5 for spectrographic analyses.)

Two occurrences of vein tourmaline were mapped.

One is at the crest of the ridge west of Seagull creek just south of Camp 12. The vein strikes N 80° E and dips 80° south. The main part of it is about a foot wide but there are several branches over a total width of ten feet in which the country rock, normally a pale green quartzite, is bleached a creamy white. The walls are tight and rather irregular but reasonably straight. Black fibrous tourmaline crystal aggregates, growing at acute angles to the walls, constitute most of the vein filling. Disseminated among the crystals of these aggregates are abundant fluorite and calcite, and minor quartz, chalcopyrite, and pyrrhotite. Both purple and pale green fluorite were noted, in crystals up to 5 mm. across. A thin-section of part of the vein and wall contains tourmaline crystals up to 1 mm. long and 0.5 mm. across, which are pleochroic from colourless to blue-green. A measurement of the refractive indices gave e = 1.625, w = 1.66-. Associated vein quartz occurs in anhedral crystals up to 0.5 mm. diameter. The wallrock consists of very fine-grained quartz, tourmaline, calcite, sphene and black metallics.

The second occurrence of vein tourmaline is in the cirque west of the magnetite-pyrrhotite deposit at the head of the south fork of Swift river. Veinlets trend roughly north-south and are less than an inch wide. Tourmaline and axinite occur together. The tourmaline is pleochroic in blues or browns. The wall rocks are light-coloured quartzites.

Bunches of tourmaline crystals occur in encrinal limestone and dolomite on the east side of Seagull creek batholith just north of mile 731 on the Alaska highway. The crystals appear to be associated with siliceous bands in the dolomitic beds. They are minute and perfectly euhedral. The brown colour and refractive indices ($e = 1.631$, $w = 1.646$) suggest a magnesian tourmaline. The specific gravity, 3.14, suggests a composition of 50% dravite, 50% schorlite (Winchell, 1951, p. 466).

A rounded and fractured grain of tourmaline was noted in thin-section 66 from the quartzite on the south boundary of the Seagull Creek batholith. Its texture and relationship suggest formation before or near the beginning of metamorphism. Section 65, from a locality a few hundred feet closer to the granite contact, contains tourmaline which appears to be moulded around quartz grains suggesting formation late in the process.

Fluorite occurs most abundantly in the granite, but is also present in veins with tourmaline. Its colour ranges from colourless to green and to purple.

Clinohumite occurs as a gangue mineral in the magnetite-pyrrhotite drill core specimens. Small anhedral amber-coloured crystals are disseminated through massive pyrrhotite in some specimens. They have a hardness of 6 and a specific gravity of 3.20 ± 0.05. In thin-section they show high relief, pleochroism from colourless to pale lemon-yellow, and lamellar twinning. The extinction angle, measured on the twinning in a section normal to z, is 9°. Another thin-section shows clinohumite associated with calcite, magnetite and ludwigite. Here an interference figure was obtained showing the mineral to be biaxial positive with a large optic angle.

A mineral, probably near the ludwigite end-member of the ludwigite-paigeite series, was identified by x-ray study. It occurs with magnetite, calcite, clinohumite and dolomite in some of the drill core specimens. Its optical properties, under reflected light, are described later in the chapter.

A mineral somewhat similar to ludwigite in its physical properties, but apparently differing in its atomic structure, occurs in the drill core specimens of intersection No. 1. The mineral is apparently a tin-bearing magnesium iron borate, and may be a variety of ludwigite, but until its identity is established it will be referred to as an unknown borate.

Investigations regarding the identity and composition of this mineral are described in Chapter 5.

The Contact Metamorphic Deposit

A magnetite-pyrrhotite deposit outcrops on the east bank of the south fork of Swift river, one mile north of two small lakes that mark its source (Camp 12). The mineralized rocks are limestones and dolomites that trend N 80° W and dip 40° southwest. A vein, exposed for 20 feet, is about three feet wide, strikes N 20° E, and dips gently southeast. The vein matter consists almost entirely of metallic minerals. Rough banding parallel to the walls consists of - from the footwall to the hanging wall - galena with minor sphalerite, pyrrhotite, and chalcopyrite, 3"; sphalerite with minor galena, 9"; magnetite and pyrrhotite, 24". Several diamond drill stations are marked on the hanging wall side of the vein, and about two thousand feet of core lies stacked at the outcrop. The work is believed to have been done in 1946 and 1947 by the Hudson Bay Mining and Smelting Company.

Specimens from intersections, about five feet thick, of mineralized rock, were collected (Table 1) along with a few specimens of country rock. The principal metallic mineral is magnetite. It occurs disseminated and massive, often intergrown with pyrrhotite and various gangue minerals, chief of which are dark green serpentine, dark green diopside, calcite, dolomite, and minor chlorite and clinohumite.

The following minerals, in order of abundance, were observed in polished sections of this material: magnetite, pyrrhotite, sphalerite, chalcopyrite, arsenopyrite, galena, pyrite, marcasite, stannite, ludwigite, ruby silver (probably pyrargyrite), tetrahedrite (?), native silver (?), and the unknown borate.

Magnetite occurs in the majority of the sections, associated most commonly with pyrrhotite, and with smaller amounts of chalcopyrite, sphalerite, and arsenopyrite.

Exsolution blebs of chalcopyrite, pyrrhotite, rarely stannite, and tetrahedrite (?), occur in the sphalerite. Galena and pyrite are rare in the drill cores. Some of the galena contains blebs of ruby silver and native silver (?). Some secondary marcasite has formed in the outcrop material at the expense of pyrrhotite and arsenopyrite. Laths of ludwigite in association with magnetite occur in Specimens 3, 6 and 11. The laths, about 0.1 by 0.5 mm., are strongly pleochroic from silver-grey to bluish slate-grey, and very strongly anisotropic, giving four extinctions per revolution, from fiery red-orange to bluish-green. Some of the laths are slightly curved.

The unknown borate in polished section appears homogeneous but is extremely fine grained. It takes a poor polish, compared to ludwigite, but appears to have similar anisotropic colours, and to occur in tiny rectangular grains.

The difference in mineralogy and texture of the vein-like outcrop and the mineralized zones, intersected by the drill cores, suggests that either the deposit changes rapidly in character or the drill holes missed the downward extension of the vein. However, for the purposes of this paper the significant features are the deficiency of silica and the presence of boron, fluorine and tin which have led to the formation of tin-bearing borates, and of clinohumite. The deposit lies within the tin belt outlined by Warren and Thompson (1944) and the main geologic features are similar to those of certain regions containing important tin deposits, which will be described in Chapter 4.

CHAPTER 4

BORON METASOMATISM

Turner (1948), quoting Goldschmidt (1922), defines metasomatism as "a process of alteration which involves enrichment of the rock by new substances brought in from the outside," such enrichment taking place "by definite chemical reactions between the original minerals and the enriching substances." This definition is more limited in its scope than a later one by Lindgren (1933), viz. "the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate."

Boron metasomatism in this area falls within the more limited definition as the bulk composition of the rock is changed by the addition of boron.

The agents of metasomatism are chemically active liquids or gases, for example aqueous silicate solutions enriched in the rare constituents of the magma.

The main types of metasomatism have been classified by Goldschmidt (1922) as

A. Metasomatism of silicate and quartz rocks.

B. Metasomatism of carbonate rocks.

C. Metasomatism of salt deposits.

D. Metasomatism of sulphide deposits.

Eskola (1939) subdivides Type A as

1. Alkali metasomatism.
2. Lime metasomatism.
3. Iron-magnesium-silica metasomatism.
4. Metasomatism with introduction of Si, Sn, B, Li, F, Cl, S.
5. CO_2 metasomatism.

Ussher et al. (1909) describe metasomatism in the country around Bodmin and St. Austell, Cornwall, stating that pneumatolitic action on greenstones by boric and fluoric vapours given off by the granite has produced axinite, less commonly tourmaline, and rarely fluorite. Calcareous beds of the Meadfoot Series, north of the granite, contain larger amounts of axinite. Pneumatolitic alteration of the granite itself produces a tourmaline-quartz rock or "schorl rock". Tourmaline replaces mica and feldspar and is occasionally an original constituent. The tourmaline is brown, yellow, blue, violet and occasionally green or colourless. Shades may alternate in well-marked concentric zones, deep brown in the centre of the crystal. Strong pleochroic halos are frequent. Tourmaline started crystallizing with biotite and may be enclosed in feldspar. It went on crystallizing till orthoclase and quartz separated out. It is not uncommon to find shapeless masses of tourmaline enclosing idiomorphic crystals of quartz, orthoclase and albite in normal unaltered granite. Sometimes an early crystal of tourmaline has been partly surrounded by feldspar and protected from subsequent deposit. The zonal bands indicate that the tourmaline crystals were idiomorphic at the start. Later zones are more and more irregular. Fluorite, formed during the pneumatolitic stage, is colourless, violet, or dark blue. Dark coloured crystals show zonal and hour-glass structures and weak birefringence. It occurs in grains scattered through the feldspar, especially plagioclase, but principally as interstitial deposits in cavities which may have been of miarolitic origin, or formed by removal of other minerals (e.g. feldspar).

Three sorts of changes are effected by vapours passing through granite:-

1. Tourmalinization - no remains of the original granite structure are shown. Feldspar has disappeared. Tourmaline is always intensely zonal, the centres brown, the outer zones blue. The zones may alternate. The brown magnesian variety is formed from biotite and the more alkaline blue variety may be formed from feldspar. Tinstone, in the form of small dark brown tetragonal prisms, lies in a secondary matrix.

2. Greisening - this is the conversion of granite into an aggregate of quartz and mica, with the development of secondary topaz. Fluorite, some lithium-bearing mica, and a little tourmaline, magnetite, zircon and cassiterite appear.

3. Kaolinization - not important for the purposes of this

paper.

Barrow and Thomas (1908), describing the relations between contact metamorphic minerals and metasomatic minerals in the Bodmin and Camelford area, Cornwall, state that thermal metamorphism, produced by the intrusion of granite, caused the formation of vesuvianite, garnet, pale and bright green pyroxene, epidote and actinolite. Later alteration by the action of heated gases penetrating along cracks and fissures of the thermally metamorphosed rocks profoundly altered them, converting shales to aggregates of axinite and green prismatic pyroxene. Other metasomatic minerals are fluorite, sphalerite, and bright yellow garnet.

The geology of the Seward Peninsula, Alaska, is described by Knopf (1908), who states that early Paleozoic slates, and Ordovician and Carboniferous limestones are intruded by coarse-grained granite containing phenocrysts of feldspar and smoky quartz. The granite is unusually rich in boron, fluorine, chlorine, and iron, and is characteristically surrounded by a pneumatolitic contact aureole. Large amounts of the magmatic emanations were retained by the limestones in such minerals as tourmaline, axinite, ludwigite, hulsite, paigeite, boron(?) vesuvianite, magnetite, hedenbergite, fluorite, scapolite and chondrodite.

The mineral assemblages, textures and paragenesis of the Seagull creek area are strikingly similar to those of the Seward Peninsula, and to a lesser extent to the Cornish areas. Conclusions drawn from field and petrographic evidence by the authors quoted may be applied with reservations to the Seagull creek area. The metamorphism has not been as intense in the Seagull creek as in the other localities nor have the metasomatic changes been as complete.

The relative importance of liquids and gases in effecting metasomatic changes is not known. The problem is closely linked to that of the emplacement of ores in metallic mineral deposits. Considerable difference of opinion exists among various authors. The proponents of a gaseous agency are Fenner, Lacroix, and many of the earlier writers such as Flett, Barrow, and Thomas.

Fenner (1933) believes that the gases liberated at the time of the peak of the thermal and chemical energy of the magma are the mineralizing agents. His concept permits an explanation for ore deposits in and near cupolas. Summarizing Lacroix' writings (Fenner, 1926) he states that volatile emanations (gases) at Vesuvius have transformed limestone to crystalline aggregates of silicates containing drusy cavities.

Later writers believe that liquids are more important. Bowen (1933) reaches the conclusion that the gas phase is less effective as a solvent and thus can carry less solute than the liquid phase of the same composition. He believes that acid solutions are the principal agents of transfer of material. Ross (1933) and Schaller (1933) hold that the dominant agent of transport and deposition is an alkali-rich liquid of late magmatic derivation. Graton's conclusions (Graton, 1940, pp. 340-350) are too lengthy for more than a brief mention of the most pertinent to this discussion. Regarding the relative times of the pneumatolitic and ore-forming stages he concludes that ore deposits are post-pegmatitic but are direct descendants of the main magma. Separation of the ore fluid from the main body may be accomplished either "by crystallization of the other magmatic components leaving the special ore fluid as the final and only liquid then existing in the magma chamber, or by breakdown of the residual liquid at about the pegmatitic stage, into two immiscible liquids, of these the less abundant, less dense and less viscous would be the special ore fluid." Such immiscible liquids were produced experimentally by Smith (1948, p. 538). Regarding liquids versus solids as transporting agents Graton concludes the "capacity of the gas phase, whether above or below critical [temperature] to accomplish the necessary great task of mineral transport is found completely inadequate under those conditions of under-cover intrusion which alone are suitable for the degree of metal concentration required to form ores."

The field and petrographic evidence from the metamorphic aureole of the Seagull creek batholith and from the magnetite-pyrrhotite deposit does not appear to have made any significant contribution to the knowledge of the processes of metasomatism and ore deposition, other than to concur with evidence of this type from similar localities, on which the theories of the nature of such processes are, in part, based.

From the foregoing discussion it is concluded that, although gases were probably effective in the formation of early boron minerals, aqueous solutions were most likely the dominant agents in the formation of tourmaline veins and the magnetite-pyrrhotite deposit. Unfortunately no criteria are known for distinguishing products of gas transport from those of liquid transport. Furthermore, since because a gas phase generally exists in equilibrium with a liquid phase the two may well act together.

CHAPTER 5

SPECTROGRAPHIC AND X-RAY STUDIES

Tourmaline

The formula given by Winchell (1951) for tourmaline is $(Na,Ca)_5(Al,Fe,Mg,Mn,Ti)_{27}(Si,B)_{27}O_{86}(OH)_4$(?). Although tourmaline varies widely in composition, certain end members and continuous series between pairs of them are recognized. Of these the most common are:-

Dravite	$H_4NaMg_3Al_6B_3Si_6O_{31}$
Schorlite	$H_4NaFe_3Al_6B_3Si_6O_{31}$
Elbaite	$H_8Na_2Li_3Al_{15}B_6Si_{12}O_{62}$

There is a continuous series from dravite to schorlite and from schorlite to elbaite but not from dravite to elbaite.

In an effort to determine the differences in composition from the four types of occurrence in the area, samples consisting of about 20 mg. of powdered mineral were subjected to spectrographic analysis. The procedure used was as follows. The powdered samples were placed in a small drilled hole in the lower carbon electrode of a Hilger medium quartz spectrograph. Each was fused separately and the arc spectra exposed for a ten- and twenty-second period on Eastman type II F (Tropical) plates which have a useful range from 2200 to 6800 Angstrom units on this instrument. Standards used were - 1. the iron arc from Hilger's "Specpure" iron rods; 2. R.U. ("Raies Ultimes") powder which gives lines for 30 of the common elements; and 3. a wave length scale.

The analyses are only semi-quantitative, and consist of comparisons of strengths of lines of the various elements. The results are shown in Table 2.

Table 2

Spectrographic Analyses of Tourmaline

	Intensities of Lines			
Locality	Amphibolite	Limestone	Vein	Granite
Iron	moderate	low	high	very high
Magnesium	very high	very high	high	low
Boron	very high	very high	very high	very high
Sodium	moderate	low	low	very high
Aluminum	moderate	moderate	moderate	high
Manganese	very low	very low	very low	very low
Silicon	very high	very high	very high	very high
Calcium	high	moderate	nil	nil
Lithium	nil	nil	nil	nil
Tin	low	low	low	low

Optical and physical properties indicate that the tourmaline of the amphibolites is probably in the dravite-schorlite series. The spectrographic analysis suggests that it is probably closer to dravite in composition than to schorlite.

The tourmaline of the limestone is brown. The spectrographic analysis confirms previously cited evidence that it is close to dravite in composition.

The vein tourmaline is probably closer to the schorlite end of the dravite-schorlite series than the amphibolite tourmaline, as suggested by the blue-green colour in thin-section. This is also shown by the analysis.

The tourmaline of the granite is probably almost pure schorlite as indicated by the above analysis, and the optical properties. That replacing biotite may be magnesian, however, as evidenced by the pale yellow to greenish-yellow colours in thin-section, compared with pale and deep blue of the primary tourmaline of the cavities.

Borates

Of the anhydrous borates listed by Dana (1951) the following were studied in connection with attempts to determine the borate minerals occurring at the contact metamorphic magnetite-pyrrhotite deposit on the south fork of Swift river.

1. Ludwigite-Paigeite
2. Pinakiolite
3. Hulsite
4. Warwickite

The end members of the ludwigite series are: ludwigite, $[(Mg,Fe)_2Fe'''BO_5]$ and paigeite, $[(Fe,Mg)_2Fe'''BO_5]$. Ludwigite occurs as fibrous masses with a faint silky lustre, as embedded sheaf-like aggregates, as rosettes of needle-like crystals, or granular. It lacks cleavage, and is tough upon fracture. It has a hardness of 5 and a specific gravity of 3.6 (pure ludwigite) to 4.7 (pure paigeite). The colour is coal black to greenish black in paigeite and inclining toward dark green in ludwigite. The streak is black to blackish green. It is opaque except in small grains of highly magnesian ludwigite. Material with Mg Fe" is called ludwigite, with Fe" Mg, paigeite.

Al substitutes for Fe"' in small amounts. Mn and Ca may substitute for (Mg,Fe"). Sn apparently substitutes for Fe'" in some material (Schaller, 1910). The members of the series are high temperature minerals found in contact metamorphic deposits associated with magnetite, diopside, forsterite and szaibelyite (a hydrous magnesium borate). Localities are Moravicza, Hungary; Hol Kol mine, Korea; Norberg, Norway; and in the United States the Big and Little Cottonwood districts, Utah; Lincoln County, Nevada; Lemhi County, Idaho; and Philipsburg, Granite County, Montana,as well as other districts. Paigeite was originally from Brooks Mountain on the Seward Peninsula, Alaska. Vonsenite (= paigeite) is from Riverside, Riverside County, California. X-ray photographs are shown of ludwigite from Moravicza, Hungary, the type locality, from Philipsburg, Montana, and from Seagull creek, and of paigeite (vonsenite) from Crestmore, Riverside County, California. Slight differences in the patterns indicate that the compositions are slightly different but the structures are similar.

The physical properties of the Seagull creek ludwigite are almost identical to those given in Dana (1951). The only differences in the x-ray patterns are the lines of admixed magnetite (see Plate II).

Pinakiolite is a magnesium manganese borate, occurring generally as thin tablets with a rectangular outline and showing good (010) cleavage. It has a hardness of 6, a specific gravity of 3.88, a brilliant metallic lustre, and is black with a brownish grey streak. In transmitted light pinakiolite is deep reddish-brown. It is found at Langban, Sweden, in bands in granular dolomite with hausmannite ($MnMn_2O_4$), tephroite (Mn_2SiO_4), and other rare manganese minerals. The x-ray pattern of pinakiolite is simpler than that of ludwigite and in this respect is more like that of the unknown borate, but although the grouping of certain lines is the same in both, the distances between them suggest that perhaps the pinakiolite structure, if similar, is more contracted than that of the unknown borate (Plate III)[1].

Warwickite is a magnesium iron titanium borate. It has perfect cleavage, a hardness of $3\frac{1}{2}$ to 4, and a specific gravity of 3.35 ± 0.01. The lustre is dull to subvitreous, the colour dark hair-brown to dull black, and the streak bluish-black. In transmitted light it is reddish-

1. An expanded pattern indicates a smaller unit cell.

brown in colour. It occurs in crystalline limestone associated with chondrodite, blue and black spinel, graphite, magnetite, ilmenite, diopside, and pseudomorphous grains and masses of serpentine. The x-ray pattern of warwickite (Plate IV) shows little resemblance to any of the other borates studied.

Hulsite is possibly an iron calcium magnesium tin borate. The formula derived from an average of several partial analyses by Schaller (1910) is possibly $[(Fe,Ca,Mg)_4(Fe''',Sn'''')_2B_2O_{10}]$. Hulsite occurs as small, rectangular crystals, with uneven and dull faces; also as tabular masses. It has good 110 cleavage, a hardness of 3, and a specific gravity of 4.28. The lustre is submetallic to vitreous and the colour and streak, black. It is found in marmorized limestone, about 10 feet from the granite, with vesuvianite, diopside, magnetite, brown garnet, and fluorite at Brooks mountain, Seward peninsula, Alaska. The x-ray powder photograph of hulsite (Plate III) indicates about the same complexity of structure as the other borates but is dissimilar in other respects.

An unknown magnesium iron borate from the St. Christophe Mine, France, is at present being studied by Dr. R.M. Thompson of the University of British Columbia. The mineral is black, has a hardness of 5, and is rather tough. Its optical properties are similar to those of ludwigite, but the x-ray powder pattern is quite different, and is in fact almost identical to that of the unknown borate from Swift river.

The physical properties of the unknown borate are as follows:- colour and streak black, possibly reddish brown in thinnest splinters, hardness 5, specific gravity 3.45 $\pm$ 0.02, lustre faintly silky, cleavage absent. The mineral occurs intimately intergrown with magnetite, some of which is fibrous and may be pseudomorphous after it, ludwigite, or chrysotile. It is also in contact with serpentine which, normally a pale green, is very dark green for about an eighth of an inch from the boundary between it and the unknown borate. In some specimens the fibrous magnetite is associated with an unknown soft white powdery mineral which has been in large part removed leaving the fibres as open space filling. Attempts to x-ray this mineral have so far been unsuccessful. A spectrographic analysis of the unknown borate (Table 3) shows the presence of magnesium, iron, tin, boron, and a little manganese, and it is concluded that the mineral is a tin-bearing magnesium iron borate in which manganese substitutes for a small part of the iron. Ludwigite from Philipsburg, Montana, and from Seagull creek area were also spectrographed for comparison with the unknown borate.

The tin content of the Swift river borates may be 5 or 10 percent. Paigeite, described by Knopf (1908), contains probably 15% SnO_2. Hulsite, analysed by Schaller (1910), contains 7.07% SnO_2.

Table 3

Spectrographic Analyses of Borates

	Intensities of Lines		
Mineral Locality	Unknown Borate Swift River	Ludwigite Swift River	Ludwigite Philipsburg
Magnesium	very high	very high	very high
Iron	high	very high	high
Boron	high	high	high
Titanium	nil	nil	moderate
Tin	high	high	nil
Silicon	low	low	low
Manganese	moderate	moderate	very low

Further work will be done on these minerals in the near future. It is premature to claim the unknown borate a new mineral species, but, although the physical properties are most like those of the ludwigite series, the powder pattern is as different from it as are the other borates described, and there must therefore be considerable difference in structure between ludwigite and the unknown borate.

CHAPTER 6
CONCLUSIONS

It has been shown by descriptions of the rocks and by reference to the literature that the Seagull creek batholith, while perhaps unusual, is by no means unique in composition, texture, and paragenesis. The other areas described are remarkably similar in these respects.

It is concluded that the fine-textured phase of the Seagull creek granite is younger than the coarse. The relationship is best illustrated by field evidence, but contributary evidence has been provided by laboratory study.

The miarolitic cavities have almost certainly been formed by concentrations of late magmatic liquid, which probably either boiled or formed an immiscible watery fraction with the more viscous silicate-bearing liquid.

The mechanism of metasomatism is not completely understood and no definite conclusions can be reached from the limited study attempted in this paper. The effects of metasomatism on the rocks of the contact aureole of the Seagull creek batholith are, in general similar to those of the localities referred to in the body of the report, namely, Seward peninsula, Alaska, and the Bodmin and St. Austell areas, Cornwall.

The Seagull creek area lies within the tin belt postulated by Warren and Thompson (1944), and the occurrence of tin-bearing borates as well as the similarity of the area to tin-producing localities suggests the possible occurrence of cassiterite deposits.

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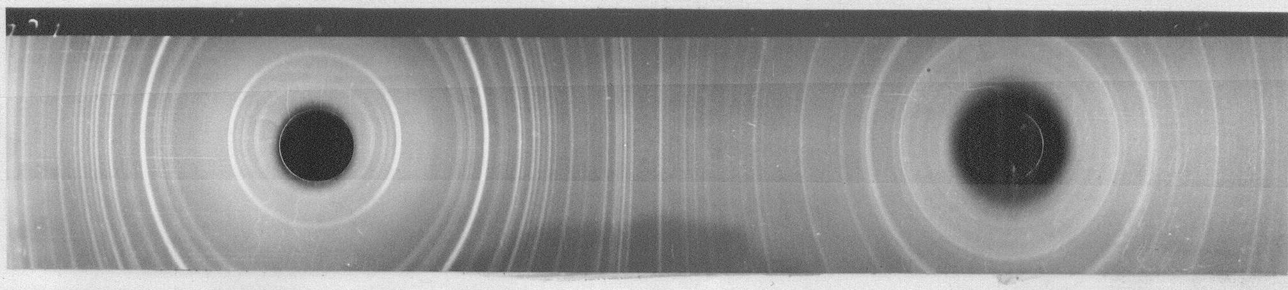

Ludwigite, Moravicza, Hungary

I	d(meas.)	I	d(meas.)	I	d(meas.)	I	d(meas.)
1	7.42	7	2.16	½	1.536	1	1.158
1	6.12	½	2.13	½	1.523	½	1.142
½	5.58	6	2.04	4	1.501	2	1.088
8	5.12	3	1.998	4	1.473	½	1.051
½	2.97	½	1.952	5	1.377	1	1.045
½	2.89	3	1.908	½	1.310	2	1.022
½	2.81	½	1.870	½	1.295	½	1.004
½	2.74	3	1.769	½	1.281		
10	2.56	½	1.687	½	1.253		
½	2.32	4	1.580	½	1.205		

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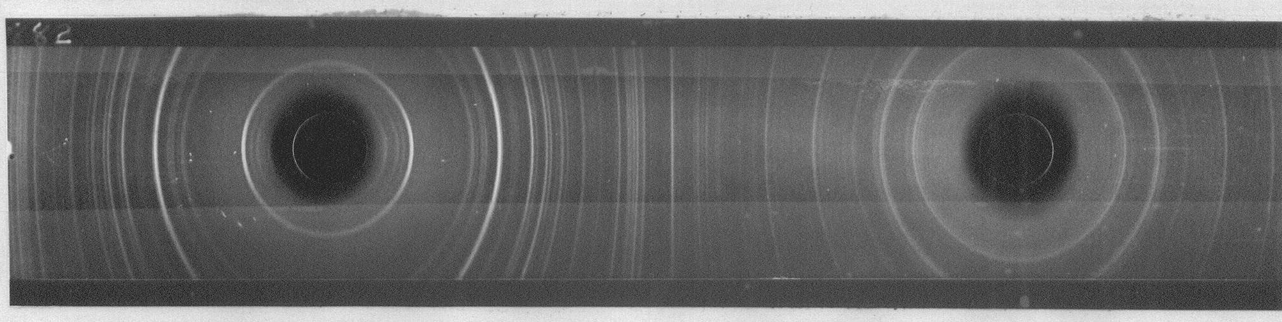
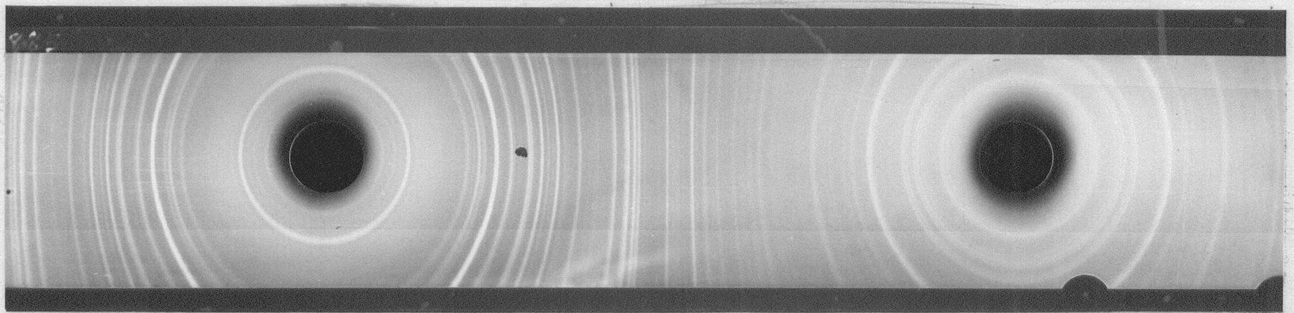


Ludwigite, Philipsburg, Montana

I	d(meas.)	I	d(meas.)	I	d(meas.)	I	d(meas.)
½	7.32	½	2.30	½	1.706	½	1.303
½	6.12	8	2.17	½	1.668	½	1.291
½	5.63	1	2.12	4	1.577	½	1.281
9	5.10	7	2.03	½	1.539	½	1.253
½	3.00	5	1.995	½	1.529	½	1.205
½	2.92	½	1.955	½	1.516	½	1.178
½	2.80	1	1.911	2	1.504	½	1.164
½	2.73	½	1.867	1	1.473	½	1.087
10	2.55	1	1.762	6	1.379	½	1.044
½	2.34	½	1.710	½	1.316	½	1.023

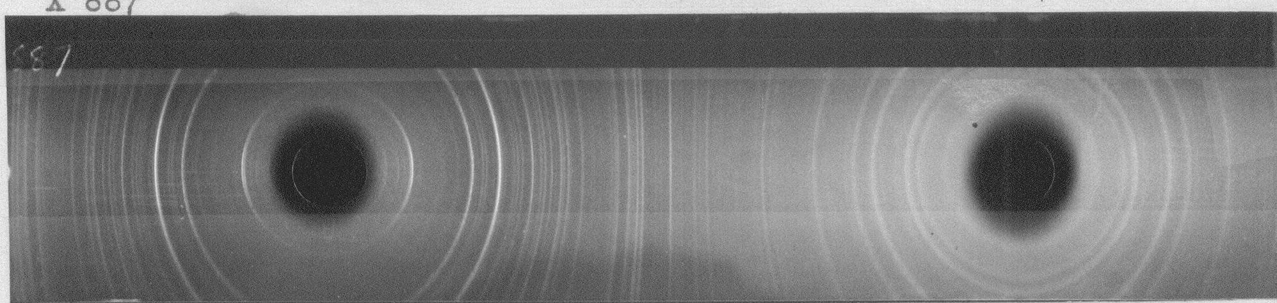
X 885



Vonsenite = (Paigeite) California

I	d(meas.)	I	d(meas.)	I	d(meas.)	I	d(meas.)
2	7.42	10	2.56	3	1.778	½	1.216
1	6.16	5	2.36	4	1.580	½	1.086
1	5.61	1	2.33	½	1.529	½	1.028
8	5.17	6	2.17	5	1.504		
½	4.70	2	2.14	5	1.482		
½	3.73	6	2.05	½	1.468		
2	3.05	1	1.995	2	1.387		
½	2.92	½	1.964	5	1.314		
5	2.82	6	1.923	1	1.281		
2	2.75	½	1.875	½	1.250		

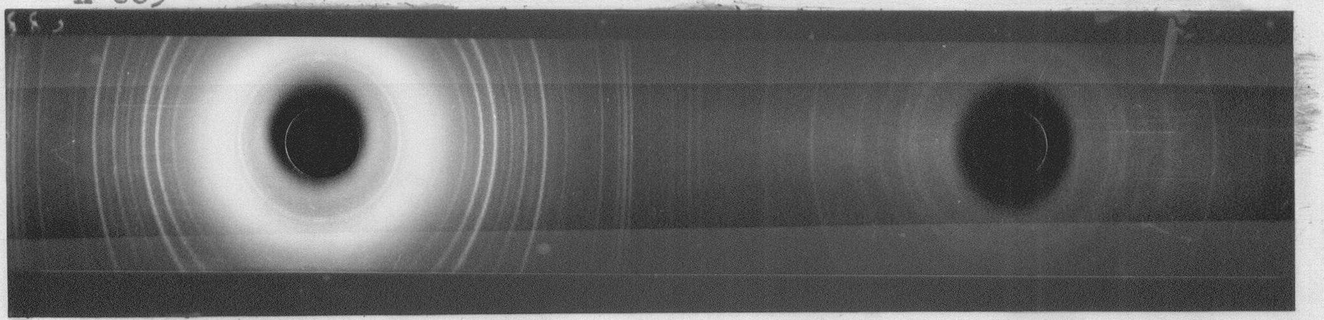
X 887



Ludwigite, Seagull creek, with
Fibrous Magnetite

I	d(meas.)	I	d(meas.)	I	d(meas.)	I	d(meas.)	I	d(meas.)
1	7.37	½	2.95	5	2.17	½	1.621	½	1.320
1	6.16	½	2.90	½	2.14	½	1.595	½	1.281
½	6.06	1	2.82	1	2.09	2	1.584	½	1.163
½	5.22	1	2.76	1	2.05	5	1.536	½	1.089
8	5.10	10	2.56	3	2.00	5	1.504	½	1.043
½	4.64	½	2.54	½	1.958	5	1.482	½	1.028
½	3.83	½	2.48	4	1.923	½	1.434	½	1.003
½	3.72	½	2.36	½	1.897	½	1.415		
½	3.33	1	2.32	4	1.870	½	1.384		
9	3.01	1	2.27	3	1.783	½	1.363		

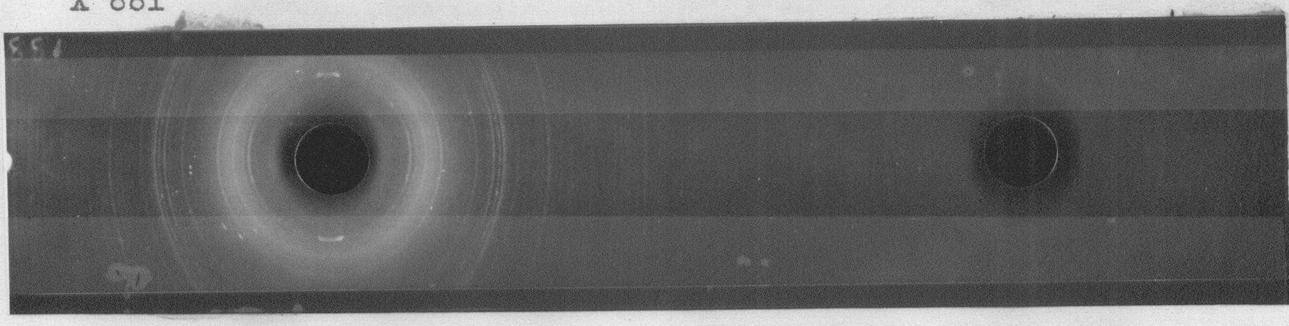
X 883



Pinakiolite, Langban, Sweden

I	d(meas.)	I	d(meas.)	I	d(meas.)
½	5.75	½	2.07	1	1.080
6	5.42	8	1.989	½	1.032
½	3.60	½	1.828		
3	2.99	2	1.621		
9	2.69	1	1.542		
10	2.50	2	1.513		
½	2.39	2	1.491		
1	2.30	1	1.305		
½	2.23	½	1.281		
1	2.16	½	1.148		

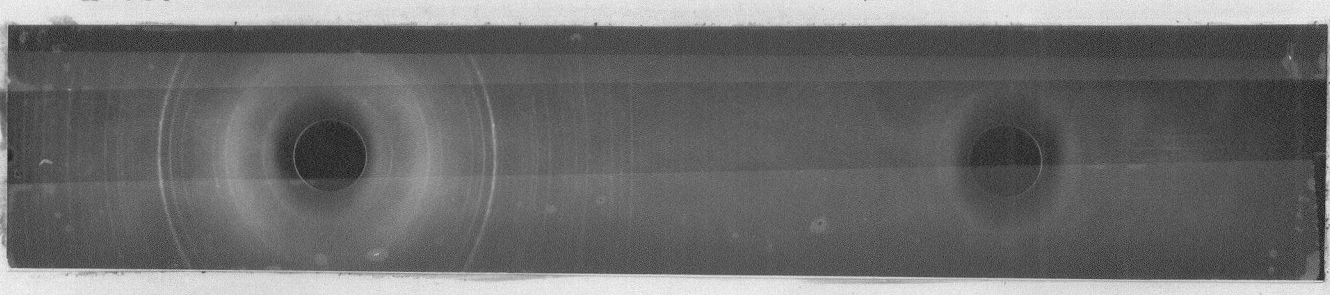
X 881



Hulsite, Brooks Mountain, Seward, Alaska

I	d(meas.)	I	d(meas.)	I	d(meas.)
5	5.34	1	2.35	½	1.732
1	4.99	½	2.25	½	1.644
4	4.49	½	2.19	½	1.613
4	3.88	½	2.13	½	1.580
4	2.98	½	2.09	½	1.563
½	2.74	6	2.04	½	1.546
7	2.67	½	1.979	2	1.479
5	2.59	½	1.937	½	1.439
10	2.52	½	1.864		
½	2.49	½	1.778		

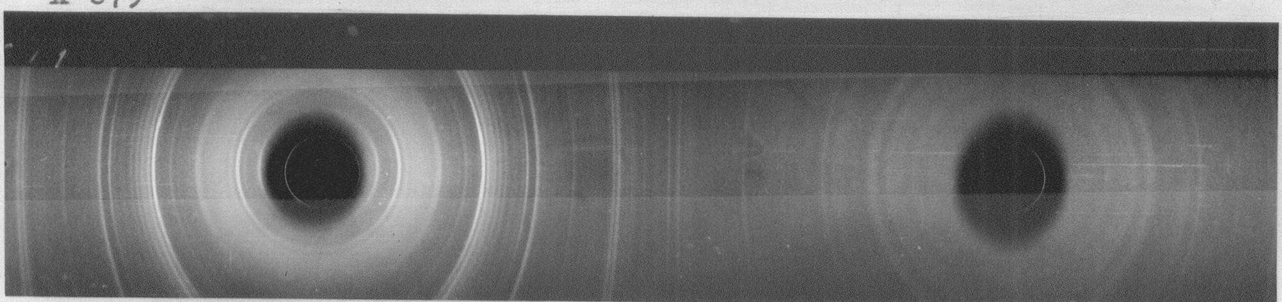
X 886



Warwickite, Edenville, New York

I	d(meas.)	I	d(meas.)	I	d(meas.)
2	6.55	1	2.13	2	1.501
2	4.21	1	2.09	½	1.468
1	3.73	3	1.976	½	1.182
3	2.96	1	1.865	½	1.105
½	2.83	½	1.833		
8	2.74	½	1.788		
10	2.58	2	1.719		
1	2.47	3	1.628		
½	2.24	½	1.591		
½	2.20	1	1.546		

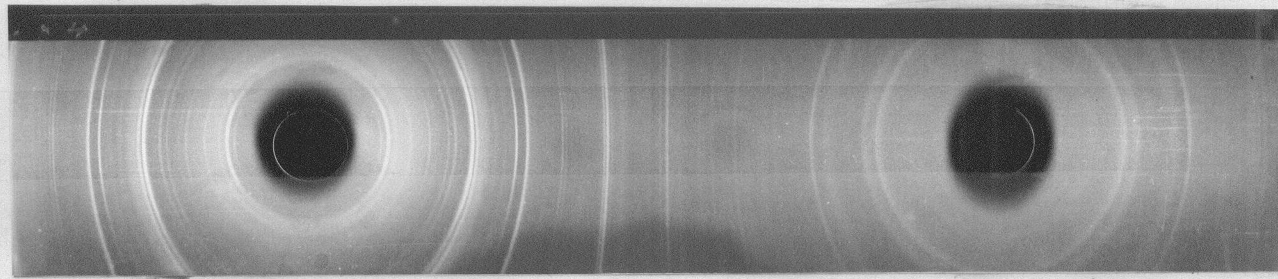
X 879



Unknown borate
Drill Core No. 1

I	d(meas.)	I	d(meas.)	I	d(meas.)
5	7.32	1	2.35	½	1.485
1	5.87	½	2.27	½	1.439
8	5.31	½	2.24	2	1.358
2	4.90	½	2.18	2	1.333
½	3.60	5	2.13	½	1.181
2	2.95	7	2.04	½	1.064
10	2.67	2	1.774		
1	2.60	2	1.563		
1	2.49	2	1.540		
1	2.43	½	1.507		

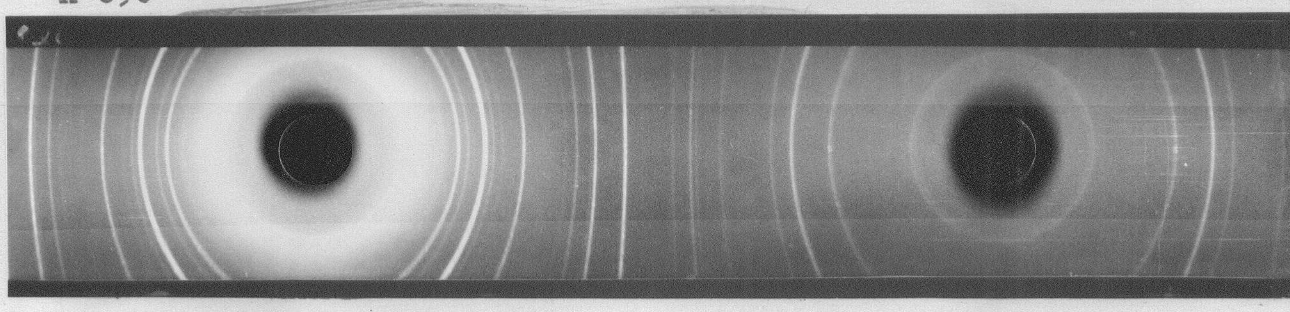
X 884



Unknown borate
St. Christophe Mine, France

I	d(meas.)	I	d(meas.)	I	d(meas.)
1	5.90	7	2.03	½	1.181
9	5.34	½	1.778	½	1.069
1	4.88	½	1.755	½	1.019
2	4.18	½	1.559	½	1.010
2	3.55	½	1.546		
2	3.09	½	1.529		
2	2.94	½	1.358		
10	2.66	½	1.335		
3	2.60	½	1.252		
½	2.13	½	1.229		

X 890

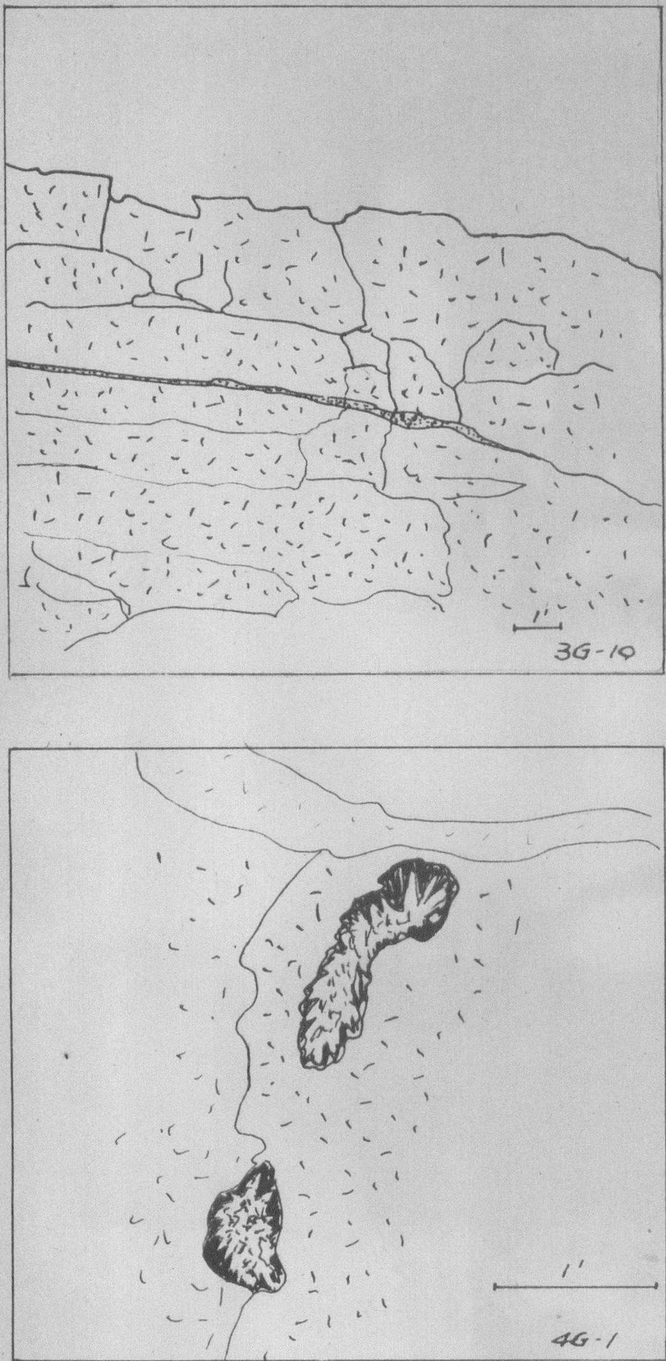


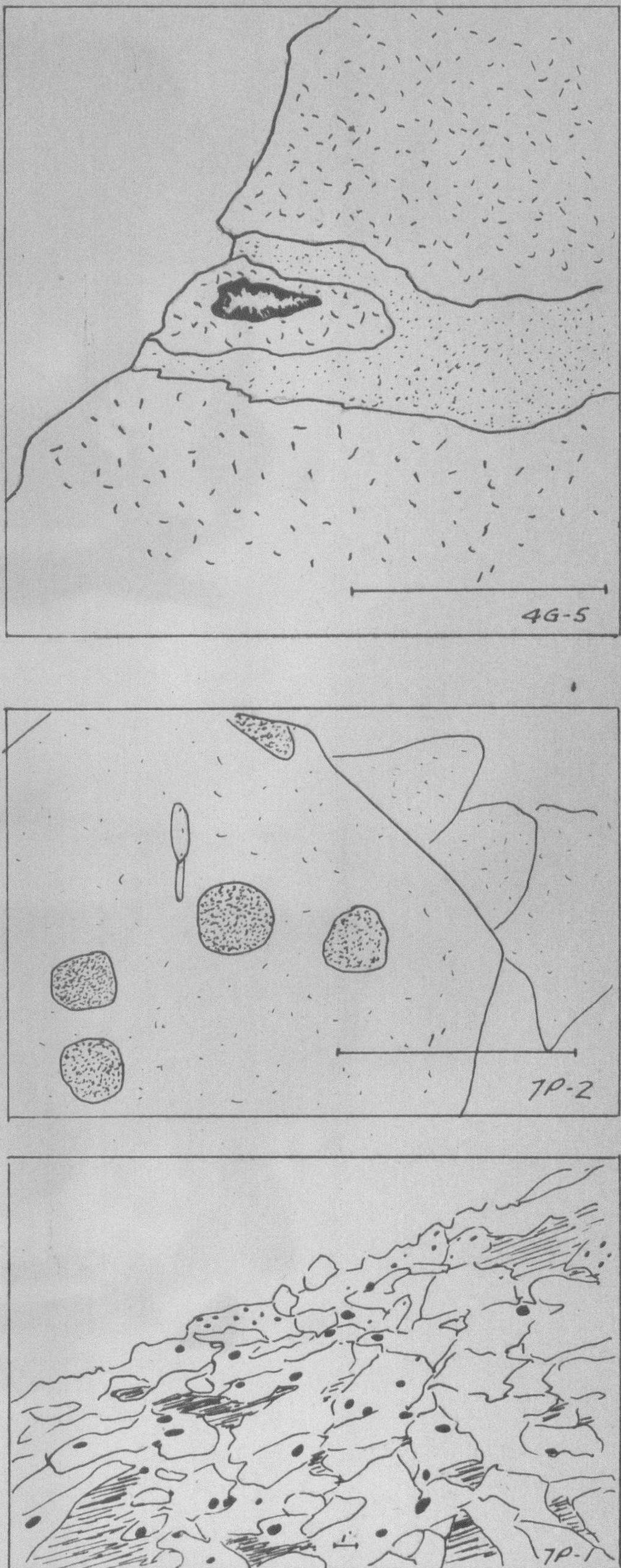
Magnetite

I	d(meas.)	I	d(meas.)
3	4.86	8	1.621
½	3.31	9	1.491
8	2.98	½	1.333
1	2.79	1	1.283
10	2.54	½	1.270
1	2.43	1	1.216
½	2.32	2	1.124
5	2.10	4	1.096
½	1.788	3	1.051
2	1.719		

The Seagull creek batholith
from the northeast

The amphibolite xenolith
south of Camp 18





3G-10. Band of Tourmaline bearing Fine-grained Granite in Coarse-grained Granite
4G-1 Miarolitic Cavities in Coarse-grained Granite
4G-5 Miarolitic Cavity with Coarse- and Fine-grained Granite
7P-2 Tourmaline rich patches in Fine-Grained Granite
7P-1 Talus with Tourmaline rich granite

FIGURE 1 · TOURMALINE IN GRANITE