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THE METAMORPHISM OF THE ROCKS OF THE
ALDRIDGE FORMATION
KIMBERLEY, B.C.

BY

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THE METAMORPHISM OF THE ROCKS OF THEALDRIDGE FORMATIONKIMBERLEY B.C.

BY

J.W. HOADLEYABSTRACT

The area near the Sullivan Mine, Kimberley B.C., is underlain by rocks of the Purcell series which consist of two sedimentary formations of late Pre-Cambrian age, the Aldridge and the Creston. Both are composed of argillite, siltstone, and quartzite.

The Sullivan ore body is a replacement deposit in certain favourable horizons in the Aldridge formation. The only known igneous rocks near the mine are the Purcell intrusives of late Pre-Cambrian age. These intrusives occur as large sheets, or sills, at a small angle to the bedding of the Purcell series. They are chemically about the same as gabbro.

The object of this research was to determine the changes induced in the sedimentary rocks of the Aldridge formation near the Sullivan Mine by the intrusion of the Purcell sills; to compare the alterations found with the alterations known to be present in the wall rocks of the Sullivan ore body; and from this comparison, determine whether there is any justification for relating the mineralization of the Sullivan ore body to the

intrusion of the Purcell sills.

In order to obtain the information required the writer made a petrographic examination of thirty-six thin sections of specimens of the core of the Sullivan Diamond Drill Hole 249 located just east of the mine. The hole was drilled vertically through a sixty foot sill, and on into the underlying sediments of the Aldridge formation.

The results obtained from this examination indicated that the sediments adjacent to the sill have been subjected to low grade thermal metamorphism, which has resulted in the development of a pronounced biotite spotted contact zone. Late magmatic emanations, either from the partially consolidated sill, or from the parent magma chamber caused metasomatism in the sedimentary rocks of the contact zone, and the effects of the metasomatic action are super imposed upon the effects of the thermal metamorphism. Tourmaline, albite, pyrrhotite, sphalerite, sphene and rutile are the main minerals produced by the hydrothermal action.

A comparison ^{of} ~~between~~ the alterations found in these sedimentary rocks examined, ^{with} ~~and~~ the alteration present in the Sullivan ore body and its wall rocks, reveals a distinct similarity. This similarity, plus the fact that the drill hole is within one half mile of the mine suggests a common origin for the magmatic solutions.

Therefore, the solutions which produced the Sullivan Mine ore body may have been genetically related to the Purcell intrusives.

INTRODUCTION

Object of the Research

The geology of the Sullivan mine has been studied in detail by officers of the Geological Survey of Canada, and by geologists employed by the owners, the Consolidated Mining and Smelting Company. The various workers are not in complete agreement regarding the age of the mineralization.

H.M.A. Rice (1) believes that the mineralization occurred during Cretaceous or early Tertiary time, and is genetically related to the granite intrusives of that age.

C.O. Swanson and H.C. Gunning (2), feel that the assignation of the age of mineralization to the Cretaceous or Tertiary period is open to question. They suggest, as an alternative, that it may ^{be} related to the Purcell Intrusives that are of Pre-Cambrian age.

It was suggested that a study of the alteration occurring in the sedimentary rocks near one of the Purcell sills, and a comparison of this alteration with that found in the wall rock of the Sullivan ore body, might reveal further information regarding the age of the ore forming solutions.

The writer, therefore, undertook a petrological examination of specimens of the core of a diamond drill hole, located just east of the Sullivan mine. The hole was drilled vertically through a sixty foot sill and continued on into the underlying sediments for approximately five hundred feet.

1. Rice, H.M.A. 1937, G.S.C. Mem. 207
2. Swanson, C.O. and Gunning, H.C. 1945, Geology of the Sullivan Mine, C.I.M.M. Vol. 48, pp 645 - 667

The work consisted of a detailed petrographic examination of thirty-six thin sections and the interpretation of the results obtained from this examination.

The extremely fine-grained nature of the rock made it difficult to determine and estimate the relative amounts of the minerals in the thin sections.

An important part of the interpretation was to decide how much of the alteration was caused by reconstitution of original material and how much was due to the introduction of material from some outside source.

GENERAL GEOLOGY

The Sullivan mine is located in the south-east corner of British Columbia, about one and one half miles north-east of the town of Kimberley, B.C.

The area in the vicinity of Kimberley is underlain by gently folded sediments of the Purcell series, of Pre-Cambrian age. These sediments were intruded by a large number of sills, known as the Purcell sills, in late Pre-Cambrian time.

The Sullivan ore body is a replacement deposit in the lower member of the Purcell series, called the Aldridge formation. This formation is an assemblage of thin bedded quartzites, siltstones, and argillites approximately 16000 feet thick.

The ore body conforms roughly with the strike and dip of the sediments, and grades into them. The horizons replaced represent a stratigraphic thickness of about 200 feet.

The ore is an intimate, fine-grained mixture of galena, and sphalerite, with minor amounts of pyrrhotite, pyrite, magnetite, and jamesonite; the scant gangue contains manganese garnet, garnet, tourmaline, diopside, actinolite, and biotite, with subordinate calcite. Some cassiterite is present.

In the vicinity of the mine, the regional dip is east, the region as a whole being on the east side of a broad anticline which has an axis lying a few miles west of the area shown in fig. 1. However, the regional dip is modified by several gentle warpings and by minor folds which are ~~frequently~~ ^{commonly} quite sharp.

Figure 1 portrays the nature of the gentle warpings by means of subsurface contours of the footwall of the ore zone.

The Kimberley fault is one of the major features of the area. As shown in Figure 1, it strikes about E.W. and dips 45 to 55° N.

The Sullivan fault, together with a number of similar ones which form a well defined set, constitute the only other important fault structures. Of these, the Sullivan, East and Lois faults are shown on the map.

The Purcell intrusives, locally called diorites are the only large intrusives known in the immediate vicinity of the mine. Typically they occur as large sills or sheets at a small angle to the bedding of the Purcell series. Many of them are approximately uniform in composition, and are chemically about the same as Gabbro. In the upper part of some of the sills there is a gradation to a type that is definitely more acid.

All the large sills (see figure 1) near the Sullivan mine are accompanied by a contact zone 100 feet or so thick in which the sediments have developed a spotted character.

WALLROCK ALTERATION OF THE SULLIVAN ORE BODY

The formation of the Sullivan ore body was accompanied by considerable alteration of the wallrock. Briefly, this wallrock alteration may be described as tourmalinization of the footwall sediments and albitization and chloritization of the hanging wall members.

PETROGRAPHY OF THE UNALTERED SEDIMENTS

In order that the alteration in the sediments in the vicinity of the Sills may be properly appreciated it will be necessary to give a brief description of the unaltered sediments.

"Strictly speaking, the beds are not unaltered sediments, as they have all suffered more or less recrystallization. However, the changes so produced have been slight in comparison with those caused by replacement and contact metamorphism in the sediments adjacent to the ore body, and are in general less than the changes encountered in the contact zones of the Purcell Sills.

The beds are largely composed of sericite flakes .01 mm. to .03 mm. in diameter, and quartz grains of silty to sandy sizes. The sericite flakes have random orientations and evidently represent clayey material that recrystallized under static conditions. The quartz grains are usually irregular in outline but new growth has not materially changed the size of the coarser grains. However, the smaller ones, less than 0.03 mm. in diameter, which are intergrown with sericite, owe their shapes and sizes entirely to recrystallization.

Lithologic types which range from argillite to siltstone form a large part of the sediments, and can be arranged into a linear series. It has been found convenient to classify as argillites those which are more than 75% sericite, and as siltstones those which are more than 75% quartz occurring as

grains up to .01 mm." (3)

This classification will be adhered to throughout this report.

(3) Swanson, C.O. and Gunning, H.C. 1944 - Op. Cit:

MINERALS OCCURRING IN THE SECTION OF THE
ALDRIDGE FORMATION CUT BY DRILL HOLE 249.

In the following paragraphs, the minerals are listed according to Dana's classification.

SULPHIDES

PYRRHOTITE: $\text{Fe}_{n-1}\text{S}_n$

Pyrrhotite is very wide spread throughout all the sediments of the Aldridge formation. It occurs in varying amounts in practically all the thin sections examined.

It is found as fracture filling and, or, replacement of certain favourable horizons (see Appendix thin section 289A), as concentrations of irregular shaped grains in the spots of the spotted bands, and as small, more or less evenly distributed grains in certain horizons.

Where a pyrrhotite-rich layer or veinlet occurs in or near a spotted horizon, the concentration of the pyrrhotite in the spots varies directly with the distance from the pyrrhotite-rich zones.

The most common associates are biotite and clinozoisite.

SPHALERITE Zn S.

A bright orange yellow variety of sphalerite was identified in most of the thin sections of specimens taken within ten feet of the contact with the Sill. In most cases it occurred as very minute grains which were only positively identified with the aid of a microchemical test for zinc. However, thin section 154B contains a coarse biotite and

sphalerite-rich zone in which the sphalerite was found in large grains replacing calcite. It was associated with some pyrrhotite, clinozoisite, and chlorite.

OXIDES

QUARTZ: SiO_2

This is the most abundant mineral in the sediments of the Purcell series. It occurs as very small irregular shaped interlocking grains generally less than .01 mm. in diameter. Spots or concentrations of larger grains up to .05 mm. in diameter are common in some of the beds.

The interlocking grains and the presence of many inclusions indicate that the quartz has been largely recrystallized.

RUTILE: TiO_2

There is abundant development of rutile throughout the majority of the thin sections examined. It most commonly occurs as clusters or aggregates of short stubby euhedral crystals, which often show good geniculated twinning. It is also found as minute needles replacing biotite.

There is a marked increase in the concentration of rutile in the spots and along the contacts between argillaceous and silty layers. It appears to be closely associated with the biotite in the spots and is not found in the bleached zones.

CARBONATES

CALCITE: CaCO_3

Calcite occurs in appreciable amounts in a number of the sections examined. It is always associated with chlorite

either as vein filling or as irregular patches in the more highly chloritized areas.

SILICATES

ALBITE:

There appears to be a fairly abundant development of Albite in the thin sections studied. It occurs as small grains scattered throughout the general matrix, or as vein filling material. Albite twinning was observed in a few cases. The maximum extinction angle measured was $12-1/2$ to 13° . A biaxial positive interference figure with a large 2V was obtained on a few grains.

An attempt was made to determine the amount of feldspar present in the sections by selective staining of the feldspar grains. Detailed explanation of the process used is included in the appendix. The results indicate that there was a greater degree of feldspathization than was apparent in the unstained sections. The stained sections showed that there was a tendency for the concentration of feldspar to be greater in the spots than in the general ground mass. One section revealed the presence of a strongly feldspathic layer parallel to the bedding.

CORDIERITE: $H_2 (MgFe)_4 Al_8 Si_{10} O_{37}$

The presence of cordierite was suspected in some of the thin sections, but no definite proof was obtained. See appendix thin section 146A.

WOLLASTONITE $Ca Si O_3$

One fibrous grain of wollastonite was identified in thin

section 340B. The optical properties were found to be as follows: Index 1.60 ⁺; Birefringence 0.010, orientation length slow, biaxial negative with 2V moderate to large.

The crystal identified contained numerous small inclusions of tourmaline.

CLINOZOISITE: $\text{Ca}_2\text{Al}_3(\text{OH})(\text{SiO}_4)$

This mineral is common in the thin sections examined. It is generally found intimately associated with pyrrhotite and biotite and quite often forms a rim around grains of the former mineral. It was noted that it occurred in greater concentration in the spots than in the matrix, and that those spots high in pyrrhotite contained more than those which showed a deficiency of pyrrhotite.

EPIDOTE: $\text{Ca}_2(\text{Al Fe})_3(\text{OH})(\text{SiO}_4)_3$

This mineral is found replacing muscovite and biotite in some of the spots. It is commonly associated with clinozoisite. Epidote is much less widespread in occurrence than clinozoisite.

TOURMALINE: A complex borosilicate of aluminum and other metals.

Tourmaline is of widespread occurrence in the sediments cut by drill hole 249. It is commonly found as minute euhedral crystals which appear slightly greenish in thin section. A number of larger crystals of pale yellow tourmaline were encountered which showed marked pleochroism, with maximum absorption parallel to the analyzer. Cross fractures were well developed.

Large sievey anhedral of this yellow pleochroic

tourmaline were found in some of the more spotted bands. In thin sections 160 A & B, these anhedral range up to .3 mm. in size and occur within the spots, in some cases, occupying as much as 25% of the total area of the spot. On the whole, the concentration of tourmaline was found to be greater in the spots than in the fine-grained ground mass.

MUSCOVITE: $H_2KAl(SiO_4)_3$

Well crystallized muscovite is rare in the sections examined. Where present, it occurs as large sievey flakes up to .4 mm. in size, associated with epidote and chlorite.

The fine-grained variety sericite is second to quartz in order of abundance. It occurs as minute, evenly distributed, lath-shaped grains, generally less than .01 mm. in length.

It was noted that there is a considerably lower concentration of sericite in the spots than in the surrounding matrix.

BIOTITE: $H_2K(MgFe)_3Al(SiO_4)_3$

Biotite is the most common accessory mineral. It occurs in three distinct ways; (a) As equidimensional grains, averaging .04 - .06 mm. in diameter, more or less evenly distributed throughout some of the beds. In some cases, it comprises 25% of the minerals present; (b) as concentrations of larger grains, up to .2 mm. in diameter, in more or less circular spots, associated with large grains of quartz and feldspar. In some cases, the biotite clusters form a central core in the spots, and are surrounded by a ring of biotite-

free quartz grains. In others, the whole spot consists of closely packed biotite flakes, while in still other spots, the biotite grains form a ring around the periphery of the spot leaving a more or less bleached core of quartz grains;

(c) In small veinlets containing biotite grains more or less oriented with their long axis parallel to the length of the veinlet. The veinlets cut all structures including the spots. In all cases the biotite is more or less chloritized.

CHLORITE: $H_2(Fe,Mg)Al_2SiO_7$

The sediments examined have been considerably chloritized. Pale greenish chlorite occurs in small veinlets and in relatively large irregular patches. It is commonly associated with calcite and pyrrhotite.

TITANOSILICATES

SPHENE: $CaTiSiO_5$

This mineral was identified in only one thin section. It occurred with albite in a small veinlet which cuts a biotite-rich zone in thin section 241B. The grains average .04 mm. in size and exhibit typical diamond-shaped outlines. The index was 1.80 + and the birefringence very high. The grains were optically positive with $2V = 20^\circ \pm$.

It is thought that some small isolated grains with high index seen in thin section 340A are probably sphene but no positive determination could be made.

ALTERATION OF THE ALDRIDGE FORMATION

The development of the pronounced spotting is the most noticeable change induced in the rocks of the Aldridge formation by the intrusion of the Purcell sills. Other changes have occurred which are equally important but which do not materially alter the megascopic character of the rocks. They are, tourmalinization, chloritization, carbonatization, and introduction of the sulphides, pyrrhotite, and sphalerite.

The following few pages will be devoted to a detailed description of these and other changes.

DESCRIPTION OF SPOTTING:

The spotting is characterized by the pronounced development of areas largely composed of coarse quartz and biotite. The amount of biotite varies from almost 100% to almost zero. The grain size of the main minerals occurring in these spots is consistently coarser than that of the same minerals occurring in the ground mass.

The spots are usually roughly circular in outline and gradually increase in size from approximately .2 mm. in diameter in the beds near the contact with the sill - to a maximum of 6 mm. in diameter in the beds 500 feet below the sill. However, as the size of the spots increase^s, the number of spots per unit area decreases proportionally, so that the total area occupied by spots is approximately the same throughout the section. (See stratigraphic section) in appendix)

VARIATION IN TEXTURE AND COMPOSITION OF THE SPOTS WITH
REGARD TO THE FOLLOWING MINERALS.

Biotite:

The distribution of the biotite within the spots varies considerably. In some cases the grains are concentrated in the centre of the spots and are surrounded by a distinct rim of quartz. In other cases the biotite is concentrated around the periphery of the spot leaving a barren central core. The latter type is very well developed in specimens 340, (see plates 4 and 5). The grains forming the outer portion of the rim are noticeably finer-grained than those occurring closer to the centre. The biotite rim grades into the barren core and shows definite radial arrangement.

Pyrrhotite:

There is a distinct tendency for the pyrrhotite in the spotted layers to be concentrated within the spots. The amount of pyrrhotite in the spots appears to vary inversely with the distance between the spots and a pyrrhotite-rich layer or vein.

Tourmaline:

There is, in general, a wide distribution of tourmaline throughout the rocks examined. In most of the spots there appears to be a slight increase in concentration. In some, the increase is very pronounced, in which case, the tourmaline assumes the role of the major constituent of the spots. This is best illustrated in sections 160 A & B where large sievey grains of tourmaline occupy approximately 25%

of the spots. See Plates 16 and 17.

Rutile:

Rutile is probably the most common accessory mineral. Its ~~distribution~~ is not confined to the spots but is found in greater amounts in the spots than elsewhere. Rutile appears to be more closely associated with biotite than with any other mineral. Minute needles are found replacing biotite along cleavage planes; clusters of larger stubby crystals are common in the well developed spots, such as appear in thin section 340, and are found in the biotite rims and not in the barren core. See plates 4 and 5.

Clinozoisite:

~~The occurrence of~~ Clinozoisite is very closely associated with pyrrhotite, thus it is more commonly found in the spots and in the pyrrhotite-rich zones. See plate 7.

Chloritization:

Chloritization is not confined to definite areas but it was noted to be more pronounced where the concentration of pyrrhotite is high.

FORMATION OF THE BIOTITE

Sediments of the type found in the Purcell series are formed by pronounced chemical and physical decomposition of pre-existing land masses. It is therefore unlikely that the amount of biotite now found in the contact zone could be of detrital origin.

Argillaceous sediments are notably low in lime and soda, high in potassium^a magnesia and alumina, and usually contain some iron, generally present as limonite. These constituents, with the possible exception of iron, are largely reconstituted to form sericite and minerals of the serpentine and chlorite groups. Under conditions of rising temperature, temporary solution would be initiated at isolated points in the rock. With continued elevation of temperature this process would gradually spread and would be followed by recrystallization and the production of new minerals. According to Harker (1), biotite is very often the first important new product. It is formed from chlorite, sericite, iron ore and rutile of the original sediment. As its first appearance this mineral is in numerous very small elements, shapeless, or sometimes rounded, but it soon develops characteristic flakes which may have criss-cross or parallel arrangement.

This, therefore, gives a probable explanation as to the source of the biotite, but it does not explain why its development in some layers is very pronounced while in others it is entirely lacking.

(1) Harker, Alfred Metamorphism 2nd Edition P 49

Harker states that the mineral formed at any given point depends upon the composition of the rock within a very small radius about that point. The limit of effective diffusion thus indicated is commonly a small fraction of an inch. It may, therefore, be assumed that material dissolved in one thin bed would not be transported by diffusion from that bed into another; and so, while biotite might have been produced in one layer which contained the requisite minerals, it would not have formed in an adjacent bed which lacked one of the essential original components.

The increase in temperature need not have been great, indeed, it could not have been great, otherwise there would have been a development of the medium and higher temperature silicates such as hypersthene, garnet, etc. However, although the rise in temperature was not great, the duration of the temperature elevation must have been quite prolonged. This is evident from the fact that the spotting occurs hundreds of feet from the sill contact. It is thought that the actual spotting may have resulted during this prolonged elevation in temperature, due to isolated local increases in the amount of solvent, giving rise to solution of the biotite over small areas, and diffusion of the dissolved material towards a common centre where recrystallization took place. Continued action would tend to form a core of large grains surrounded by an area comparatively free of biotite. Slight variations in any of the controlling factors would have a decided effect on this tendency to form spots, and upon the shape of the spots.

In those spots which exhibit an outer ring of biotite surrounding a barren core, there must have been solution at what is now the centre of the spot and diffusion outward from this centre. This might account for the radial arrangement of the biotite noticed in some spots.

It has been noted that there is a gradational change in the size of the spots throughout the length of the drill hole. Near the sill are numerous small spots, whereas at the farthest point from the sill, the spots are fewer in number and considerably larger in diameter. However, it seems that the overall areal extent of the spotting is approximately the same throughout the length of the drill hole. The change in the number of spots per unit area may be due to the fact that near the contact, solution and recrystallization was initiated at a large number of points, and that the number of centres of solution decreased as the distance from the contact increased. Why there should be an increase in the size of the spots as the distance from the sill increases is not understood.

ORIGIN OF TOURMALINE AND SULPHIDES

The development of biotite and spotting can be attributed to the reconstitution under the influence of low grade thermal metamorphism.

However, this process does not explain the presence of appreciable amounts of tourmaline, pyrrhotite, and in some cases, sphalerite, found throughout the sediments examined. Moreover, the quantity of tourmaline present appears to be too

great for it to be merely recrystallized detrital material and the possibility of the pyrrhotite and especially the sphalerite being formed from original material in the rock seems remote. It therefore, must be assumed that material has been introduced from outside to form these minerals. It is thought that late magnetic emanations from the sills, possibly partly pneumatolytic in character were responsible for this introduction. Whether the tourmaline and the sulphides were formed contemporaneously is not known. It is known, however, that the pyrrhotite is definitely later than the spotting.

In order to form these minerals, the ascending solutions must have contained appreciable quantities of boron, sulphur and water, plus some zinc and titanium.

The solutions appear to have entered along fractures and along more permeable layers in the sediments, and to have penetrated extensively into the surrounding rock, giving rise to solution and subsequent formation of the new minerals in the more porous areas. Evidence to support this theory is found in the fact that in the spotted zones both pyrrhotite and tourmaline are found in greater concentration in the spots than in the ground mass. It was also noted that where a veinlet of pyrrhotite cuts through a spotted layer, or where a pyrrhotite-rich layer occurs in contact with a spotted layer, the percentage of pyrrhotite in the spots is inversely proportional to the distance the spots are from the pyrrhotite veinlet or band. The tourmaline content in the spots does not

show any relationship to pyrrhotite veinlets. In fact it is greatest in the spots in sections 160 A & B which contain little or no pyrrhotite. There does not appear to be any apparent connection between the concentrations of pyrrhotite and tourmaline in any one layer, and the distance of the layer from the diorite contact.

ORIGIN OF ALBITE

During the examination of the sections a ^{small} ~~certain~~ amount of albite was identified. In ^{some} ~~certain~~ instances grains were found to occupy veinlets which were younger than the spotting. In one case it was found in a small veinlet associated with sphene. Selective staining indicated that some sections were ~~quite~~ highly feldspathized.

~~A certain amount~~ ^{Part} of this albite is quite probably the result of recrystallization of detrital feldspar but there seems to be a ~~distinct~~ possibility that some of it may have been introduced.

Harker (1) believes that argillaceous sediments bordering certain basic intrusions may have been albitized and converted to adinoles by the action of juvenile liquids carrying sodic compounds. He postulated that since the igneous rocks responsible for the transformation are themselves rich in soda ~~that~~ they have been albitized by the juvenile liquid after their first consolidation, and that the same liquid solutions have invaded the adjacent rock, and have brought about radical metasomatic changes.

(1) Harker, Alfred, Metamorphism 2nd Edition P.128

The albitized argillaceous rocks contain other minerals in varying proportions, such as chlorite, epidote, actinolite, "iron ore", sphene and rutile. At Dinas Head, Cornwall, the adinoles grade into rocks composed essentially of dravite.

A comparison of the sedimentary rocks adjacent to the Purcell intrusive with the adinoles described by Harker reveals ~~certain points~~^{some} of similarity.

In both cases, the original sediments were notably argillaceous. Both contain albite and have similar accessory minerals. Both are associated with basic igneous intrusives.

The intrusives associated with the adinoles are rich in soda and it has been postulated that the liquid magmatic solutions responsible for this increase in soda content were also responsible for the albitization of the adjacent sedimentary rock.

It is known that granophyric rocks are associated with many of the Purcell intrusives and that these granophyric rocks are richer in acid plagioclase than the normal type.

It is, therefore, suggested that the albite in the sedimentary rocks of the Aldridge formation adjacent to the Purcell intrusives may also be of magmatic origin, and that the same magmatic solutions which caused the albitization, were responsible for the increase in soda content of ~~certain~~ portions of the adjacent intrusives.

ORIGIN OF RUTILE

The widespread distribution of rutile throughout these sediments coupled with the fact that it is a very common detrital mineral in argillaceous sediments ~~would seem to~~ indicates that it is due to recrystallization of rutile in the original rock. However, the fact that sphene is associated with albite in veinlets, ~~would seem to~~ suggests that the ascending solutions carried a certain amount of titanium. Thus, there is a possibility that a part of the rutile present is not authogenic, but has resulted from the introduction of titanium bearing solutions after the rocks were subjected to low grade thermal metamorphism. The fact that it is ~~quite~~ ^{commonly} ~~often~~ associated with pyrrhotite and clinozoisite substantiates this theory.

CONCLUSIONS

The intrusion of the Purcell Sills has resulted in low grade thermal metamorphism of the adjoining beds of the Aldridge formation. This thermal metamorphism has resulted in the formation of biotite in a large number of the thin beds by reconstitution of original minerals in the rock. The metamorphism caused the spotting which occurs in the contact zone, but the reason for the increase in the size of the spots as the distance from the contact increases, is not known.

The thermally metamorphosed rocks were further altered by the action of magmatic emanations from the adjacent intrusive. It is thought that these emanations were essentially hydrothermal, but they may have been partly pneumatolytic. The metasomatism resulted in the production of tourmaline (dravite) albite, pyrrhotite, sphalerite, sphene, and possibly some of the rutile. The formation of the new minerals was accompanied by chloritization, carbonatization, and the widespread production of clinozoisite plus minor epidote.

A comparison between the alteration in the wall rocks of the Sullivan ore body and the alteration found in the sedimentary rocks of the Aldridge formation adjacent to the Purcell sill, reveals that while the alteration in the wall rocks is much more pronounced than that found in the rocks near the sill, the mineralogy of the alteration in both cases is essentially similar.

This similarity combined with the fact that the drill hole is less than half a mile from the ore body may indicate

that the magmatic solutions which caused the changes may have had a common source. If this is true, and if it is conceded that the alterations found in the rocks near the sill resulted from the action of magmatic solutions that originated either in the sill, or in the parent magma chamber of the sill, then it may be postulated that the Sullivan ore body is genetically related to the Purcell sills.

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APPENDIX

DESCRIPTION OF THIN SECTIONSTHIN SECTION 138 A

This section appears to be normal siliceous argillite grading to argillaceous siltstone. The main constituents are quartz, sericite, and biotite. The quartz grains show very irregular outlines and range from .01 - .02 mm. in diameter. The sericite occurs as interstitial flakes .02 - .04 mm. in size, between grains of quartz. The biotite appears as relatively large equidimensional grains .04 - .10 mm. in diameter and occupies approximately 25% of the slide. The grains are generally more or less chloritized.

Rutile occurs as very small scattered grains and fine aggregates of crystals. In places it appears as fine needles in the biotite. The section has been fractured, and the fractures subsequently filled with an intimate mixture of calcite and chlorite. Pyrrhotite occurs as isolated irregular grains up to .05 mm in size.

THIN SECTION 138 B

This section is very similar to 138 A but contains a greater amount of biotite, approximately 20% \pm . There is one vague biotite enriched layer.

Vague spotting in the form of slightly enlarged biotite and quartz grains plus a concentration of pyrrhotite is discernable. In general, the pyrrhotite is more abundant and in larger masses (greater than .2 mm.) than in 138 A. There is a vague suggestion of a concentration of pyrrhotite in

streaks parallel to the bedding. Rutile is the most abundant accessory mineral. Tourmaline and possibly zircon are present in very small amounts.

THIN SECTION 138 C

Similar to 138 A and B but showing gradational thin bedding, some lamellae contain quartz up to .05 mm in diameter.

The section contains feldspar of approximately albite-oligoclase composition. It could only be detected where the grain size was large enough to obtain a figure. 2V was found to be large- approaching 90°.

In some cases it is possible to see the cleavage by using oil immersion. Rutile is the most abundant accessory mineral, occurring either as short prismatic euhedral crystals, which sometimes show excellent geniculated twinning, or as long slender needles, .02 - .03 mm. in length, in the grains of biotite. They lie in random orientation on the cleavage planes and can only be seen distinctly in basal sections. Sphalerite occurs as very small euhedral grains less than .01 mm. in size. Its presence was confirmed by a micro-chemical test for zinc.

THIN SECTION 146 A

This is a section of spotted siltstone. The matrix is composed of irregular quartz and feldspar grains .02 - .04 mm in diameter with very minor amounts of interstitial sericite. The spots are roughly circular in outline and range in size from 0.3 - 0.8 mm. They are composed of quartz grains averaging .05 - .1 mm., biotite flakes up to 0.1 mm. and

sievey grains of muscovite showing poikiloblastic structure. The chadocrysts are, quartz feldspar, and tourmaline. An attempt was made to determine the type of feldspar present, and the approximate percentage. It was noted that a few grains showed albite twinning. The maximum extinction angle was found to be $12-1/2 - 13^{\circ}$. These grains were optically positive, with a large 2V. Under oil immersion 90° cleavage was evident. These grains were concluded to be albite.

The section also contains a number of fairly large grains of what appeared to be quartz. These grains were most commonly clouded by minute inclusions. The index was found to be just slightly above that of balsam and greater than the albite. The birefringence appeared to be slightly higher than that of the albite. The latter showed a dark grey interference color whereas the former showed a light grey to cream color, giving a birefringence of approximately .010. A careful check of several grains proved that the mineral was biaxial negative with 2V from $60^{\circ} - 70^{\circ}$. One or two grains exhibited what was thought to be a type of radial twinning. It is thought that this mineral may be cordierite. The section contains considerable tourmaline. It occurs as pale blue-green short stubby crystals which show good euhedral outlines. The larger grains show pleochroism with absorption greatest when parallel to the analyzer. Cross fractures are common. Large sievey anhedral of chlorite occur commonly through this section. They are frequently associated with clinozoisite. The clinozoisite is also associated with

muscovite, where it is found replacing the muscovite along cleavage planes. Calcite is fairly abundant in the chloritized areas. Rutile is present in small amounts as an accessory mineral.

THIN SECTION 146 B

This section consists of banded, biotite specked and spotted argillaceous siltstone. The main ground mass of the slide is composed of approximately 50% quartz grains averaging .01 - .02 mm. in diameter and 50% biotite grains averaging .02 - .04 mm. in diameter. The spots occur with random arrangement throughout the general matrix. They are roughly circular to ellipsoidal in outline and range from approximately .6 - 2 mm. in diameter. They are frequently isolated from one another but in many cases it is possible to trace a direct connection between two or more spots, giving a chainlike effect. The spots quite commonly exhibit a central core or cluster of large biotite grains up to .2 mm. in diameter. Surrounding this core and separating it from the general biotite rich ground mass is a bleached rim of quartz grains. In practically all cases the biotite grains in the spots have been more or less altered and replaced by clinozoisite. The spots have notably higher percentage of pyrrhotite than the rest of the section. Tourmaline is a common accessory mineral throughout the slide but it appears in greater amounts and in larger crystals in the spots than in the general ground mass.

The section is traversed by an irregular pyrrhotite rich band containing clusters of biotite in a coarse silty ground mass. This layer is similar to the spots previously described, except that it is continuous across the whole width of the section, is parallel to the bedding plane, and contains a much higher concentration of pyrrhotite than is found in any of the spots. A veinlet of coarse biotite crystals cuts across all the structures including the spots and the pyrrhotite rich layer.

THIN SECTION 153 A

This section is considered to be a relatively pure siltstone since it contains practically no sericite. The matrix consists of quartz and feldspar grains with a small percentage of biotite evenly distributed throughout. The slide is vaguely spotted with irregular shaped clusters of biotite grains, but no clearly marked bleached rimming can be seen. Large sievey flakes of muscovite are common and a large percentage show replacement by chlorite and epidote. The biotite in the spots is more or less replaced by chlorite and epidote and possibly some clinozoisite. The most notable feature of this section is the presence of a layer which contains a relatively high concentration of pyrrhotite. The pyrrhotite appears to have entered the section along small transverse fractures. From these fractures it has spread out and permeated a considerable amount of the surrounding siltstone. It is commonly found replacing biotite. The introduction of the pyrrhotite appears to have been accompanied by

the formation of chlorite and carbonate. The carbonate, probably calcite, is veined and replaced by sphalerite. A dark olive green mineral occurs in the parts of the section where pyrrhotite is present. It is thought to be chloritoid. It occurs as vague rims on calcite grains and in a few cases as isolated aggregates of very small grains. Tourmaline occurs as a minor accessory mineral.

THIN SECTION 154 A

In general, this section is classed as a spotted silty argillite. The matrix is approximately 80% sericite. There is little distinct quartz. The spots average 1 mm. in diameter and occupy roughly 20% of the total area. They are circular in outline and exhibit a bleached rim and biotite rich central cores. Some of the spots contain up to 25% pyrrhotite and most have coarser quartz grains than is found in the surrounding matrix. The pyrrhotite in the spots is very commonly intimately associated with biotite, and in general it appears that the pyrrhotite has selectively replaced the biotite. Quite frequently the spots contain fair sized clusters of clinozoisite grains and short stubby crystals of rutile. Tourmaline is present as an accessory mineral.

THIN SECTION 154 B

The greater part of this section is very similar to 154 A. The rock is a spotted silty argillite. The majority of the spots show the biotite cores, but a few are largely composed of coarse quartz grains averaging 10 mm. in diameter. The above silty argillite is in sharp contact with a layer of

biotite rich (35%) argillaceous siltstone with quartz grains .03 mm. in size; having a larger coarse biotite and sphalerite rich patch. The sphalerite occurs in large irregular masses and as smaller euhedral crystals (dodecahedrons). It penetrates along cleavage planes in the biotite grains and in some places appears to almost entirely replace some of the biotite grains. It also occurs interstitially between grains of quartz. The sphalerite enriched area contains a considerable amount of carbonate, probably calcite. It is commonly found rimming the grains of sphalerite.

THIN SECTIONS 160 A and B

Both thin sections show a fine grained massive layer and a specked or spotted layer. The latter has round biotite rich spots 1 mm. in diameter with thin pale rims .04 mm. wide plus interstitial cryptocrystalline material similar to that found in the massive layer. The spotting is more pronounced in 160 B than 160 A.

The massive cryptocrystalline layer is almost entirely composed of quartz and sericite grains .01 - .03 mm. in diameter. The ratio of the quartz to sericite varies from 1.2 to 1.1.

Biotite occurs as scattered grains, averaging .02 mm. in size. Rutile and tourmaline are common accessory minerals occurring as scattered euhedral crystals, the former often showing good twinning. What is thought to be zircon appears as a very minor accessory mineral.

The spots contain biotite grains ranging from .03 - .12 mm

in size, which are more or less chloritized -- the chlorite penetrating along cleavage planes.

Tourmaline is found as an accessory mineral throughout both sections. It occurs in two distinct ways. In the massive cryptocrystalline layer it appears as small isolated euhedral grains generally colourless to light greenish. It occurs in the biotite cores of the spots as large sievey anhedral up to .2 - .3 mm. in size, and forming in some cases as much as 25% of the area of the spots.

Clinozoisite and rutile occur quite abundantly as accessory minerals in some of the spots.

THIN SECTION 182 A

This section consists of two predominately silty layers separated by a thin finer-grained highly argillaceous layer.

The silty layers are biotite rich. In one layer the biotite is largely confined to irregular spots, while in the other, it is more or less evenly distributed throughout. The spots invariably contain coarser quartz grains than the surrounding matrix.

A number of the spots have a concentration of rutile crystals .02 - .04 mm. in size. These rutile grains show no common orientation, but rather exhibit complete random arrangement.

One part of the section has been highly chloritized by solutions penetrating along minute fractures. Within the vicinity of these veinlets the biotite has been severely chloritized. The alteration appears to have been accompanied

by the formation of rutile needles, which are found along cleavage planes in altered biotite. The rutile found in the chlorite does not resemble that previously described. It occurs in long acicular needles.

The argillaceous layer is relatively devoid of spotting, but it is characterized by the presence of considerable amounts of small stubby rutile crystals which occur in small aggregates in streaks, more or less parallel to the bedding. The concentration of the rutile is greatest along the contacts with the silty layers.

THIN SECTION 182 B

This section shows banded silty argillite grading to almost pure argillite. Small clusters or spots of biotite occur scattered throughout the highly argillaceous matrix.

The slide contains irregular areas of what appears to be coarse recrystallized quartz grains. They are more numerous, and the grains of quartz are larger, in the more argillaceous layers, where they occupy 50 - 75% of the total area.

These areas or spots are devoid of biotite and contain only very small amounts of sericite. The quartz grains contain a large number of small inclusions. Two irregular streaks of rutile crystals traverse the section more or less parallel to the bedding. There is a slight amount of chloritization of the biotite close to these streaks.

THIN SECTION 182 C

This is a section of silty argillite similar to "A" and "B", but lacking pronounced thin bedding and areas of

recrystallized quartz.

The section shows a slight amount of normal spotting, i.e. biotite rich core, with bleached rim. Pyrrhotite grains occur in some of the spots.

THIN SECTION 190

This is a section of mottled siltstone mainly composed of quartz grains less than .02 mm. in diameter.

The matrix contains approximately 15 to 20 per cent biotite, more or less evenly distributed throughout as equidimensional grains averaging .02 mm., with a few grains up to .1 mm.

Several veinlets of chlorite approximately .2 mm. wide cut the section. The areas adjacent to the veinlets are intensely chloritized, resulting in several highly chloritized bands separated by layers in which the biotite is only slightly altered.

THIN SECTION 195 A

This slide consists of two bands of argillaceous siltstone. One is biotite enriched and contains large spots of biotite, coarse quartz and pyrrhotite. In sharp contact with this layer is a more argillaceous band, noticeably deficient in biotite.

The most prominent mineral is tourmaline. It occurs in three ways: as very small grains generally less than .01 mm. in diameter, fairly evenly distributed throughout the section: as large isolated pleochroic grains: and as aggregates of very small grains.

THIN SECTION 195 B

This is fine grained spotted siltstone. The quartz in the matrix varies from .01 - .04 mm. in diameter. The spots are composed of coarser quartz grains averaging .05 - .1 mm. in diameter, and grains of biotite more or less chloritized, up to .4 mm in size. A few large, (up to 1.5 mm.) sievey anhedral of muscovite occur scattered throughout the section.

The biotite in the spots has been partially replaced by clinozoisite. Subsequent to the formation of this mineral a large percentage of the remaining biotite has been highly chloritized. The result is that approximately 50 per cent of the spots are now composed of an intimate mixture of chlorite, clinozoisite, and coarse grained quartz.

Tourmaline is the most common accessory mineral. It occurs as very small scattered grains and as large isolated sievey anhedral.

THIN SECTION 195 C

This argillaceous spotted siltstone has a matrix composed of sericite, quartz, and biotite averaging .01 - .02 mm. in size. The spots range from .2 - .6 mm. in diameter and show central cores of biotite surrounded by a rim of coarse quartz grains. In some cases the spots are joined together forming irregular bands. One veinlet containing large grains of biotite and quartz cuts across the section at an angle to the bedding. The biotite grains are more or less oriented parallel to the veinlet. They are considerably chloritized and in some cases replaced by clinozoisite.

Pyrrhotite is found concentrated in the spots and is always in close association with the biotite and often replaces it. Rutile is also a common constituent of the spots and appears to be more abundant in the spots where chloritization and development of clinozoisite is more pronounced.

THIN SECTION 210 A

- (1) This section shows three distinctly different bands: cryptocrystalline layer composed of quartz and sericite in equal amounts. Grain size .01 - .02 mm. Rutile grains .02 - .04 and coarse (.04 - .10 mm.) flakes of biotite are scattered throughout. There is a definite alignment of the sericite and rutile grains parallel to the banding.
- (2) In sharp contact with the crypto layer is a dark band .3 mm. wide which contains a high percentage of pyrrhotite ($10 \pm$) occurring as scattered grains .03 - .10 mm. in size. This band is approximately 85% quartz in .02 - .04 mm. size grains and 15% sericite. The latter occurs in larger grains than in (1).
- (3) The pyrrhotite-rich layer grades into a coarsely spotted band. The matrix is similar to number 2. The spots vary in size up to approximately 3 mm. in diameter. They contain pyrrhotite in considerable quantity. The percentage decreases as the distance from number 2 layer increases. The biotite in the spots is more or less chloritized. Clinozoisite and rutile are present in considerable quantity. In general the layer is quite strongly tourmalinized, but there is a distinct increase in concentration of this mineral in the spots as

compared to the surrounding matrix. In some spots the amount is over 50% of the total.

A veinlet of quartz and feldspar cuts all layers. The feldspar is thought to be albite, biaxial positive - $2V =$ large index 1.54. Where the veinlet crosses the pyrrhotite-rich layer, it contains large grains of pyrrhotite.

A number of grains of albite were identified throughout the section, and it is thought a considerable proportion of the ground mass is feldspathic, rather than purely quartzose.

THIN SECTION 210 B

The same series of three layers are observed here as in 210 A.

(1) The cryptocrystalline sericite band in this case is vaguely spotted. There are occasional muscovite sieves up to 2 mm. in size with included rutile needles, and scattered feldspar sieves .1 mm. in diameter which are most probably albite (+) $2V$ large.

(2) Dark band 1.5 mm wide similar to one in A containing approximately 10 - 12% pyrrhotite. The remainder is largely quartz .02 - .05 mm. with 10% \pm sericite.

(3) The biotite spotted band has a fine silty matrix of quartz (.01 - .03) plus minor sericite. The biotite spots contain a considerable amount of tourmaline. It occurs as small grains (.01 mm.) more or less evenly distributed throughout the spots and produces noticeable rims. Some of the smaller spots show a greater concentration of tourmaline and a much lower concentration of biotite than is observed in

the large spots.

Pyrrhotite is associated with the biotite in the spots. One albite grain was identified near a spot, but most of the colourless mineral with the biotite is quartz.

THIN SECTION 241 A

This section is composed of three well defined layers. A silty argillaceous band, made up of cryptocrystalline sericite plus 5 - 10% scattered quartz grains .02 - .04 mm. in diameter. This highly sericite layer grades into a biotite and pyrrhotite-rich band which in turn grades into a coarsely spotted layer.

The zone between the cryptocrystalline sericite layer and the biotite-rich layer is characterized by abundant rutile grains which occur in isolated streaks parallel to the general banding. The ground mass, in the spotted layer is largely quartz and sericite, of approximately .5 - .6 mm. in size. Their most striking feature is the high concentration of pyrrhotite, which amounts to over 75% in some cases. The pyrrhotite is almost always intimately associated with biotite. The spots show some coarse (.1 - .4 mm) sievey grains of albite. In some cases, these grains are entirely surrounded and engulfed by pyrrhotite.

The section is cut by a veinlet of pyrrhotite and chlorite. One side of the veinlet is occupied by pyrrhotite, the other by chlorite plus a small amount of carbonate. Where the veinlet crosses the larger spots the pyrrhotite has spread out to form large irregular masses within the spots.

THIN SECTION 241 B

This section is very similar to A. There are two coarsely spotted bands separated by a non-spotted biotite-rich layer. The matrix is quartz and sericite in approximately 1:1 proportions.

The spots are large -- up to 2-4 mm. They consist of coarse grains of quartz .05 - .1 mm. in diameter, large flakes of biotite .05 - .2 mm. and a considerable amount of coarse pyrrhotite. There is a marked decrease in the amount of sericite as compared to the matrix. Clinozoisite is found as an accessory mineral in the spots and is often very closely associated with pyrrhotite. Sphene occurs in a veinlet of albite which cuts the biotite-rich layer parallel to the banding. It was recognized by its high index, high birefringence, and diamond-shaped crystal outline. $2V=20 \pm$ biaxial positive, grain size approximately .04 or less.

Rutile and tourmaline (some sievey crystals) are also present as accessory minerals.

THIN SECTION 246 A

Three distinct layers are recognizable in this section. A mottled layer composed of numerous small spots of quartz grains in a cryptocrystalline sericite matrix occurs in sharp contact with a pyrrhotite-rich band containing about 10% scattered pyrrhotite in a matrix composed of 50% sericite and 50% quartz grains.

The pyrrhotite layer grades into one that is quite strongly spotted. The spots are largely coarse quartz and

biotite grains. Quite commonly the biotite flakes in the centre of the spots are considerably larger than those on the periphery. This produces a noticeable rimming effect.

The most common accessory mineral is rutile. It is found scattered throughout the whole slide, but is most abundant along the contact between layers 1 and 2, and in the spots.

Clinozoisite and pyrrhotite are present in most of the spots. Tourmaline occurs as a minor accessory mineral.

THIN SECTION 246 B

This section is very well spotted. In general, it consists of large, well-rounded, biotite-rich spots up to 3 mm. in size in a slightly argillaceous siltstone matrix.

The most characteristic thing about the spotting is the high concentration of both rutile and clinozoisite in the spots.

The latter shows a tendency to occur in the centre of the spots replacing some of the biotite whereas the former is quite often found as a ring of small crystals around the periphery of the spot. However, this is not always the case.

The section is strongly tourmalinized throughout.

THIN SECTION 264 A

This section is a fairly uniform argillaceous biotite enriched siltstone with an "Aplitic" texture. Both the quartz and the biotite grains average .01 - .02 mm. in diameter.

Rutile, clinozoisite and tourmaline are common accessory minerals and are found more or less evenly distributed throughout

the section.

THIN SECTION 264 B

This section is well banded with large clearly defined spots in two of the layers. Other layers show an "aplitic" texture similar to 264 A.

The "aplitic" bands are notable for the abundant development of very minute grains of rutile and tourmaline. These minute crystals give the band a dusty appearance.

Another characteristic of these layers is that they are cut by one or more very narrow irregular black bands more or less parallel to the bedding. Examination under high magnification reveals that these bands consist of a concentration of small rutile crystals less than .01 mm in size, extremely fine grains of tourmaline approximately .002 mm. in diameter, and granular clinozoisite in close association with the rutile crystals.

One of the "aplitic" bands contains a pyrrhotite-rich zone. The pyrrhotite is intimately associated with clinozoisite. Small rutile crystals are scattered throughout the layer.

In general, the spotted laminae consist of large well-rounded aggregates of coarse quartz and biotite, approximately 2 mm. in diameter, plus varying amounts of rutile, pyrrhotite, and clinozoisite.

In some cases, the spots are almost entirely made up of biotite. However, it is more common to find the biotite forming a thin peripheral ring, leaving a more or less barren core

of quartz grains.

Rutile is commonly found as clusters of small euhedral grains associated with the biotite. One spot may have up to a dozen such clusters. They are not found in the barren cores.

One spotted band located near the previously described pyrrhotite-rich zone has spots which contain a very high percentage of pyrrhotite. Clinozoisite and rutile are common associates of the pyrrhotite. See plate 3.

THIN SECTION 264 C

This section is very similar in all its fractures to the one just described. It is well banded with alternating "aplitic" and spotted layers. It lacks the pyrrhotite-rich zone and the spots do not contain any appreciable amount of pyrrhotite. They do, however, show a tendency towards bleached rims.

THIN SECTION 289 A

This section is moderately well banded. It grades from a highly sericitic "mottled" layer into a biotite-rich argillaceous siltstone band, which is cut by two irregular veinlets of pyrrhotite. It also contains numerous scattered grains of pyrrhotite.

The most notable features of the slide are the pyrrhotite veinlets. They are parallel to the bedding and appear to follow a set of parallel fractures, or porous zones. Some of the quartz grains closely associated with the veinlets are considerably coarser than found elsewhere.

The veinlets are very irregular and tend to pinch and

swell. One of the beds near the veinlets show a .3 mm. right hand offset caused by pre-mineral movement. Upon encountering this feature, the pyrrhotite follows the joint plane for a distance equal to the offset and then continues along the same layer as before. See plates 1 and 2.

THIN SECTION 289 B

This section is coarsely spotted and banded siltstone with spots ranging up to 4 mm. in diameter. In general, they exhibit markedly rounded outlines, and are mainly composed of biotite and quartz. In some cases, the biotite is almost entirely altered to chlorite, while others show very little chloritization. Some spots show a marked reduction in grain size around the borders, giving a pronounced rimming effect.

The percentage of pyrrhotite in the spots varies greatly. It is almost always associated with clinozoisite and rutile. The degree of chloritization of the biotite in the spots seems to be directly related to the amount of contained pyrrhotite.

THIN SECTION 315 A

This slide shows well spotted slightly argillaceous siltstone in which the spots range up to 6 mm. in diameter. The ground mass is composed of quartz and biotite grains generally less than .04 mm. in diameter. The proportion of quartz to biotite is approximately 60 - 40. The ground mass contains sparsely scattered grains of pyrrhotite with associated clinozoisite.

There is a notable lack of biotite in the spots. What there is, is concentrated in the centres. The remainder is

almost all quartz grains over .2 mm. in diameter plus accessory minerals. There is a decided concentration of pyrrhotite, epidote, and tourmaline, in practically all the spots.

The epidote occurs as clusters of small stubby crystals. The tourmaline occurs as (a) small isolated euhedral crystals, and (b) as anhedral cloudy masses or aggregates of small crystals which appear to be replacing biotite.

The spotted band is in sharp contact with a highly argillaceous layer. This layer shows a considerable amount of scattered rutile crystals. They do not stop at the contact with the spotted layer, but continue 3 - 4 mm. into the spotted layer before fading out.

THIN SECTION 315 B

This section is made up of two distinct bands. The contact between them is marked by a thin seam of chlorite. On one side is a layer of coarser argillaceous siltstone which was originally biotite enriched. The biotite is now largely altered and replaced by chlorite.

The argillite layer gradually assumes a mottled appearance due to the presence of small clusters of quartz grains embedded in a cryptocrystalline sericitic ground mass. The size and number of quartz clusters increases as the distance from the contact with the silty band increases.

The argillaceous matrix contains scattered rutile crystals and irregular areas of carbonate. The percentage of rutile appears to be greatest near the contact with the silty band.

THIN SECTION 340 A

This specimen is classified as a vaguely spotted siltstone. The majority of the slide consists of a fine-grained matrix of quartz grains with a few irregular clusters of biotite flakes. There is a pronounced development of rutile crystals associated with the biotite and rutile. One part of the slide has been carbonatized to a slight extent.

Several small blue-grey grains occur in the section. They have a very high index ($1.80 \pm$) and are either positive uniaxial or biaxial positive with a low 2V. The birefringence appeared to be approximately .030 - .040, but since the grains are less than .03 mm. in size this cannot be taken as accurate. They show diamond shapes to pyramidal outlines and may possibly be sphene -- the colour does not seem to be that of sphene positively identified in section 241 B.

The carbonated area previously mentioned contains two calcite grains which appear to be pseudomorphs. The shape of the original crystals is outlined by an unidentified greenish mineral. It is thought that these grains may be pseudomorphs after sphene.

THIN SECTION 340 B

This section appears to be a relatively pure siltstone containing large well-rounded spots up to 5 mm. in diameter.

The silty ground mass contains some albite which shows good twinning.

The spots show a distinct tendency towards more or less barren cores surrounded by thin rings of biotite. In some

cases the biotite has been bleached and partially replaced by what is thought to be epidote.

The spots are characterized by clusters of small rutile crystals associated with the biotite and by a marked increase in the concentration of tourmaline. The latter generally occurs in isolated euhedral crystals up to .04 mm. long, but it was also found as minute inclusions in a colourless fibrous mineral. This mineral was found to have the following properties. Index 1.60 \pm , prismatic cleavage, birefringence 0.010, length slow, biaxial negative, 2V moderate to large. The mineral is thought to be wollastonite. One one grain was identified.

THIN SECTION 340 C

This specimen is classified as an argillaceous siltstone. It resembles the more highly altered parts of the one just described. The spotting is not as pronounced, but the alteration of the biotite and the formation of rutile is exactly similar.

The most interesting feature is the selective alteration of the biotite. It has been strongly bleached, so that it is now colourless, and has been selectively replaced along cleavage planes by very thin needle-like yellow-brown crystals. They are thought to be needles of rutile.

THIN SECTION 415

This section shows a vaguely spotted pyrrhotite-rich argillaceous siltstone showing a general enrichment of biotite in small evenly distributed grains.

The spotting effect is largely due to more or less circular areas which have a marked increase in the concentration of pyrrhotite. The pyrrhotite is very nearly always associated with clinozoisite which tends to form as an outer aureole around groups of pyrrhotite giving the whole "spot" a circular outline.

The clinozoisite occurs as granular aggregates which show a distinct tendency to be elongated parallel to the overall banding.

The peripheries of some of these vague spots are marked by a distinct rim of rutile grains.

The spots contain close grains of quartz and feldspar (albite). The latter is general in larger and more irregular grains.

THIN SECTION 606 A

This section contains large well-rounded spots in a biotite-rich, slightly argillaceous, siltstone.

The spots are largely composed of coarse irregular grains of quartz up to 2 mm. in diameter and large irregular grains of pyrrhotite .3 - .6 mm. in size. The percentage of biotite in the spots is low and is generally only found closely associated with grains of pyrrhotite which in some cases appears to replace the biotite. Practically all grains of pyrrhotite have associated clinozoisite. At times, it is also found associated with rutile.

There is a general increase in the concentration and

size of the tourmaline grains in the spots as compared to the surrounding ground mass.

THIN SECTION 606 B

This slide is very similar to 606 A showing well defined spots with concentration of pyrrhotite, rutile, and tourmaline centre and a barren rim of coarse quartz. The spots are connected by irregular stringers composed of pyrrhotite grains and associated clinozoisite, and occasional rutile. These connecting stringers are parallel to the general faint banding seen in the arrangement of the biotite grains on the matrix.

SELECTIVE STAINING

The following method of selective staining of feldspar was employed.

The specimen to be stained was first ground to approximately 1 mm. in thickness. It was then etched with hydrofluoric acid for one minute, washed, and placed in a hot solution of a sodium-silicate for five minutes. The excess sodium silicate was removed by washing gently, and the specimen was then placed in a bath of Fuchian dye. After ten or fifteen minutes the chip was removed, allowed to dry, and made into a thin section in the usual manner.

A number of standards were run on specimens of rocks which were known to contain feldspar.

The tests were successful in that they proved that the dye stained feldspar, but had no effect on quartz, and that it could be concluded that any stained material was most probably feldspar.

The tests indicated, however, that in one rock a certain feldspar would react positively to the staining while in another rock, the same feldspar under exactly the same treatment, would remain unaffected. Therefore it must be concluded that while the method used, may, in some cases help in determining the presence of feldspar the fact that the specimen does not react positively is no guarantee that it does not contain feldspar.

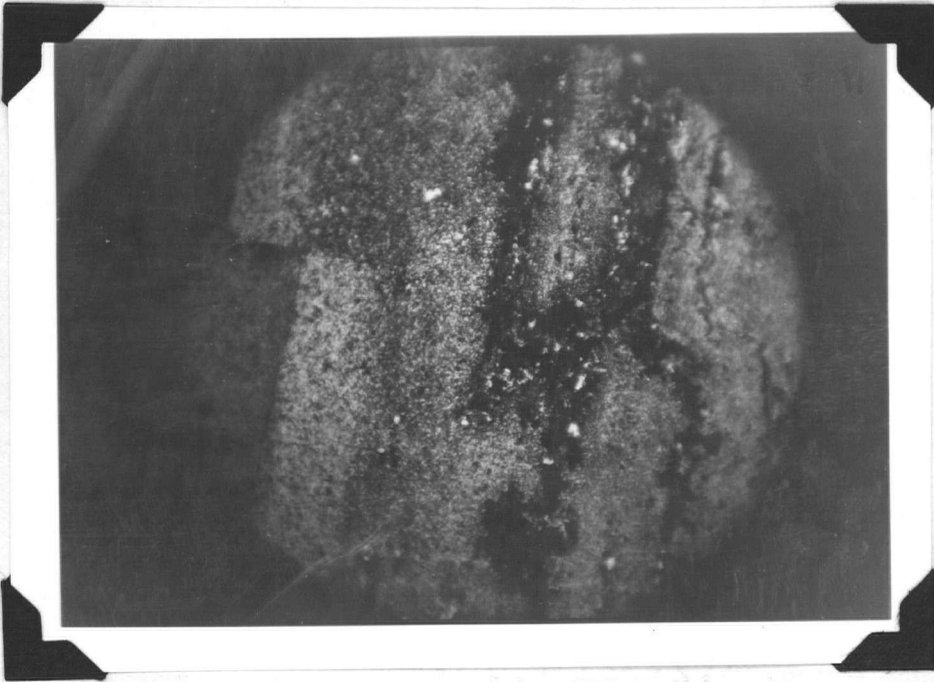


Plate 1. Photomicrograph of pyrrhotite-rich layers in thin section 289A. Mag.16X. Note how pyrrhotite follows left-hand offset.

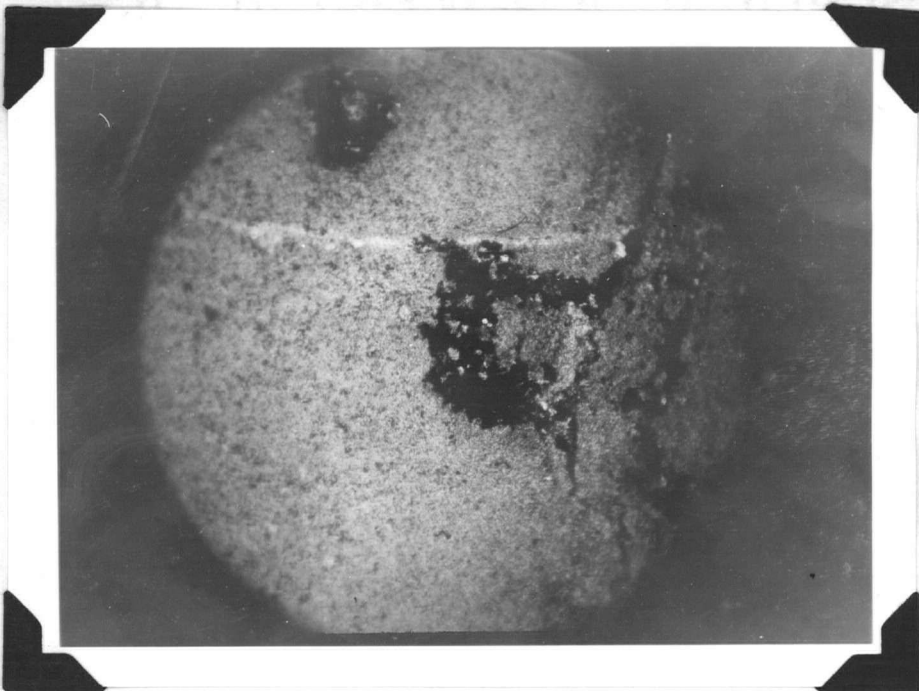


Plate 2. Photomicrograph of lens of pyrrhotite connected with veinlet shown in Plate 1. Mag.16X.

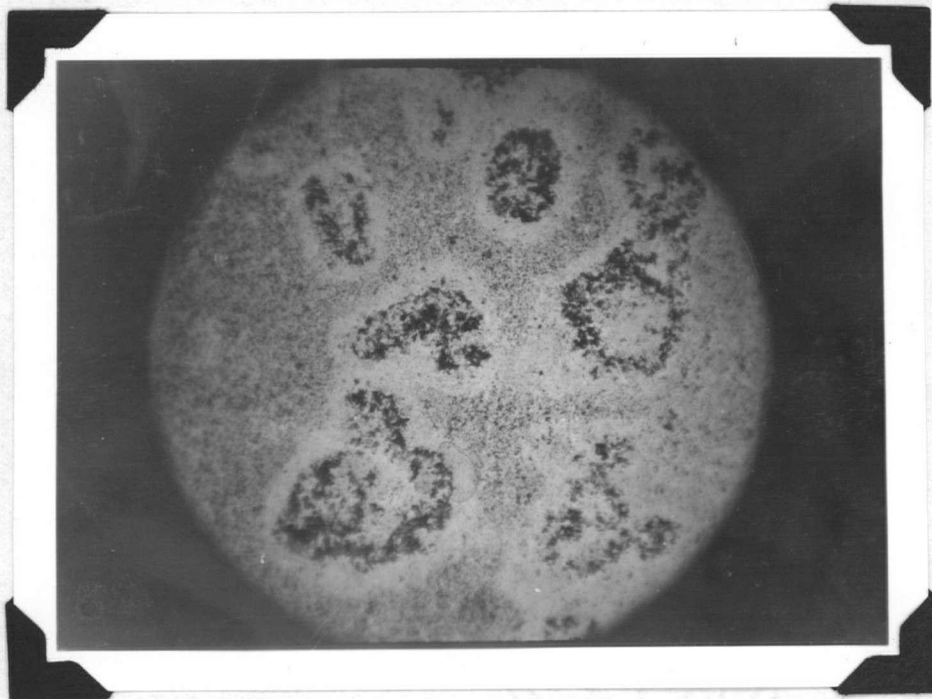


Plate 3. Photomicrograph of pronounced spotting in thin section 264A. Note concentration of biotite in the centre and rim of biotite-free quartz and feldspar. Dark mineral in ground mass is biotite. Mag.16X.

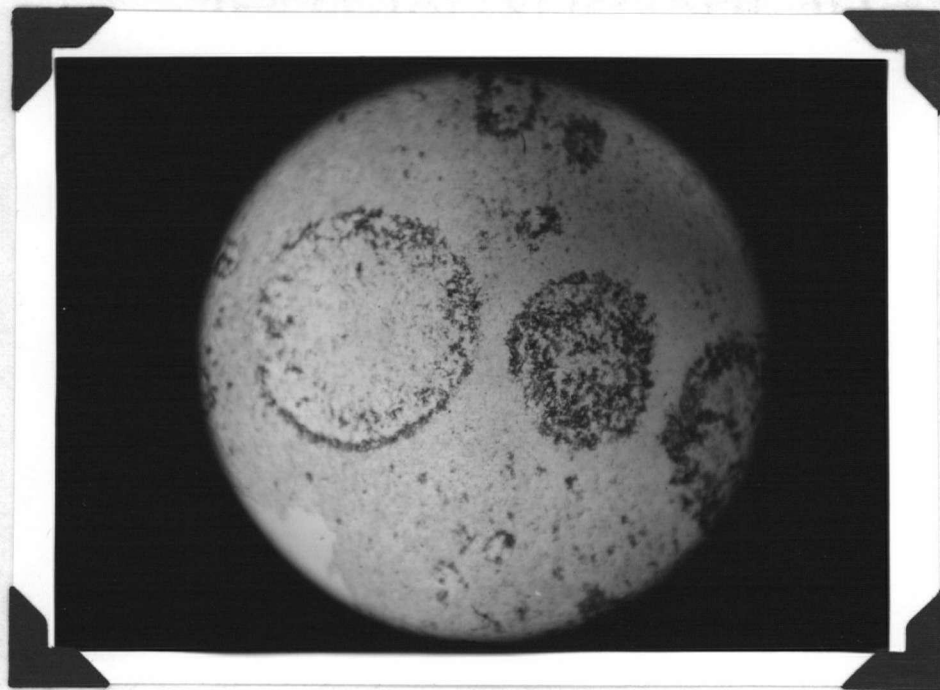


Plate 4. Photomicrograph of large spots in thin section 340A. Note pronounced concentration of biotite around the rim of the large spot. The small black grains are crystals of rutile. Mag.16X.

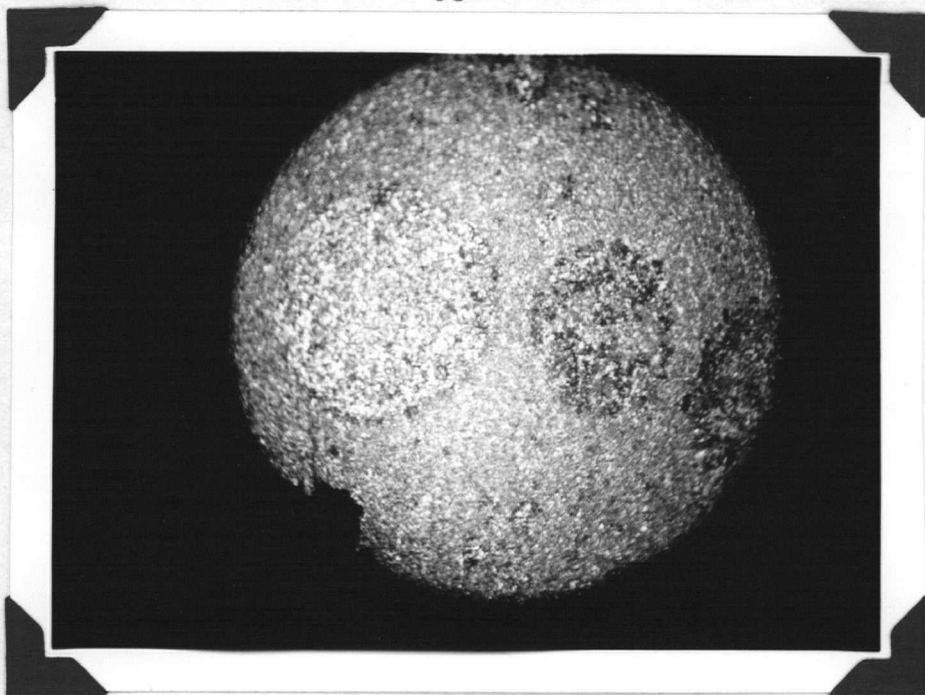


Plate 5. Photomicrograph showing same spots seen in Plate 4, but taken with crossed Nicols. Note increase in grain size of quartz within the spots. Mag.16X.

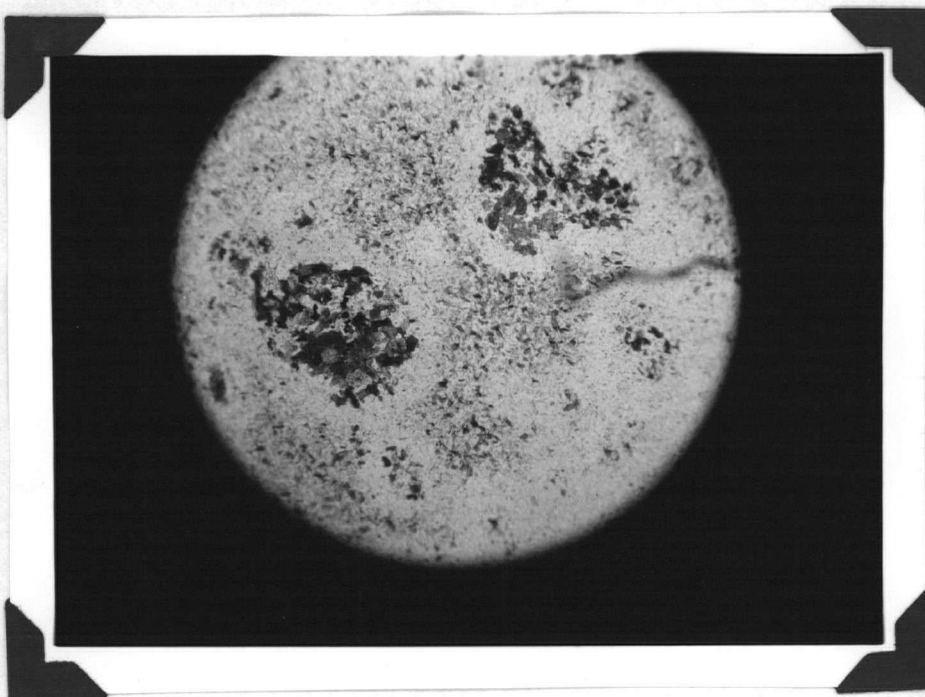


Plate 6. Photomicrograph showing large grains of tourmaline concentrated in the spots in thin section 160B. Tourmaline shows light to dark grey and exhibits a granular texture. Mag.16X.

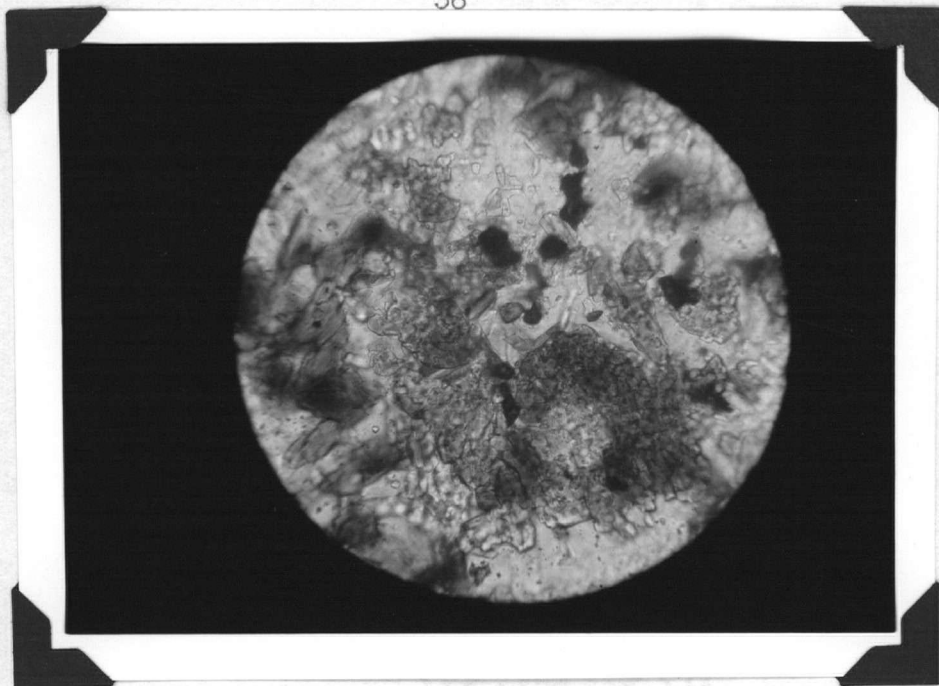


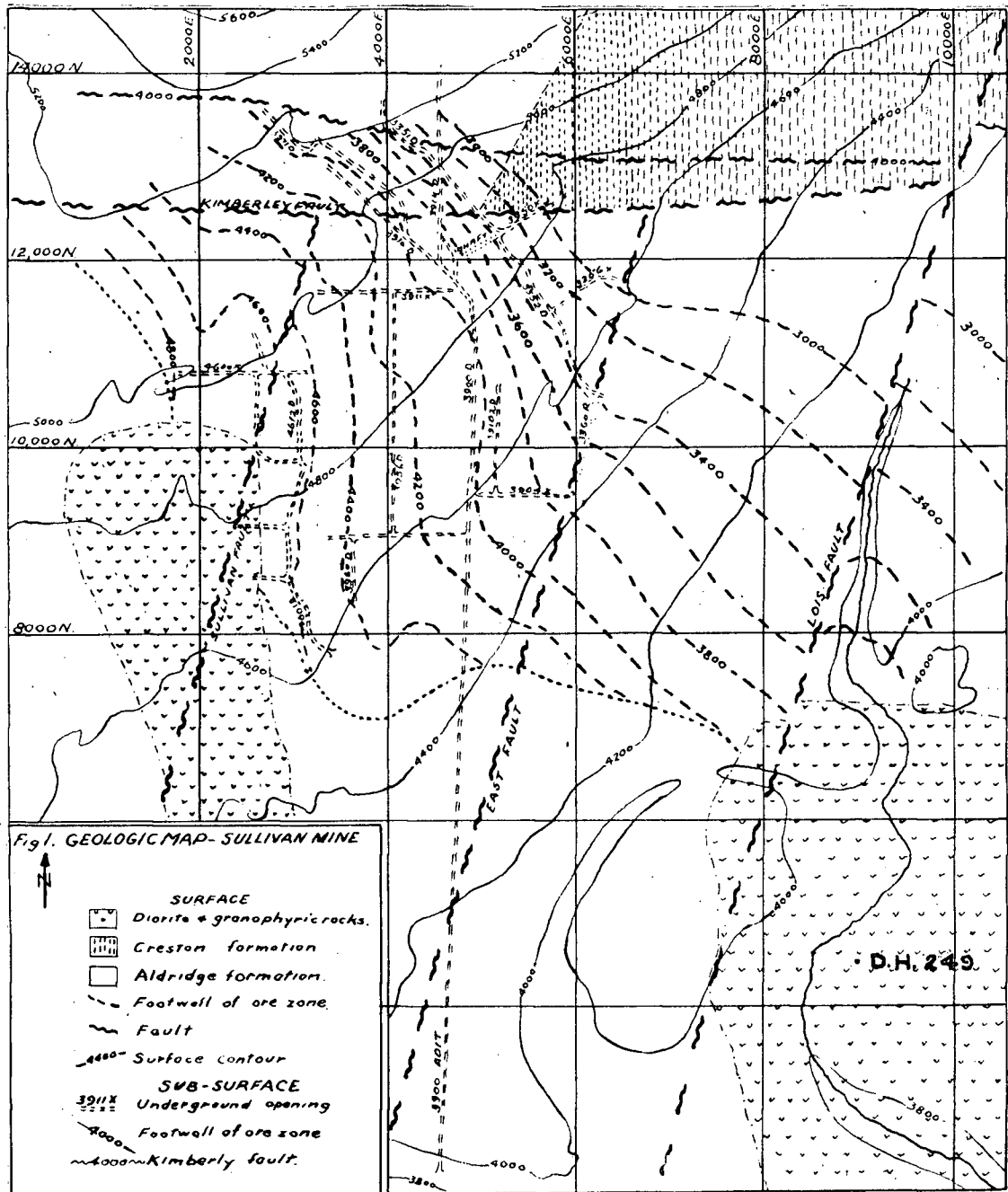
Plate 7. Photomicrograph of tourmaline grain in larger of two spots seen in Plate 6. Predominant granular mineral is tourmaline. Black grains are rutile. Mag. 50X.

EARNSCIFFE

LINEN BOND

100% RAG CONTENT - CANADA

FIG.1. GEOLOGIC MAP - SULLIVAN MINE.



After C.O. Swanson and H.C. Gunning
Trans. C.I.M.M. 1945

The photographs illustrate the thin bedding that is characteristic of these sedimentary rocks. They also show the general character of the spotting and the gradual increase in the size of the spots with increase in depth.

FOOTAGE

134 Contact with sill. No specimen available.

138 Sillicious argillite. No visible spotting. Prominent fractures.

146 Thin bedded siltstone with numerous small spots.

Spotted argillaceous siltstone.

153 Vaguely spotted siltstone.

Spotted siltstone grading into a pyrrhotite-rich layer.

Vaguely spotted siltstone.

154 Vaguely spotted silty argillite.

Biotite-rich argillaceous siltstone containing a patch of coarse biotite and sphalerite.

160 Strongly spotted argillaceous siltstone; spots up to 1 m.m. in diameter.

Argillaceous siltstone. Note absence of spotting.

Spotted argillaceous siltstone.

182 Interbedded silty and argillaceous layers. The silty layers are rich in biotite and contain numerous small spots.

195 Uniformly spotted argillaceous siltstone. The spots are largely composed of biotite flakes, which in some areas, have a bleached appearance caused by chloritization.

Fine-grained argillaceous siltstone.

210 Strongly spotted siltstone. The spots are largely composed of biotite and pyrrhotite.

Fine-grained argillaceous siltstone.

241 Silty argillite.

Spotted argillaceous siltstone. The spots contain a high percentage of pyrrhotite.

Silty argillite.

246 Well-spotted argillaceous siltstone.

Argillaceous siltstone.

264 Spotted pyrrhotite-rich layer.

Interbedded spotted and non-spotted beds. The spots are largely composed of coarse biotite flakes.

289 Highly argillaceous band.

Argillaceous siltstone layer containing two parallel veinlets of pyrrhotite. Argillaceous siltstone.

Coarsely spotted siltstone. Spots are largely composed of coarse quartz and biotite.

315 Slightly argillaceous siltstone containing coarse irregular spots which show bleached rim effect.

Highly argillaceous layer.

340 Very coarsely spotted siltstone. The spots have a core of quartz surrounded by a rim of biotite flakes.

415 Argillaceous siltstone layer with large irregular spots. The spots contain large amounts of pyrrhotite.

606 Very coarsely spotted argillaceous siltstone. The spots are largely composed of coarse quartz grains and large irregular grains of pyrrhotite.