THE STAR LAKE GOLD DISTRICT.

MANITOBA.

— G. Hanson.

ACCEPTED
in candidature for the degree
of
MASTER OF ARTS.
May 14th, 1915.

Snow Lake
Ingolf
Canadian Pacific Railway
Long Pine Lake
West Hawk Lake
Star Lake
Camp
Brooklyn
Guthrie
Denmark
Moore
Lerche
Barren Lake
Falcon Lake
Manitoba & Ontario Boundary
Algoman(?)
Laurentian
Keewatin
Geological Boundary
Unknown Boundary
STAR LAKE
DISTRICT
MANITOBA
SCALE:- 1 IN.=1 FT.
Penniac Reef Gold Mine

THE STAR LAKE GOLD DISTRICT. MANITOBA.

INTRODUCTORY.

The Penniac Reef Gold Mine is situated immediately southwest of Star lake, which is about 6 miles southwest of Ingolf, Ontario. No Geological Survey parties have visited the district; consequently the country on the Manitoba side has not been mapped geologically.

Parsons however, working in Ontario under the Ontario Bureau of Mines, has mapped the geological formations to a point about 2 miles west of the Manitoba-Ontario boundary line. During the present investigation an approximate geological map has been made of the country westwards from the boundary line for 6 or 7 miles.

GENERAL GEOLOGY.

The contacts between the Laurentian granite and the Keewatin as mapped by the writer, correspond to those mapped by Parsons on the other side of the boundary line. There are two large areas of granite in the district separated by a tongue of Keewatin schists. The contact between the northern area of granite and the hornblende schists of the Keewatin, extends in a westerly direction from Ingolf for 5 or 6 miles; it then swings to the southwest, and finally the contact runs almost due north and south. The contact between the southern granite area and the Keewatin, extends westward along the northern shore of Falcon lake, and then swings to the southwest. At the boundary line the tongue of Keewatin rocks separating the two granite areas, is about 4½ miles wide, 5 miles west from the boundary line it has a width of about 5 miles, but farther west it becomes much narrower.

Immediately south of Star lake is a third body of intrusive rock about 2 miles long and 1 mile wide. The limits of this intrusive were not explored on its south side.

It may be part of the large granite area to the south, but partly because of reports from residents of the district, and partly because of the basicity of the rock and for other reasons to be discussed later, it was mapped as a separate body.

Extending to the southwest from Star lake is the area mapped as Keewatin, it is an indefinite band of conglomerate, ½ mile or less in width along the shore of Star lake, but much narrower at a point 1 mile to the southwest. It is along the contact between the basic intrusive and these sedimentary rocks that the Penniac Reef Gold Mine is located.

KEEWATIN IGNEOUS ROCKS.

The Keewatin rocks present in the area are chiefly hornblende schists. They occur in contact with the northern area of granite. They strike roughly southwest and northeast, and the dip of the schist planes is vertical. These rocks have suffered severe metamorphism, and secondary silica occur to some extent. The minerals composing the rock are actinolite, plagioclase felspars, secondary quartz and iron oxides. As the hornblende schists of the Keewatin have been described very fully by many workers, and as the schists under consideration present no new features, a fuller description is not necessary here. Hornblende schists extend from the northern boundary of the Keewatin as far south as Star lake, where they give place to sedimentary rocks.

KEEWATIN SEDIMENTARY ROCKS.

The rock next in age to the greenstones is an ill-defined body of sedimentary material. This is composed chiefly of conglomerate with a few minor bands of quartzite. The conglomerate is much contorted and schisted, to the extent that, but for the pebbles its origin would be obscure.

Interbedded with the conglomerate are bands of fine-grained quartzite, having a total thickness of about 50 feet. These sedimentaries are important, as it is at the contact between them and the intrusive rock that the gold is found.

With the exception of a few pebbles of milky and of sugary quartz, the pebbles in the conglomerate are all greenstones. They vary in size from a fraction of a inch to a foot in diameter. No very large boulders were seen; the pebbles being notably of small size. In some places the pebbles are crowded together while elsewhere a rock surface several square yards in area show no pebbles. When the pebbles are scarce the matrix is almost indistinguishable from the greenstone schist. Except for a few angular fragments the pebbles all have smoothly worn surfaces. In form they are ellipsoids with their long axes parallel to the schistosity.

The matrix of the conglomerate is dark greenish in color. Under the microscope it is seen to consist chiefly of fibrous secondary actinolite, round grains of secondary quartz, and grains and laths of plagioclase felspar. Accessory minerals such as iron ores and apatite also occur.

From the fact that practically all the pebbles in the conglomerate are greenstones, it seems almost certain that these rocks are younger than the Keewatin greenstones with which they are in contact. Lawson has given an average analysis of the Keewatin hornblende gabbros.[I] On comparing this with an analysis of the matrix of the conglomerate of the Star lake district, a striking similarity is apparent. The increase of the silicon and alumina, and the decrease of soda and potash in the conglomerate, might be explained as the result of sub-aerial weathering.

[I] A.C.Lawson. Archaean Geol. of Rainy Lake Restudied. Mem.40.1913, p.50.

Fig. 1. Keewatin conglomerate near Star lake outside the contact zone.

SiO_2	49.58	51.22
Al_2O_3	16.37	16.99
$Fe_2O_3 + FeO$	13.28	13.12
CaO	10.26	10.60
MgO	5.37	5.32
Na_2O	2.14	1.51
K_2O	1.05	.48

1. Average Keewatin hornblende gabbro.
2. Matrix of Star lake conglomerate.

On account of the somewhat extreme thickness of these sediments, the arguments by reason of which they are classed as Keewatin rather than Lower Huronian, must be of a convincing character. The typical Keewatin formation consists chiefly of greenstones, chlorite schists, hornblende schists and agglomerates; sedimentary rocks, if the occur at all, do so to a very subordinate extent. It might perhaps be assumed that the sediments were formed on the surface of the Keewatin Greenstones in Huronian times, and have been derived entirely from that surface. The nature of the evidenceon which the classification of the sediments as Keewatin is based, is twofold; (1). structural, (2). lithological.

(1). Since the bedding and strike of the conglomerate appears to be the same as that of the greenstones the conglomerate was apparently deposited on the comparatively level surface of the Keewatin before folding took place. If the main folding which left the conglomerate and greenstones on edge was associated with the intrusion of Laurentian granite; then since the conglomerate would be older than the Laurentian, it would necessarily be classed as Keewatin.

~~A.C.Lawson. Archaean Geol. of Rainy Lake Restudied. Mem. 40. 1913, p.50.~~

While no field evidence of intrusion of the sediments by Laurentian granite was found, if the folding were associated with the granite intrusion it would be impossible for the conglomerate to get into the position it now occupies, unless it was deposited before the intrusion took place.

(2) Since no granite boulders were found in the conglomerate it was very probably deposited before the intrusion of Laurentian granite. On the same grounds A.G.Burrows[I] has classified the Temiscaming series as at least in part earlier than the Huronian granite.

The petrographical character of the Huronian conglomerate in widely separated districts will be illustrated in the following quotations.

In the Swastika Gold Area,[II] the Huronian conglomerate contains pebbles of felspar-porphyry, felsite, greenstone, jasper and granite.

In the Middle Huronian at Sudbury, the pebbles are granite, quartzite and quartz. The matrix is dark grey, with grains of quartz and scales of brown biotite. The pebbles of the Trout Lake conglomerate are granite and quartzite.[III] In relation to the Rainy lake district Lawson makes the following statements: " The pebbles and boulders of the Seine conglomerate consist chiefly of different varieties of granite, with a subordinate proportion of pebbles of greenstone, quartz, quartzite and quartz-porphyry." " At Shoal lake the conglomerate has pebbles of greenstone, quartz and quartzite. The matrix is quartzite with secondary biotite, chlorite and calcite."

[I] A.G.Burrows, Porcupine Gold Area, Ont.Bur.of Mines, Pt.1, 1912, p.220.

~~E.L.Bruce, Ont.Bur.of Mines, Vol.XIV. Pt.3, 1915, pp.93,94.~~

[II] E.L.Bruce, Ont. Bur. of Mines, Pt.1, 1912. p.261.

[III] A.P.Coleman, Ont.Bur.of Mines. Vol.XIV. Pt.3, 1905, pp.93,94.

Also in other occurrences of Huronian conglomerates described by Lawson, the pebbles are usually granite.[I]

Huronian conglomerate in the Iron Ranges of Michipicoten west is described by Bell[II] as follows: " The matrix of the Doré conglomerate where pebbles are absent is indistinguishable from a schist formed from an igneous rock. Microscopically, rounded grains of quartz, and fraged flakes of biotite are seen to be the chief minerals in the matrix, although a great deal of secondary carbonate is present. The pebbles are chert, quartz, quartz-porphyry, granites and basic igneous rocks."

Coleman states regarding Huronian conglomerates in general: " The basal Huronian conglomerate usually has a matrix of arkose and quartzite."[III]

It will be seen that the Huronian conglomerate contains a large proportion of granite pebbles, and that its matrix is of unaltered sedimentary type, consisting chiefly of quartz and biotite. In the Star lake district no granite pebbles are found and the matrix consists of secondary hornblende, altered felspar and secondary quartz.

Conglomerates have been classified as of Keewatin age in several districts.[IV] [V]

[I] A.C.Lawson, Archaeon Geol.of Rainy Lake Restudied,1913,p.60,73.

[II] J.M.Bell, Ont. Bur. of Mines, Pt.1, 1905,pp.340,341.

[III] A.P.Coleman, Sudbury Series, Internat.Geol.Cong. 1913, p.380.

[IV] Van Hise & Leith, Geol.of Lake Sup.Region,Vol.LII.U.S.G.S.p.125.

[V] A.L.Parsons, Ont.Bur. of Mines. 1912.

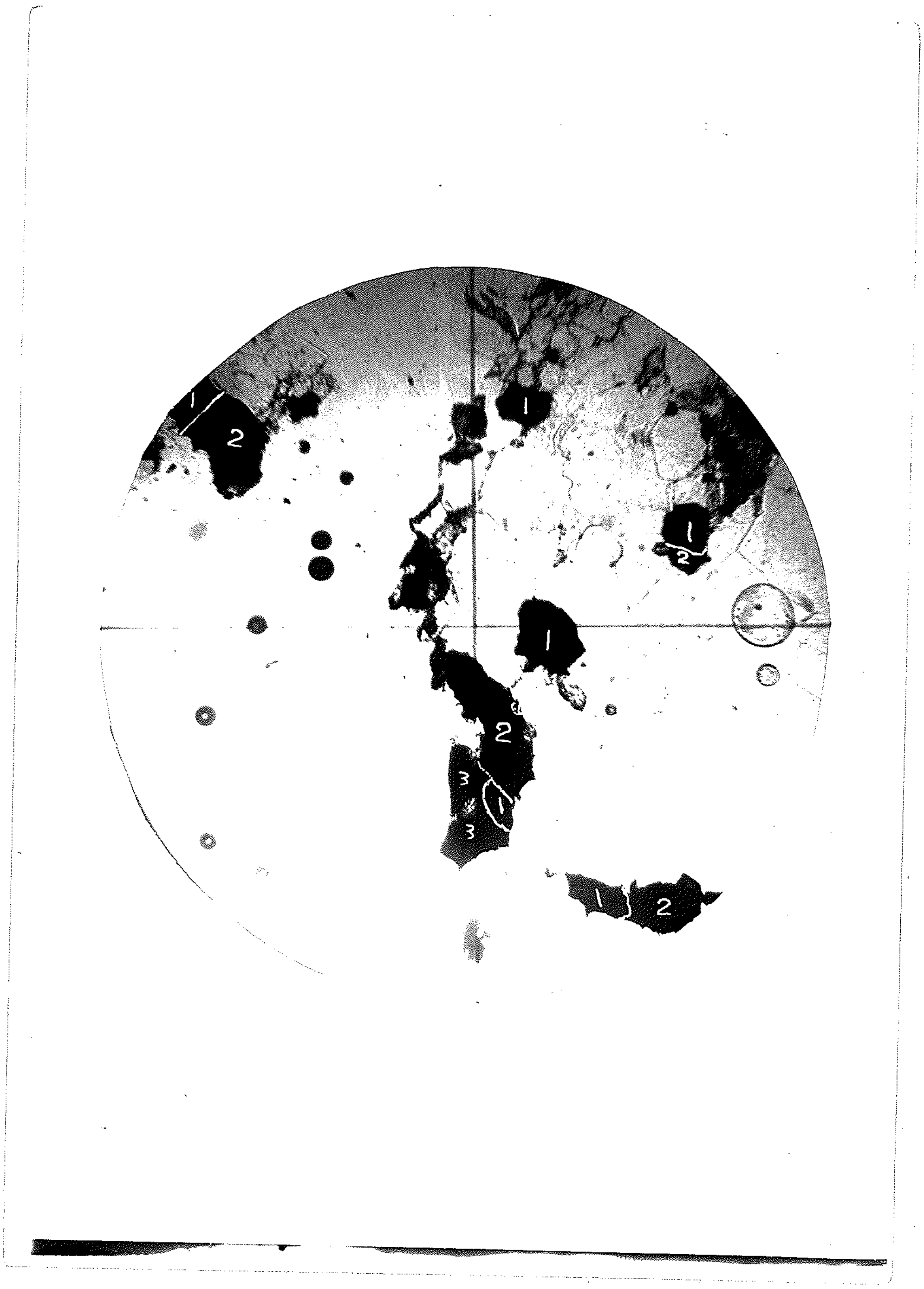

Fig.2. Photomicrograph of vein showing gold associated garnet, pyrrhotite and quartz. 1. gold; 2. garnet; 3. pyrrhotite. The colorless mineral is quartz. Magnified 45 diameters. Penniac Reef Gold Mine.

The association of conglomerate and agglomerate in rock of Keewatin age has been pointed out by Lawson,[I] in the Lake of the Woods Area. He mentions cases where agglomerate emerges into pebble conglomerate. Parsons,[II] working on the eastern extension of the Star lake belt in Ontario, states that it is very difficult to decide whether some rocks mapped as agglomerates may not really be conglomerates. In describing the rocks of the Manitoba-Ontario boundary at Ingolf and West Hawk lake he says: " The Keewatin formation is here about 4 miles wide and consists of fine-grained highly altered rocks which show little trace in the field of their origin." By analysis and microscopic examinations he comes to the conclusion that a considerable part of these rocks is sedimentary. He classes all these rocks as Keewatin in age.

In the Star lake district where extreme alteration has taken place, it is difficult to discriminate in all cases between agglomerate and conglomerate. Here too, Keewatin agglomerate and conglomerate may be associated but the relative proportions of each can not be determined.

LAURENTIAN.

The granite area both on the north side and the south side of the tongue of Keewatin rocks at the boundary line have been mapped by Parsons as Laurentian. The evidence for this has doubtless been gathered from neighboring localities in Ontario. Around Star lake there is no evidence obtainable by which the age of the granite can be definately determined. In the absence of field evidence to the contrary this granite is mapped as Laurentian.

[I] A.C.Lawson, Geol. of the Lake of the Woods, 1885, p.50.

[II] A.L.Parsons, Ont. Bur. of Mines, 1912, p.201-203.

~~The bo~~ The body of granite to the north of the Keewatin rocks lies in contact with the hornblende schists and traps. This is a pinkish colored, acid granite gneiss, with no included greenstones. Even the granite at the contact shows no traces of assimilation of basic rocks. The actual contact between the granite and the greenstones in every place visited, was covered by a muskeg about 200 yards wide, and could not be studied. These muskeg covered contacts are common in the Star lake district, and show that the rocks were more easily disintegrated and ice-eroded at the contacts. If this granite by overhead stoping had assimilated Keewatin rocks to any extent the basic rocks were very probably retained near the top of the magma and removed by subsequent erosion. The assimilation along the sides of the magma was not very extensive as a very acid base is shown at a distance of 200 yards from the greenstones. A granite dyke cuts the greenstones near the contact.

The main folding of the Keewatin rocks was probably contemporaneous with the Laurentian intrusion, field evidence goes to show that the intrusive process was associated with the pressure causing the folding. The strike of the greenstone schist swings from almost due east and west to southwest and northeast, and the contact between the Laurentian and Keewatin behaves in the same way. On this account it would seem that the granite induced the schistosity and tilted the rocks. If the rocks were in a plastic state during the intrusion, the basic Keewatin rocks at some distance from the contact would tend to sink and displace the less dense granite. On the other hand, it may be that the strata were folded sharply into anticlines and synclines before the intrusion took place, and the granite absorbed the northwestern limb of an anticline, and left the southeastern limb dipping vertically.

There is not enough field evidence to prove either case, but it seems most likely that much of the folding was contemporaneous with the intrusion.

Several parallel granitic veins were seen cutting perpendicularly across the strike of the greenstones. Near the granite they were 4 or 5 feet wide and contained much felspar, to the south they pinched out as quartz stringers. These veins were probably thrown out from the granite into cracks produced in the greenstones when the magma was cooling. They were not disturbed to any extent. Tectonic movements had practically ceased when they were formed.

ALGOMAN(?)

Between the Laurentian granite to the south and the Keewatin sediments there is a rather basic granite boss. This is roughly elliptical in outline, about 2 miles long by 1 mile wide. The contact between this boss and the Keewatin schists is marked by several granite dykes parallel with the strike of the schists. The intrusive boss shows extensive assimilation of Keewatin rocks, and near the contact large masses of undigested Keewatin are imbedded in the granite.

It would seem that the present surface of the boss represents approximately its final cap. Had it reached as great an elevation as did the northern area of granite the more basic cap of the boss resulting from the overhead stoping would have been eroded, and a more acid phase would now be seen. From the field evidence it cannot be decided whether this intrusion is Laurentian or Algoman in age.

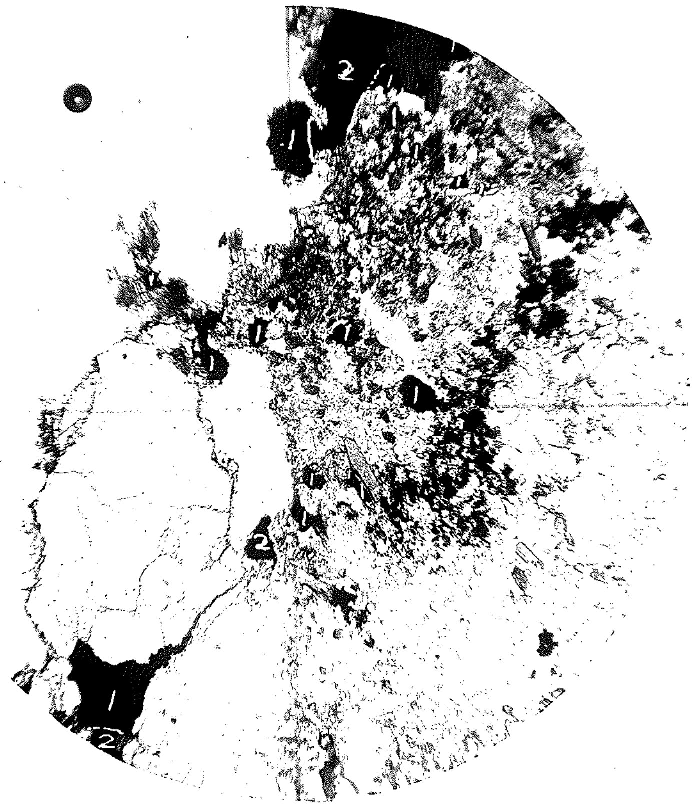

Fig. 3. Photomicrograph of vein showing gold associated with pyrrhotite and quartz. 1. gold; 2. pyrrhotite. The colorless mineral is quartz. Magnified 45 diameters. Penniac Reef Gold Mine.

MICROSCOPIC CHARACTERISTICS OF THE GRANITE.

A comparison of the microscopic characteristics of both granites may be of interest in view of the necessity of obtaining microscopic criteria for the mapping of Laurentian and Algoman. Under the microscope, the Laurentian granite northwest of Star lake is seen to consist chiefly of quartz, orthoclase and microcline. There are patches of secondary as well as primary quartz. Muscovite, green hornblende, and brown biotite with included crystals of apatite and zircon are present. Accessory minerals are haematite, and sphene altered to leucoxene. Felspar crystals contain numerous simaltaneous extinguishing inclusions of quartz. The rocks shows the effect of strain in its broken crystals and shadowy extinctions.

A section from a very basic phase of the boss was used for microscopic study. It is composed chiefly of felspar; microline, albite, and orthoclase being the most abundant. A few small crystals of more basic plagioclase were also seen. Flakes of brown biotite and grains and flakes of arvedsonite were present. Of the accessories, apatite is very abundant. The felspar presents a peculiar brecciated appearance resembling perthite. Shadowy extinctions of the felspar show that the rock had been subjected to strain.

A much more acid modification of the boss is shown in the dykes which occur along the contact. A specimenfrom one of these dykes shows much quartz, some orthoclase and plagioclase, small flakes of biotite and hornblende, and a little arfvedsonite. Accessories are apatite, zircon and iron oxides. The rock shows extreme effects of strain; the larger crystals are crushed and the resulting granules give shadowy extinctions.

The fact that the boss contains sodic amphiboles and feldspar and the very little quartz suggests that it was perhaps originally an elaeolite syenite. It will be observed that the mineralogical differences between the Laurentian granite and the boss are exceedingly marked. Attention has not yet been directed to a study of the chemical and mineralogical criteria if such exist, by which Laurentian and Algoman granites may be distinguished. As the major tectonic movements of Pre-Cambrian times had ceased before the end of the Middle Huronian stage, it is to be expected that the Algoman granites will reveal fewer evidences of strain than the Laurentian plutonics. It is unlikely on the other hand that internal evidences will be available (such as less well defined pleochroic halos), to indicate that the Algoman plutonics are of much younger age than the Laurentian. From the chemical point of view, differences may well exist because of the fact that the Algoman granites have absorbed in the main acid sediments, while the Laurentian batholiths assimilated by overhead stoping basic volcanic material.

	1.	2.	3.
SiO_2	47.45	56.96	43.42
Al_2O_3	23.67	21.65	22.37
$Fe_2O_3 + FeO$	9.09	3.39	10.06
CaO	10.80	1.75	13.08
MgO	4.46	.56	5.75
Na_2O	3.03	8.81	1.24
K_2O	.84	6.56	1.43

(1) Basic phase of the boss.

(2) Elaeolite Syenite. Daly. Igneous Rocks & Their Origin, p.24.

(3) Gabbro-diorite. F.W.Clarke, Bull. 419. U.S.G.S. p.32.

For chemical analysis a specimen of the boss was taken in an area showing extreme assimilation of basic Keewatin rocks. The high percentage of alumina and the low percentage of silica are characteristics of sodic rocks. On comparing the results of the analysis with that of the elaeolite syenite (2), the higher percentage of ferric oxide, calcium oxide and magnesium oxide are readily explained by the fact that these constituents are important ingredients of the Keewatin rock that was absorbed. If the composition of the rock that was absorbed be approximately that represented by analysis (3), the low percentage of silica in the plutonic rock is at once accounted for. The percentage of alumina would remain practically unaltered.

MINERALIZED CONTACT ZONE.

Along the contact between the sedimentaries and the northern side of the intrusive boss there is a sulphide zone or fahlband of variable width, extending on an average about 200 feet into the conglomerate. Of the metallic minerals present pyrrhotite and arsenopyrite are the most common. Pyrite and chalcopyrite occur to a subsidiary extent.

The pyrrhotite is present as small patches disseminated throughout the rock, and as flaky bands infilling small fractures. These patches are irregular in shape and are seldom more than half an inch in diameter. They decrease in size farther from the contact and at the side of the fahlband farthest from the boss, the pyrrhotite is present only in microscopic grains. Beyond this zone the iron occurs in the form of small grains of iron oxides. As the distance from the boss increases there is a gradation from numerous large patches of pyrrhotite to scattered microscopic grains, and finally to iron oxides.

The arsenopyrite occurs in small white flakes. It is also combined in small quantity with the pyrrhotite.

In the analysis of pyrrhotite with some admixture of arsenopyrite, 5.10 per cent of arsenic was obtained. In the immediate vicinity of the Pontiac Reef Gold Mine pyrrhotite is the commoner mineral, but at a few other properties in the district arsenopyrite is more extensively developed.

The similarity between the Hedley Mining district (Charles Camsell. Mem. No. 2. Geology & Ore Deposits of the Hedley Mining District, B.C.) and the Star Lake district is worthy of comment.(a).

ORIGIN OF THE PYRRHOTITE.

The pyrrhotite was evidently formed at a comparatively early stage of the intrusion. It was present in the zone prior to the formation of the quartz veins as the amount of pyrrhotite present while it varies inversely with its distance from the boss, is only slightly if at all affected by the quartz veins.

The fact that the pyrrhotite is collected in bunches and that these bunches are disseminated throughout the rock, suggests that the sulphide was carried in solution as such. Precipitation may have begun with iron oxides as nuclei, the iron oxides being converted during precipitation into pyrrhotite. The points of initial precipitation would then grow by abstraction of pyrrhotite from the supersaturated solution around them, consequently bunches of the mineral would be formed. The fact that the boss, and the quartz veins derived from it contain pyrrhotite, shows that the pyrrhotite was actually present in the magma.

(a) In the Hedley mining district the mineralization was due to a basic intrusion. Arsenopyrite, pyrrhotite, chalcopyrite and pyrite are present in the mineralized zone. Pyrrhotite is disseminated throughout the rock in the form of irregular bunches. The minerals were derived from the magma as emanations of water and metallic substances originally contained in the magma but released by diminution of pressure in reaching higher levels.

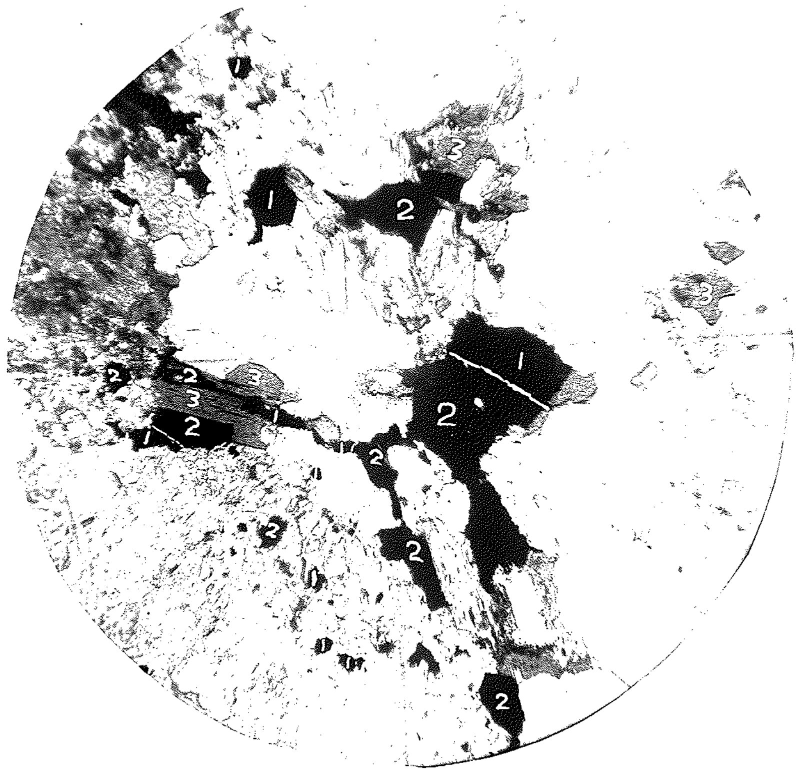

Fig. 4. Photomicrograph of vein showing gold associated with pyrrhotite. 1. gold; 2. pyrrhotite; 3. biotite. The colorless mineral is quartz. Magnified 45 diameters. Penniac Reef Gold Mine.

On the other hand, although it is probable that most of the pyrrhotite near the contact was derived from the magma as such, it is also probable that much of this sulphide especially at some distance from the contact was formed by the action of magmatic gases and solutions on iron compounds present in the schist. The conditions necessary for the formation of pyrrhotite have not been fully worked out. It has been shown however that a strongly reducing atmosphere is necessary. Doelter[I] prepared pyrrhotite by acting on solutions of ferrous chloride and carbonic acid with hydrogen sulphide, at a temperature of 250°C. He also prepared pyrrhotite by the action of hydrogen sulphide on solutions of ferrous sulphate, ferrous carbonate and ferrous silicate. Magmatic gases such as hydrogen sulphide might possibly act on the iron oxides to form pyrrhotite under conditions of high temperature and pressure. Thin sections taken from the margin of the sulphide zone farthest from the boss show grains of an opaque mineral composed partly of iron oxide and partly of pyrrhotite. It would appear that the oxide has been partially altered to pyrrhotite. The grains of pyrrhotite near the edge of the sulphide zone are comparable in size with the grains of iron oxides farther from the contact, and were probably originally iron oxides. The fact that within the sulphide zone as far as 100 feet or more from the contact no iron oxides are seen shows that they have been altered to pyrrhotite. In brief, it would appear that while near the contact pyrrhotite as such had been supplied from the magma to the sediments during the intrusive process, at greater distances from the magma the pyrrhotite that occurs is due to transformation of iron oxides that were present in the sediments before the metamorphic process began.

I Tschermaké Mittheilungen, vol. Vll.pp.85,86. cited by C. W. Dickson in " Ore Deposits of Sudbury District".

(a) Pyrrhotite is developed to a great extent at the contact. Large quantities of pyrrhotite do not indicate high values in gold.

QUARTZ VEINS.

The quartz veins near Star lake are not of the true fissure type. They are very irregular and in some cases seem to be merely enrichments of silica along planes of weakness. The imperceptible gradation of quartz into country rock and the absence of any definite vein walls, show that they were formed to a very large extent by replacement. Definite cracks must have existed in some cases however, as several of the quartz leads cut across the strike of the country rock. As the conglomerate is low in silica lateral secretion has played little or no part in the infilling of the veins. Outside the fahlband quartz veins are to be found only as narrow stringers.

The quartz vein on which work is being done in the Penniac Reef Gold Mine, occurs at the contact between the boss and the conglomerate. Granite offshoots from the magma are cut by it in several places. The quartz vein is about 2 feet wide and usually grades imperceptibly into country rock with no trace of a wall on either side, though sometimes a fairly definite foot wall is seen. The lead consists of a series of lenses, and in some places it is split into several parallel stringers, separated by highly silicified country rock a few inches thick.

From microscopic study it is seen that the minerals present in the vein are quartz, felspar, biotite, chlorite, pyrrhotite, garnet, sphene, calcite, zircon, and gold. In other parts of the Star lake district Molybdenite and galena occur as well. It is said that platinum has been found in the gold of the Penniac Reef Gold Mine. The quartz has an extremely dusty appearance which is due to minute crystals of iron oxides, and of some anisotropic transparent mineral probably quartz, surrounded in each case by a dark border. Quartz deposited at two widely different times is present in the slides, the latter deposition taking place in small fractures in the earlier material.

(See fig. 5). The quartz grains of the earlier material are small and have irregular outlines. They are strikingly uniform in size. The appearance of the slide would point to a large number of crystallization centres, all initiated at about the same time. The quartz of the latter deposition is very fine grained.

The felspar present was decomposed to such an extent in the sections studied as to render identification impossible. Flakes of quartz giving simultaneous extinction occur frequently in the decomposed felspar.

The biotite shows pleochroism from very light brown to dark brown. In places it is altered to chlorite. Pleochroic halos around included crystals of zircon are characteristic. Allotriomorphic sphene occurs in several patches. Pyrrhotite and melanite are also allotriomorphic. Calcite is rare and is found surrounding quartz and lining fractures.

The gold occurs native in the quartz in grains easily visible to the naked eye. In the thin sections studied it was noted that although the gold was perhaps most frequently surrounded by quartz, very often it was associated with pyrrhotite or garnet (see fig.2,3,4,). In hand specimens it is ~~to be~~ seen that the rich values in gold lie along definite lines in the quartz. The association of gold with garnet occurs rather frequently, too frequently to be accidental. Gold has been found associated with garnet in other districts as well, and is reported as often appearing as inclusions in the garnet.[I]

I Becker in 16th. Annual Report.U.S.G.S. Pt. 3, 1895, p.297. cited by J.M.MacLaren.

In this connection MacLaren[I] says, " It is not difficult from the general principles of metasomatic replacement to construe this association to denote a deposition of gold in situ prior to the formation of garnet followed by contact metamorphism arising from the granitic intrusion." It may be supposed that in the district under investigation one of the solutions reacting to form garnet was a solvent of gold. Under these conditions if gold were present it would be precipitated together with the garnet. Sodium silicate is a solvent of gold. If this solution reacted with ferric chloride in the presence of calcium carbonate at high temperatures and pressures, garnet might be formed according to the following equation.

$$3Na_2O\,SiO_2 + 2FeCl_3 + 3CaCO_3 = Ca_3Fe_2(SiO_4)_3 + 6NaCl + CO_2$$

Gold is also frequently associated with pyrrhotite. Carbonic acid in the presence of an alkaline carbonate decomposes metallic sulphides at great depths giving alkaline sulphide solutions. These are solvents of gold and of the sulphides of the heavy metals. If such a solution contained iron, and if the temperature were sufficiently high, in a reducing atmosphere pyrrhotite and gold would be precipitated together.

In the later deposition in the veins are found such minerals as quartz, pyrrhotite, garnet, sphene, biotite, calcite and gold. The percentage of gold found in this material is far greater than in that of the earlier crystallization. The gold, pyrrhotite, biotite, and garnet were deposited about the same time and were the first to crystallize. Biotite formed usually at a slightly later stage than the other three minerals.

[I] J.M.MacLaren, Gold, p.589.

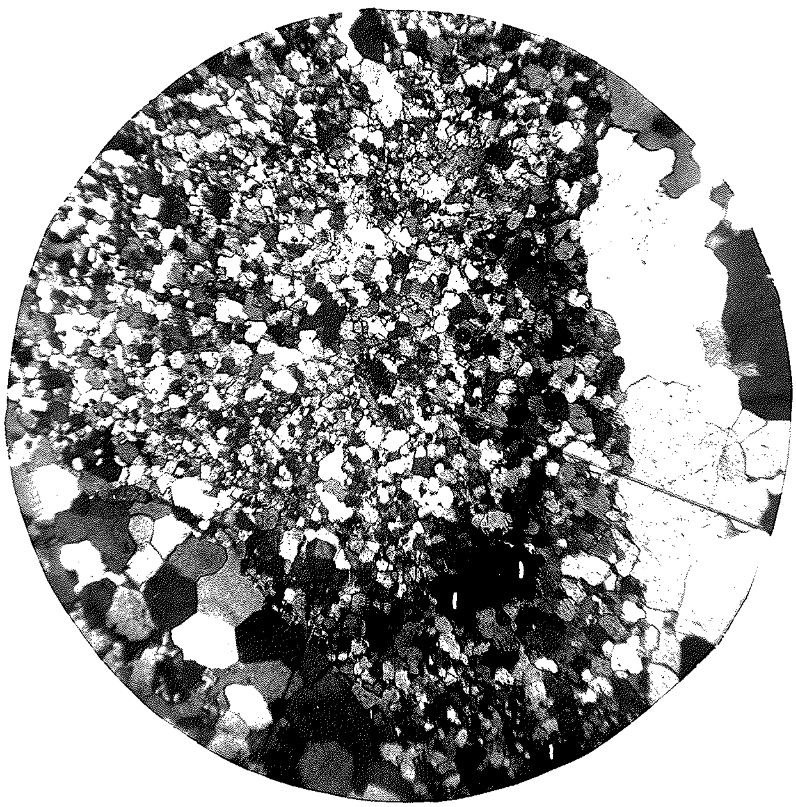

Fig.5. Photomicrograph of vein showing a fracture infilled by fine-grained quartz. 1. gold. Crossed nicols. Magnified 45 diameters. Penniac Reef Gold Mine.

The presence of such minerals as calcite, sphene and melanite in the latter material in the veins indicates a higher percentage of lime than in the first crystallization. As the biotite shows pleochroic halos this material was not derived from lateral secretion but came very probably from a magmatic source.[a]

	1.	2.
SiO_2	92.00	64.52
Al_2O_3	.35	4.04
Fe_2O_3	3.80	7.30
CaO	.23	6.12
MgO	.42	1.65
Na_2O		4.06
K_2O		.89
S	2.20	.84
As	.92	

(1) Quartz vein. Penniac Reef Gold Mine. Colorada Assay Co.

(2) Granitic rock associated with quartz vein, frequently as wall rock.

Analysis (2) represents a granite high in soda. This is a further example of the association of sodic rocks with gold deposits.

(a) Apart from the presence of pyrrhotite it is interesting to note the resemblance between quartz veins in the Star lake district to those in the Porcupine gold area. (A.G.Burrows, Ont. Bur. of Mines, Pt.1, 1912. pp. 222-228.) The quartz veins have no definite walls; the gradation from quartz into country rock often being impreceptible. Crushed zones and minute fractures infilled by later solutions occur frequently in the original quartz. Practically all the gold in the veins was deposited by the later solutions in these crushed zones and fractures.

PRESSURE AND TEMPERATURE CONDITIONS.

Assuming that the quartz veins were derived from the magma at a later stage in its solidification, a rough estimate can be formed of the maximun if not ~~of~~ the actual thickness of rock under which the quartz veins were formed.

If the granite boss be ~~the~~ Laurentian in age the maximum thickness would be that of the Keewatin formation. Lawson[I] has estimated the average thickness of the Keewatin in the Rainy lake district as 23,700 feet. Van Hise and Leith[II] doubt the correctness of this estimate as they beleive that there is a ~~xxxxxxx~~ repetition of strata in the sections studied by Lawson. Their estimate would consequently be lower than that of Lawson. If the boss be Algoman in age there would be added to the maximum thickness that of the Middle Huronian.[III] The thickness of the Middle Huronian in the Marquette district has been estimated as 3000 feet.[IV] Consequently, if in the district under consideration a similar thickness of Middle Huronian rocks be postulated, there would be a total thickness of 26,700 feet of rock.

In estimating the temperature during deposition of the gold the pressure of the superincumbent rock must consequently not be neglected.

I A.C.Lawson, Geol. of the Lake of the Woods Region, p. 108.

II Van Hise & Leith, Geol. of the Lake Sup. Reg.U.S.G.S. vol. LII,p.145.

IV Van Hise & Leith, Bull. 360, U.S.G.S. p. 336.

III Van Hise & Leith, Geol. of the Lake Sup. Reg. vol. LII. p.146.

On the basis of the small temperature gradient of 1° C. per 100 feet in depth, the maximum temperature due to depth would be about 240° C. for a thickness of 23,700 feet, and about 270° C. for a thickness of 26700 feet. Even if the thickness be halved the quartz veins would still be well within the limits of deepseated deposits.

As field evidence that deposition took place under high pressure the following points may be noted: The intrusive rock is microcrystalline and panidiomorphic. The quartz leads are in the form of narrow lenses following the strike of the country rock. The walls are very ill-defined.

The temperature at the time of the intrusion even at some distance from the contact, would be considerably higher than that due to rock pressure. At ordinary pressures and at temperatures above 565° C. iron sulphide, whether formed directly from magmatic solutions, or indirectly by the action of magmatic gases on iron oxides, crystallizes invariably as pyrrhotite. Under great pressures the temperature of alteration of pyrite into pyrrhotite would be considerably higher. Allen, Greenshaw and Johnson[I] have shown that above 565° C. pyrite changes to pyrrhotite in a reducing atmosphere. Below this temperature unless in a very strongly reducing atmosphere pyrrhotite is unstable. Consequently in order to account for the extensive development of pyrrhotite and the lack of pyrite in the country rock near the contact, it must be assumed that the temperature was considerably above 565°C.

I Allen, Greenshaw, Johnson & Larson. The Mineral Sulphides of Iron, p. 194.

Allen, Greenshaw & Johnson believe that pyrrhotite is a solid solution of ferrous sulphide and sulphur. In their synthesis of pyrrhotite they found that the higher the temperature of formation of the pyrrhotite the lower was the percentage of dissolved sulphur. On this basis it would be possible from chemical analysis of the mineral to estimate the temperature of formation of pyrrhotite in nature. The chemical composition would depend as well on the pressure. At higher temperatures some of the sulphur ~~would~~ escapes. Increase of pressure especially if sulphur were present in the neighborhood would retard this action, consequently, the temperature at which pyrrhotite of a definite composition forms in nature increases with increase of pressure.

Analyses of the pyrrhotite at the Penniac Reef Gold Mine gave the following results.

SiO_2	—	7.65
Fe	—	53.06
S	—	33.89
As	—	5.10

The arsenic present was possibly due to admixture of arsenopyrite. On subtracting the silica, the arsenic and the equivalent iron and sulphur, the iron and sulphur remaining are present in proportions corresponding to the formula Fe_5S_6. This according to above considerations would represent a solution of 4.1 per cent of sulphur in ferrous sulphide, and would form under ordinary pressures at 800° C.[I] Owing to the impurity of the material such figures must be considered as only approximate. Pure pyrrhotite may however be profitably utilized as a geological thermometer.

I Allen, Greenshaw, Johnson & Larsen, The Mineral Sulphides of Iron, p.201

In the quartz veins though formed later and at a lower temperature than the sulphides in the country rock, the presence of such minerals as biotite, melanite, muscovite, magnetite, sphene and pyrrhotite, points unmistakably to high temperatures of deposition.

SUMMARY.

Summarizing briefly the following conclusions may be drawn:

1. The rocks present in the district are referred to Keewatin, Laurentian and probably Algoman formations. A band of conglomerate of considerable thickness associated with Keewatin greenstones is held on structural and lithological grounds to be Keewatin in age.
2. There is a well defined mineralized contact zone in the sediments. This zone is highly impregnated with pyrrhotite. Deposition of gold has taken place only within this zone.
3. The pyrrhotite in the sulphide zone was in part precipitated from the magma and is in part a transformation product of iron oxides through the agency of magmatic gases.
4. A relatively small amount of gold was precipitated during the original infilling of the quartz veins. A much greater amount of gold was deposited from later solutions. The solvents were alkaline silicates and alkaline sulphides.
5. The veins are true deep seated deposits. Temperature and pressure were at the time of deposition abnormally high.