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WALL ROCK ALTERATION IN THE NIPISSING DIABASE SILL COBALT, ONTARIO

by

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Scope and contents of this thesis:

A petrographic description of the wall rock alteration bordering joints and veins in the Nipissing diabase sill at Cobalt, Ontario; a comparison with Butte, Montana, and a proposed mechanism to account for the observed alteration sequences. Illustrated with photographs, photomicrographs, and maps.

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CHAPTER I

Introduction

During the field season of 1950, Dr. R. Thomson, Resident Geologist for the Ontario Department of Mines at Cobalt, suggested as material for an M.Sc. thesis, the wall rock alteration bordering quartz-carbonate veins in the Nipissing diabase sill. While mapping, the writer had the opportunity to see much of this type of alteration and to collect a representative set of specimens from surface outcrops, mine dumps, and from underground mine workings.

The alteration, as illustrated in Figure 1, consists of a narrow black band immediately adjacent to the vein, followed outward by a white band; the alteration is more evident on a wet or weathered surface. It occurs along veins and joints only in the Nipissing diabase sill and always shows the same succession outward: quartz-carbonate vein or joint, black zone, white zone, except where overlap of alteration effects has eliminated the lower grade mineral assemblage. Each of the alteration zones averages from 1½ to 2 cms. wide, the contacts between the two bands of alteration and between the white zone and unaltered diabase being gradational. The alteration zones almost always show good bilateral symmetry about the vein or fracture.

This type of wall rock alteration is present irregardless of the geographical location of the vein or joint in the diabase sill. For example, the writer has seen it on the 649-foot level of the Temiskaming mine which is very close to the top of the sill, as well as on the 270-foot level of the Shag Silver mine and in surface outcrops of the diabase on the west side of Peterson Lake in lot 5, Con. V of Coleman Township, both of which are close to the lower contact of the sill. It also occurs on the 1125-foot level of the Castle-Trethewey mine in Gowganda although it is not prominently developed there.

Two other important generalizations can be made. The first is that this type of wall rock alteration is not restricted to any one type of quartz-carbonate vein in the diabase. For example, it occurs along veins containing silver and ruby silver as on the 649-foot level of the Temiskaming mine, as well as along chalcopyrite-pyrite-hematite veins as at the Hecla and Kirk Budd mines. Secondly, the alteration occurs along productive veins (as at the Temiskaming mine) and along unproductive veins (or at least along an unproductive part of a vein) as at the Shag Silver mine.

As far as outward appearances are concerned, then, the wall rock alteration along fractures and quartz-carbonate veins is consistent throughout the sill, showing the same relation between the two zones of alteration, and occurring irregardless of the location of the vein or fracture in the sill, or the type of vein, or whether the vein is productive or unproductive. Laboratory work, however, has shown that there are noticeable variations in the mineral assemblages forming the two zones of alteration depending on the location of the specimen. It is for this reason that this study must be regarded only as a preliminary survey of the wall rock alteration in the Nipissing diabase sill at Cobalt. Much more will have to be done on this type of alteration before a complete understanding of the problem is achieved.

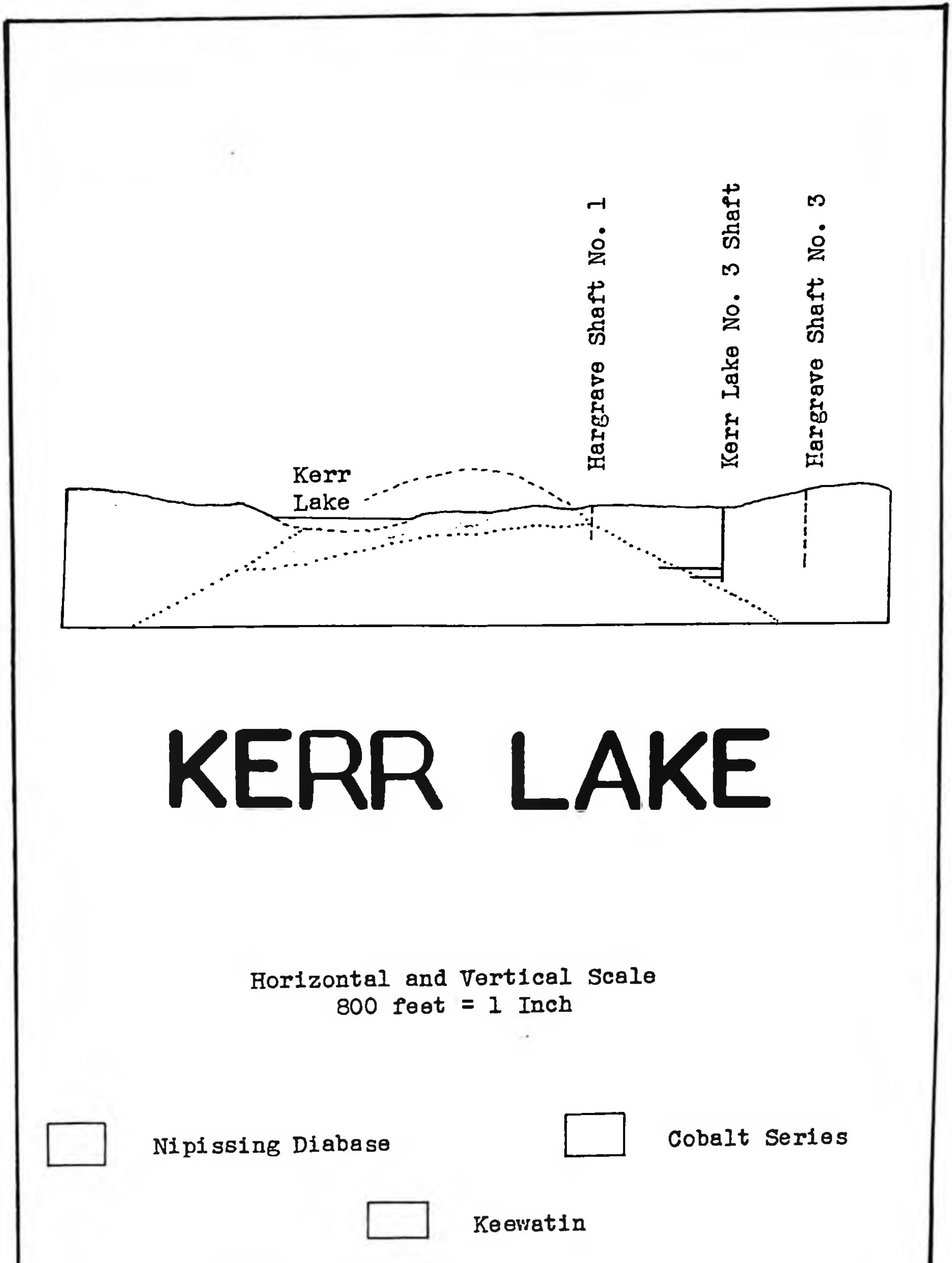
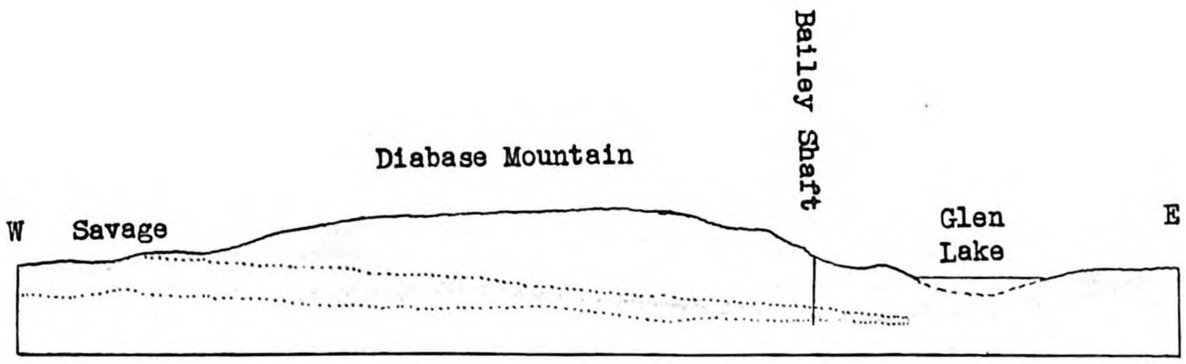


Figure 2

After Miller (1913)

General Geology of the Cobalt Area

The oldest rocks in the Cobalt district, the "Keewatin", are a complex of acid and basic lavas with associated pyroclastics and slate bands, all of which have been highly altered and isoclinally folded. Upon these rocks were laid the Timiskaming sediments which now dip at steep angles also. The Timiskaming series is not prominently developed at Cobalt but good exposures are found at Haileybury and New Liskeard a few miles north of Cobalt. The above two series are cut by dikes and sills of lamprophyre, peridotite and diabase generally assigned to the Haileyburian. The above rocks were then intruded by the Lorrain granite of Algoman age, of no economic importance in the Cobalt district. A prolonged period of weathering and erosion then took place followed by the deposition in Huronian times of the Cobalt series of conglomerate, quartzite, greywacke, slate, and arkose, possibly of glacial origin. These sediments are practically undisturbed with dips generally less than 30°. This series is very important economically since most of the ore to date has occurred in veins in these sediments. The Nipissing diabase was then intruded in Keweenawan times into the above series in the form of a sill about 1000 feet thick and is itself cut by dikes of "aplite" and olivine diabase. Limestone, shale, sandstone and conglomerate of Silurian and Ordovician age outcrop north of Cobalt at Haileybury and New Liskeard and are separated from the Precambrian rocks by a great unconformity.



DIABASE MOUNTAIN

☐ Nipissing Diabase ☐ Cobalt Series ☐ Keewatin

Horizontal and Vertical Scale
800 feet = 1 Inch

Figure 3

After Miller (1913)

Mineralogy and Ore Deposits

Since its discovery on August 7, 1903 Cobalt has produced over 390,000,000 ounces of silver, ranking third among the great silver camps of the world. The Timiskaming area, including Cobalt, Gowganda, South Lorrain, Casey Township, Maple Mountain, etc., has produced over 442,000,000 ounces. The productive veins are narrow and discontinuous but exceedingly rich, high-grade sections often assaying up to 10,000 ounces of silver to the ton; the veins occur in joints and faults with some associated replacement. Although a vein may contain irregular patches of cobalt arsenides and native silver along most of its length, the valuable portions occur in shoots generally less than 1000 feet long and about 500 feet in depth. Silver occurs mainly in the native form although it is also found in dyscrasite, argentite, and the ruby silvers as well as in several rare sulfo-salts. Associated with the silver are skutterudite, cobaltite, löllingite, arsenopyrite, niccolite, breithauptite, minor chalcopyrite-galena-sphalerite, and many rarer minerals. Opinions concerning the paragenesis of the ores vary but in the latest work on the Cobalt camp, Bastin (1950, p. 812) gives the following paragenesis as determined from ores from several of the Cobalt mines:

Older calcite	———						
Cobaltite		———					
Lollingite			———				
Smaltite			———				
(Fracturing)				xxxxx			
Niccolite					———		
Breithauptite					———		
Silver						———	
Argentite						———	
Younger calcite							———

Most of the silver is considered to be primary in origin although at the

Keeley mine in South Lorrain, Bell (1923, p. 694) states that a "substantial part of the silver in certain of the rich shoots of the Keeley is secondary and derived from the impoverished highly oxidized upper portions of the veins".

The production of silver from the three main rock formations of the area is given by Reid (1943, p. 4) as follows:

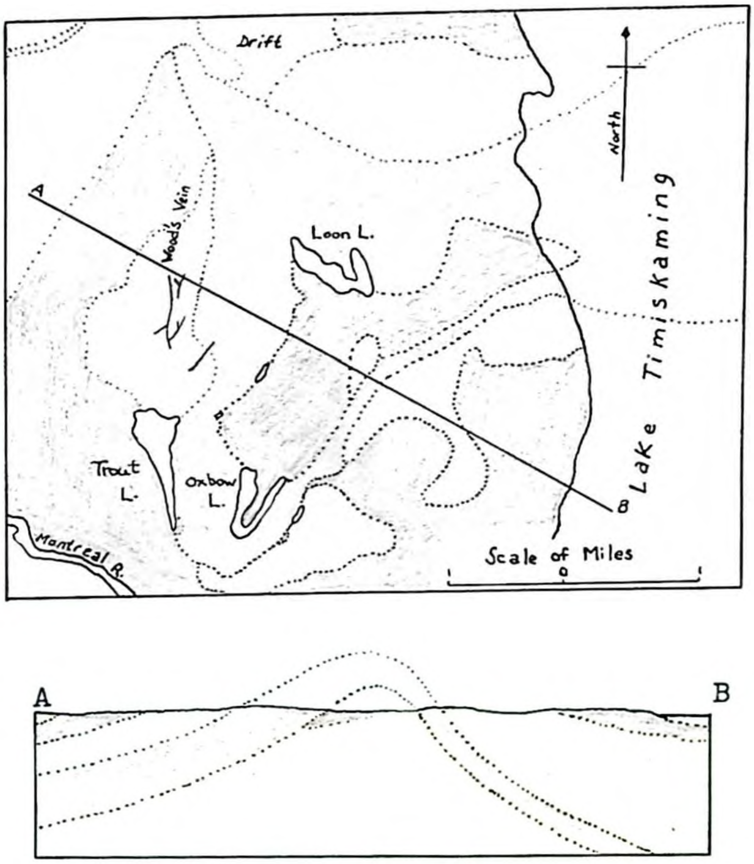
Cobalt sediments	77%
Keewatin	13%
Nipissing diabase	10%

These percentages, however, are currently changing in favour of the Keewatin and Nipissing diabase.

Nipissing Diabase

At Cobalt, the Nipissing diabase occurs in the form of a gently undulating sill about 1000 feet thick; cross-cutting relationships with the older rocks of the area are common. The contacts generally dip at low angles although, locally, dips are steep as, for example, in the vicinity of Kerr Lake, illustrated in one of the accompanying sections. In South Lorrain Township, the sill is 875 feet thick, and at Miller Lake in Gowganda, 1250 feet (Reid, 1943, p. 4). According to Knight (1924, p. 34), the sill at Cobalt was probably intruded from the southeast towards the northwest, evidence for this being found at the Beaver mine where a large block of granite was caught up in the sill, in all probability from the outcrop of Algoman granite a few hundred yards to the southeast.

Generally speaking, the sill is a quartz diabase although Satterly has shown it to consist of a number of phases, gradational into other. For the Kerr Lake (lower contact) to Brady Lake (upper contact)



SOUTH LORRAIN

☐ Nipissing Diabase

☐ Cobalt Sediments

☐ Keewatin

☐ Lorrain Quartzite

☐ Algoman Granite

⧄ Veins

Figure 4 After Bruce (1933)

section of the sill, Satterly (1928, pp. 16-17) describes the following phases and their thicknesses:

Quartz diabase	30 ft.	(1000 ft. - 970 ft.)	upper contact
Hybrid and coarse types	380 ft.	(970 ft. - 590 ft.)	
Quartz diabase ?	140 ft.	(590 ft. - 450 ft.)	
Quartz norite	350 ft.	(450 ft. - 100 ft.)	
Quartz diabase	100 ft.	(100 ft. - 0 ft.)	lower contact

Locally, an olivine-rich phase is developed occurring close to the lower contact. Areas of pink micropegmatite and narrow "aplite" dikes cutting the diabase are common in the Elk Lake region and have been explained as due to differentiation (Hore, 1911, and Collins, 1917) or to hydrothermal replacement (Bowen, 1910, and Bastin, 1935).

According to Satterly, the thickness of any one of these phases may control the development of silver ore shoots. From field work it appears that the typical quartz norite phase may be considered a barren phase and wherever it occurs, no silver will be found.

> The depth to which ore shoots will extend in the upper portions of the sill is controlled by the thickness of the quartz gabbro phase. Where it is poorly developed the ore will be shallow, and if it reaches its maximum thickness shoots may be found in the sill 500' from the upper contact. (Satterly, 1928, p. 28).

The main petrographic change in the sill is in the composition of the plagioclase which becomes more sodic in the upper portions of the sill. Flow structure is not evident although "in one case the laths of plagioclase more or less paralleled the contact" (Satterly, 1928, p. 8). Columnar jointing is well displayed in the diabase of Diabase Mountain at Cobalt, and circular jointing is developed in the diabase in the Gowganda area. Some writers regard the quartz norite of the Nipissing diabase sill at Cobalt as the beginning of the development of this phase "which reaches its culmination as norite to the southeast in the Sudbury field, where it is associated with the important nickel-copper deposits" (Satterly, 1928, p. 28). Several cross-sections are included throughout Chapter I of this thesis. These are designed to illustrate the occurrence of the Nipissing diabase sill in the Cobalt and outlying silver camps.

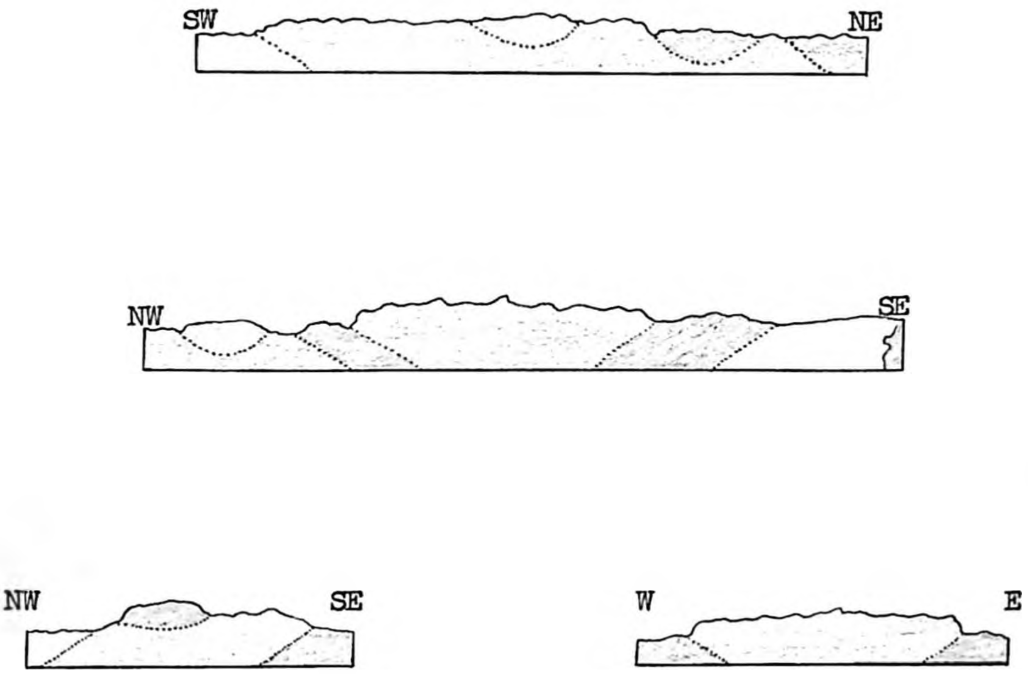
Relation of the Nipissing Diabase Sill to the Ore

The intimate relation between the Nipissing diabase sill and the silver ore has been recognized for a long time. Four mines had their total or a large part of their production from this formation: the O'Brien mine at Cobalt, the Wettlaufer mine in South Lorrain Township, and the Miller Lake O'Brien and Castle-Trethewey mines in Gowganda. The No. 3 Vein of the Kerr Lake mine, which occurred in diabase, produced approximately 3,000,000 ounces of silver. The most important ore shoots currently being mined at the Silver Miller mine at Cobalt are in the diabase.

> In a broad, general way it may be said that the dominating factor in the deposition of the ore-shoots is the Nipissing diabase sill. Wherever silver ore occurs, there also will be found the Nipissing diabase. No silver ore-shoots occur in the entire camp where the diabase sill is absent. (Knight, 1924, p. 6).

The earliest geologists working in the Cobalt camp thought the ore deposits to be genetically related to the Nipissing diabase itself but further work has shown that it is much more likely the ore came from a deeper-seated source, possibly a parent magma giving rise both to the ore and to the diabase.

> The Nipissing diabases were not only completely crystalliz but had been fractures by faults, some of them of considerable displacement, prior to mineralization. It is unlikely, therefore, that the mineralizing solutions came from the diabase sills. . .



Horizontal Scale, 1 Mile = 1 Inch. Vertical Distances are not Drawn to Scale.

ANIMA - NIPISSING

▢ Nipissing Diabase

▢ Lower Cobalt Series

▢ Upper Cobalt Series

▢ Algoman Granite

▢ Keewatin

Figure 5

After Todd (1926)

> It seems probable that in the Cobalt and neighbouring districts . . . the solutions which deposited the ores and hydrothermally altered the rocks came from magmas of granitic or at most intermediate composition. (Bastin, 1939, pp. 39-40).

Previous Work on the Alteration at Cobalt

There is an extreme paucity of published material on the alteration at Cobalt, particularly with reference to the type of wall rock alteration described in this thesis. Various writers, notably Collins (1913, p. 78) and Thomson (1930) have mentioned the "spotting" in the Cobalt sediments, but as far as can be ascertained from a careful examination of the pertinent literature, Bastin (1925, p. 10, and 1935, pp. 727-730) is the only one who has recognized the wall rock alteration along quartz-carbonate veins in the Nipissing diabase sill. On page 4 of his 1925 paper, under wall rock alterations, Bastin writes:

> Two samples were collected from the third level [of the Frontier mine, South Lorrain] especially to show the character of the alterations where the wall-rock was Nipissing diabase. The vein was 4 inches wide and largely pink calcite. For ½ to 1 inch bordering the vein the diabase is slightly darker than normal. . . In the specimen immediately adjacent to the vein the diabasic texture is still recognizable, but augite, epidote and biotite have been completely altered to chlorite.

A more complete account of the wall rock alteration along quartz-carbonate veins in the Nipissing diabase sill is contained in Bastin's 1935 paper.

> At the Devils mine, Elk Lake, vein material on the dumps showed calcite, chalcopyrite, cobaltite, argentite, native silver, and cobalt and nickel bloom. To the unaided eye, the Nipissing diabase adjacent to the vein appears unaltered, but the microscope shows that although the texture is still diabasic the primary minerals have been almost completely altered. . .
>
> To learn whether similar wall-rock alterations characterize the diabase walls in the more productive districts, specimens of Nipissing diabase bordering veins in the Frontier mine at South Lorraine, collected by the writer in 1932, were studied.

> On the third level of the mine, samples of the diabase were taken immediately adjacent to a 4-inch vein and also 5 inches away from it. For ½ to one inch from the vein the wall-rock is somewhat darker than farther away. . . .

Whitehead (1920, Plate VIII, b) mentions wall rock alteration in several places in his paper but neglects to say what the wall rock is. Of particular interest to the problem discussed in this thesis are his remarks on page 132 under the source of the silver-cobalt arsenide veins at Cobalt:

> It seems, therefore, unreasonable to attempt to connect the origin of the veins with hydrothermal activity from the diabase itself. The metals may, however, have been derived from the cool diabase by leaching, but if this leaching were by circulating waters alteration along fractures and joints throughout the diabase would take place. No such phenomena have been observed.

His last statement is, of course, not true. The type of wall rock alteration studied in this thesis occurs not only along veins in the diabase but also along fractures and joints in this type of rock. This can be seen in surface outcrops of the Nipissing diabase on the west side of Peterson Lake in lot 5, Con. V of Coleman Township.

Acknowledgements

I should like to express my appreciation to Dr. Thomson who suggested the material for this thesis and who donated several photographs and two rock specimens. Thanks are also extended to Mr. L. J. O'Shaughnessy, operator of the Shag Silver mine, and to Mr. Wesley Preston, Mine Captain for Silanco at the Temiskaming mine, for their help and co-operation underground. I am also indebted to Mr. D. M. Shaw under whom this thesis was written for much help in the petrographic study of the slides, to Mr. H. S. Scott for assistance in the photographic work, and to Dr. H. S. Armstrong who kindly procured several reprints for the writer.

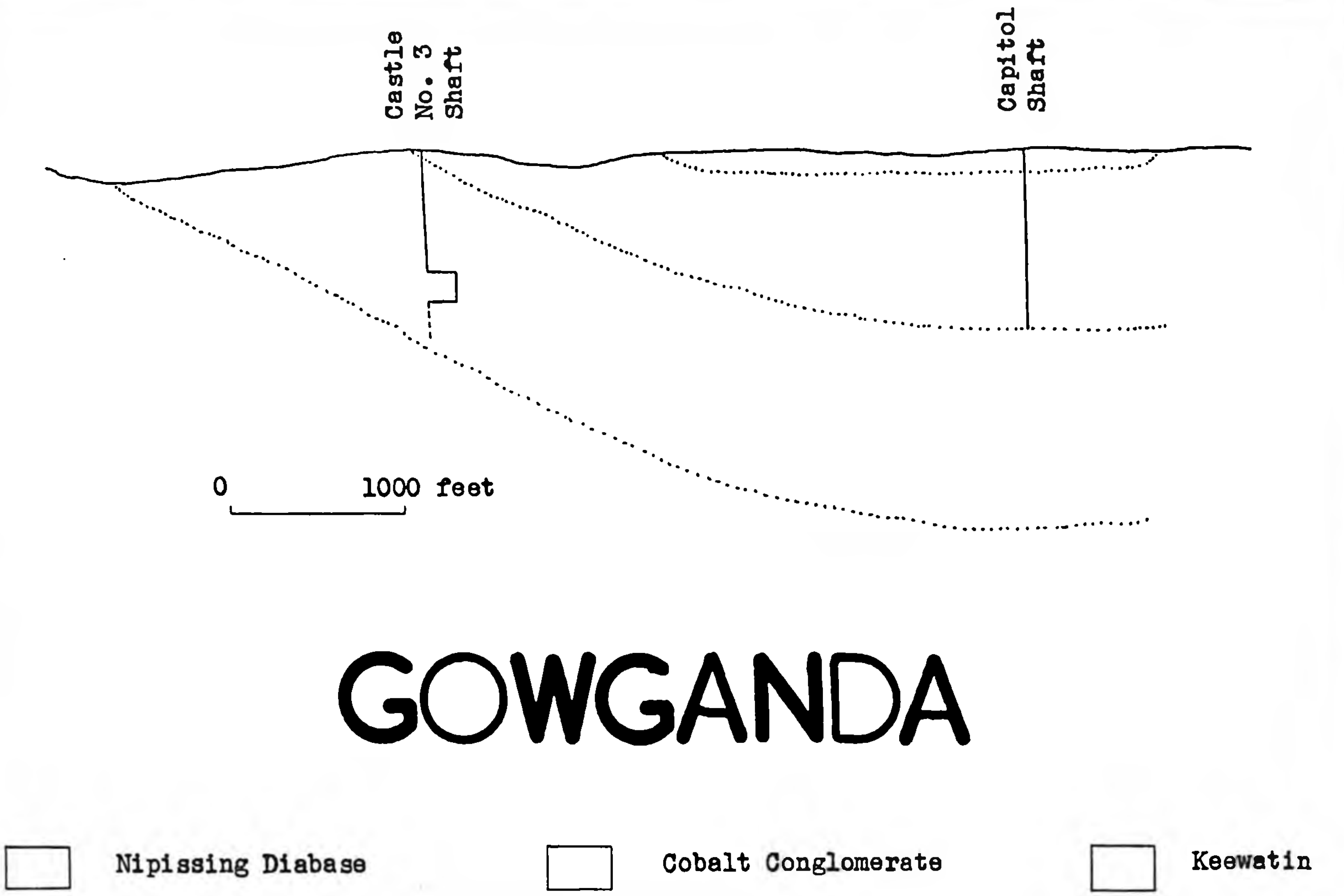


Figure 6

After Campbell (1950)

CHAPTER II

INTRODUCTION

Suites of specimens were collected from the following four localities:

Temiskaming Mine	lot 1, Con. III	Coleman Township
Hecla Silver Mine	lot 2, Con. X	Lorrain Township
Shag Silver Mine	lot 2, Con. V	Coleman Township
Hound Chutes	Block 25	Gillies Timber Limit

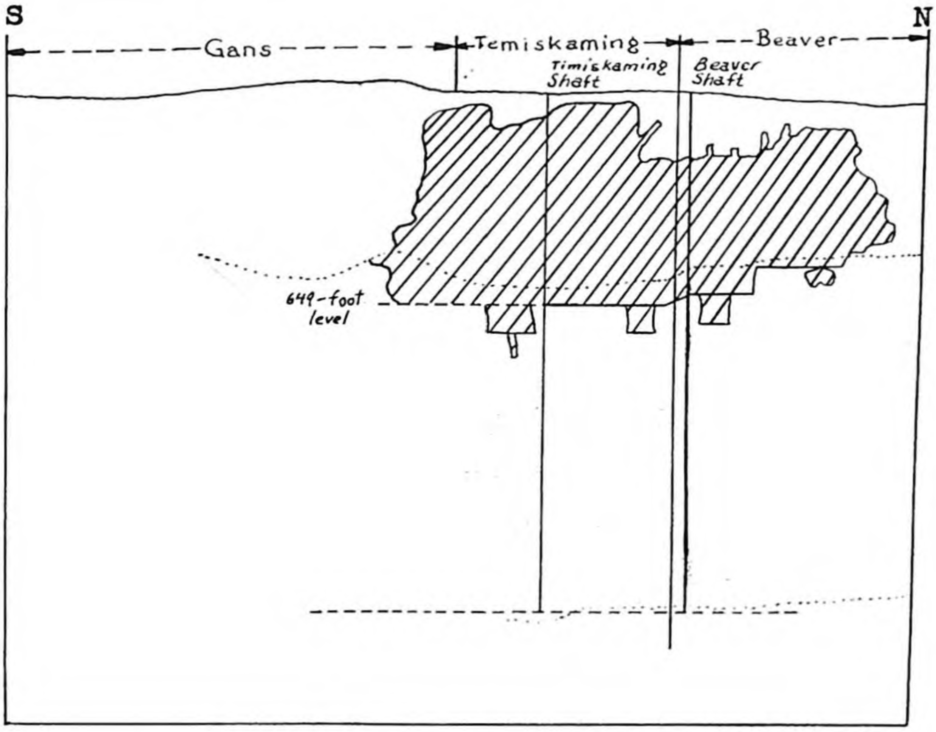
Additional information was obtained from specimens collected from the dump of the Kirk Budd mine in Block 8 of Gillies Timber Limit, and from prospect pits in the Nipissing diabase at the north end of Kirk Lake in lot 1, Con. X of Lorrain Township. Laboratory work consisted of examining 35 thin sections and three polished sections with the microscope and Federov Universal Stage in the usual manner.

TEMISKAMING MINE

The Temiskaming mine is one of the Silanco group of mines being wholly owned by the Silanco Mining and Refining Company Limited and is situated in lot 1, Con. III of Coleman Township. It is located in the northeast portion of the New Lake Basin, an area of "Keewatin" rocks underlain by the diabase sill. This area is the scene of most of the present silver production from Cobalt as it includes the highly productive Silver Miller and Cobalt Lode mines which are located one-half to one-quarter mile west of the Temiskaming claim. Extensive underground exploration is currently being carried on at the Christopher, Silver Banner (formerly the Victory) and Mayfair mines, all of which are in the New Lake Basin. The surface rocks of the Temiskaming mine are all "Keewatin" which strike approximately north-south and dip vertically. These are underlain by the Nipissing diabase sill through which the shaft has been sunk showing the sill to be 1000 feet thick. The Lorrain granite outcrops about 1,300 feet east of the main shaft but is not exposed underground. A generalized north-south section through the Temiskaming shaft is shown in Figure 7.

The vein system at the Temiskaming consists mainly of two parallel veins about 200 feet apart which strike a little east of north; this system is approximately 2,400 feet long. The productive part was terminated at the north on the Beaver claim by the Beaver Fault. All the ore at the Temiskaming mine occurs at the top of the sill and in the overlying "Keewatin", most of it having been mined from veins in the "Keewatin". As near as can be ascertained, the silver production from this mine totals about 12,000,000 ounces.

Specimens were collected by Dr. Thomson and the writer from the 649-foot level. The co-ordinates of the specimen collected by Dr. Thomson are 600 feet south, 600 feet east (Figure 8). The writer collected additional specimens from the same vein slightly southeast of the above co-ordinates. At this time (September 19, 1950) native silver and ruby silver were seen in the face and back of the drift.



Scale, 600 feet = 1 Inch

TEMISKAMING MINE

☐ **Nipissing Diabase** ☐ **Keewatin**

▨ **Stoped Areas**

Figure 7 After Knight (1924)

Vein

The vein studied averages 2 cms. in width and consists mainly of white to grey calcite with minor quartz, the latter occurring in subhedral crystals projecting out from the walls of the vein into the calcite which occupies the central portion of the vein. The calcite occurs in interlocking, anhedral grains averaging about 0.7 mm. in width. Although not seen in thin section, silver, minor chalcopyrite, and a black mineral possibly one of the ruby silvers are present. Along each wall of the vein is a zone about 2 mm. wide of slickensiding with the development of pennine chlorite (Figure 9). In places, the walls of the vein are also coated with a very thin film of ruby silver, locally known as "ruby wash".

Diabase

The relatively unaltered diabase forming the host rock for the vein consists of sodic labradorite and augite in about equal proportions with minor amounts of titaniferous magnetite, pyrite, biotite, apatite and interstitial quartz. The plagioclase and pyroxene have, however, been rather badly altered, the former to sericite and the latter to hornblende and thence to biotite. Titaniferous magnetite has been slightly altered to leucoxene, while pyrite, biotite, apatite, and quartz are unaltered.

Labradorite occurs in idiomorphic lath-shaped crystals between which the ferro-magnesian minerals are moulded producing the ophitic texture. In alteration, the interior of the plagioclase changes first. The reaction series augite to hornblende to biotite is probably a

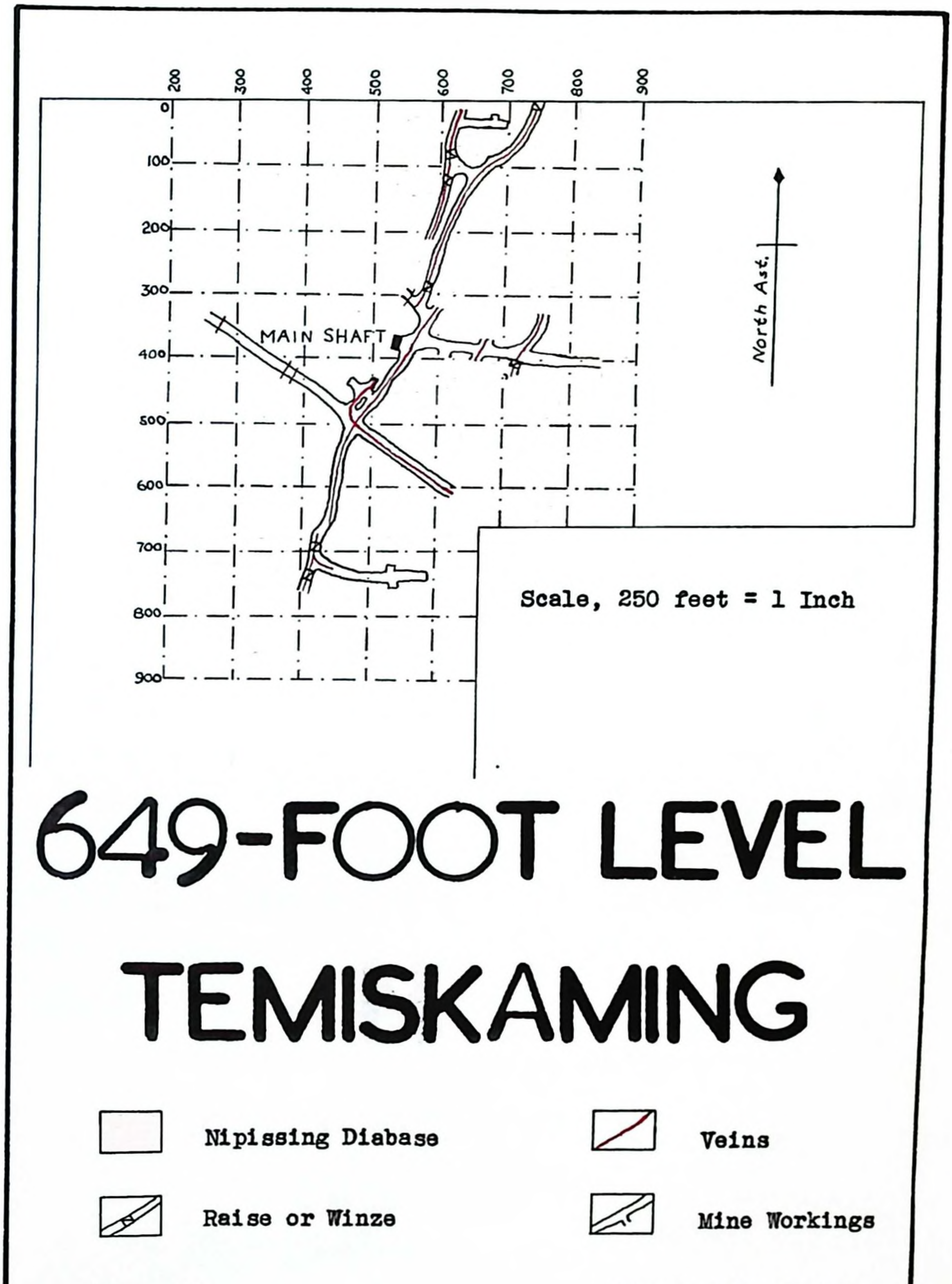


Figure 8

After Knight (1924)

deuteric one aided, perhaps, by the hydrothermal solutions; some of the biotite is, however, a primary constituent of the diabase. The alteration of titaniferous magnetite produces a grid-like structure, the titanium-bearing component altering to leucoxene.

White Band of Alteration

In the specimens examined, the white band of alteration averages about 2 cms. in width and has a noticeably greasy appearance. It is the more interesting of the two bands of alteration and represents the lower grade mineral assemblage. The contacts between the two zones of alteration and between the white zone and the wall rock diabase are gradational, in places over as much as 1 cm. Pyrite, apatite and quartz are unaltered in this zone and titaniferous magnetite has been more extensively altered to leucoxene. The feldspar laths have been severly sericitized with minor but noticeable amounts of epidote and clinozoisite.

The ferro-magnesian minerals have been altered mostly to fine-grained magnesium-rich carbonate with important amounts of epidote, clinozoisite and exuded magnetite (Figure 10); for purposes of this thesis, this assemblage is conveniently called "saussurite". Detailed examination of the slides with particular attention to textures makes it clear that it is the secondary hornblende and not the biotite which has altered to "saussurite". That is,

$$\begin{tikzcd}
 & \text{Biotite} & \\
\text{Augite} \arrow[r] & \text{Hornblende} \arrow[u] \arrow[r] & \text{"Saussurite"}
\end{tikzcd}$$

and not,

$$\begin{tikzcd}
\text{Augite} \arrow[r] & \text{Hornblende} \arrow[r] & \text{Biotite} \arrow[r] & \text{"Saussurite"}
\end{tikzcd}$$

Any grains of primary biotite remain unaltered in the white zone of alteration. The secondary hornblende has a somewhat fibrous appearance, is pleochroic from blue to green, and has slightly inclined extinction (maximum about 16°).

The white colour of this band of alteration is due to the presence of magnesium-rich carbonate, epidote, and clinozoisite (collectively called "saussurite"), the alteration products (in part) of both the feldspars and the ferro-magnesian minerals. This was first observed by examining the slide in reflected light. The "saussurite" occurs as fine-grained masses, in places almost opaque. The dominant constituent is a magnesium-rich carbonate with important amounts of granular epidote and clinozoisite and smaller amounts of exuded magnetite. The identification of the magnesium-rich carbonate was accomplished with some difficulty. A slide was chosen showing the "saussurite" mineralization and the cover glass slipped off exposing the rock chip. Dilute hydrochloric acid was then applied to the areas of "saussurite" and weak effervescence took place indicating the presence of a carbonate. The slide was then washed and dried and a few drops of Lemberg's solution (Fairbanks, 1925, pp. 126-127) were applied to similar areas of "saussurite". The lack of staining indicates the presence of a magnesium-rich carbonate.

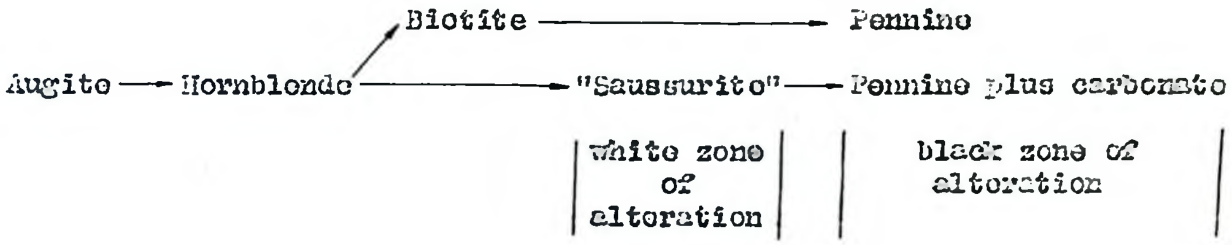
The above alteration, although it has affected each individual grain, has not obliterated the ophitic texture, the rock being easily identified as diabase.

Black Band of Alteration

Generally speaking, the black band of alteration averages about half a centimeter less in width than the corresponding white band, although the contacts are gradational; it represents the higher grade mineral assemblage. Quartz, apatite and pyrite remain unaltered, the titanium-bearing component of titaniferous magnetite has been completely altered to leucoxene with minor amounts of titanite, and flakes of primary biotite have been altered to pennine chlorite.

In the black zone, the sericitized feldspar laths have been altered to pennine chlorite with minor amounts of epidote; this has also been accompanied by the recrystallization of the feldspar lath to the more sodic variety, oligoclase. In general, the feldspars in this band of alteration have a fresher looking appearance than in the corresponding white band of alteration, probably due to the recrystallization.

It was shown above that the alteration products of the ferro-magnesian minerals in the white zone were magnesium-rich carbonate, epidote, clinozoisite and exuded magnetite, an assemblage called "saussurite"; in the black band of alteration, the "saussurite" alters to pennine chlorite with small amounts of carbonate thereby giving the black colour to the inner band of alteration. Thus the complete sequence for the alteration of the ferro-magnesian minerals is:



The pennine occurs as irregular masses showing rosette- or sheave-like forms. It is pale green in colour, faintly pleochroic, and shows its characteristic anomalous blue interference colours between crossed nicols. The alteration of the groundmass and ferro-magnesian minerals to pennine has obliterated the ophitic texture of the diabase. This has partly been accomplished by the crystallization of the pennine in rosette-like forms.

As mentioned previously, the contact between the two bands of alteration is gradational but sufficient evidence is available to show that the pennine (black zone) is replacing the "saussurite" (white zone). Sections taken across the contact show the penning engulfing areas of "saussurite" prior to replacing them. As will be explained later, this does not imply that the two bands of alteration are separated by any time break; both were formed from the same hydrothermal solution and as such are essentially contemporaneous.

The complete alteration sequence for the constituent minerals of the diabase is illustrated in Table 1 on the next page:

TABLE I

Sequences of Alteration at the Temiskaming Mine

Fresh Diabase	White Band	Black Band
Labradorite ↘ Sericite (sparse)	Sericite (minor epidote and clinozoisite)	Sericite ↘ Pennine (minor epidote)
Augite ↘ Hornblende ↘ Biotite	Hornblende ↘ "Saussurite"	"Saussurite" ↘ Pennine and Carbonate
Titaniferous Magnetite	Titaniferous Magnetite ↘ Leucoxene	Leucoxene
Biotite	Biotite	Biotite ↘ Pennine
Quartz	Quartz	Quartz
Pyrite	Pyrite	Pyrite
Apatite	Apatite	Apatite

Summary of the Alteration at the Temiskaming Mine

A consideration of the sequences of alteration illustrated in Table 1 shows that very few of the elements involved had to be added to the wall rock to effect the observed changes. The alteration of the titaniferous magnetite to leucoxene involved the reorganization of the titanium to another form - leucoxene - generally considered to be an amorphous hydrous titanium dioxide (Rogers and Kerr, 1933, p. 171) which necessitates the addition of water only. In the alteration of the ferromagnesian minerals to "saussurite", alumina and lime were taken up in epidote and clinozoisite, magnesium entered into the carbonate, part of the iron was incorporated in the epidote, the rest being exuded as grains of magnetite. The only additions necessary are water, the carbonate radical, and possibly minor amounts of magnesium and calcium. The further alteration of "saussurite" to pennine chlorite plus minor carbonate implies no further additions except water. In this latter alteration, most of the iron was probably exuded as magnetite (Figure 11) although some may have been incorporated in the pennine to approach delessite in composition (Winchell, 1933, p. 282). Excess silica would be flushed out as well as some of the calcium. Some of the latter was taken up by the carbonate invariably associated with the pennine and very minor amounts formed titanite, probably as a replacement of some of the leucoxene. Excess amounts of the carbonate radical and of magnesium would be lost to the conduit.

Although plagioclase feldspar may contain small amounts of potash (primary biotite indicates the presence of potassium in the diabase magma), the great amount of sericite developed from the plagioclase laths necessitates, in the writer's opinion, the addition of at least moderate amounts of potassium (unless it is the soda-bearing variety, paragonite). In the alteration of the plagioclase in the white zone, most of the lime and part of the alumina and silica were taken up in the epidote and clinozoisite. Since the latter are hydrous minerals, water was also added. The soda released in this alteration diffused back to the fracture where it joined the upward rising hydrothermal solution. In the black zone, the sericite has been altered to pennine chlorite accompanied by the recrystallization of labradorite to the more sodic variety, oligoclase.

From the above, it can be seen that most if not all of the iron, titanium, alumina, and silica were already present in the diabase before hydrothermal alteration took place; the necessary additions are water, the carbonate radical, potassium and some magnesium and calcium indicative of weakly alkaline solutions. It must be admitted, however, that these conclusions are tentative only, pending complete chemical analyses.

HECLA SILVER MINES LIMITED

Introduction

During the 1950 field season, the writer did some mapping in the vicinity of the Hecla Silver Mines Limited (formerly called the Crysler-Niles Mining Co., Ltd.) in lot 2, Con. X of Lorrain Township. Work has long since been stopped at this mine and the underground workings are flooded, hence, no examination of veins or alteration *in situ* could be made. However, the mine dump was carefully examined and a representative set of vein and alteration specimens was collected. Figure 1 is a photograph of a specimen from the Hecla mine illustrating a vein (chalcopyrite-pyrite-quartz-carbonate) bordered by a 1½ cm. wide zone of black alteration followed outward by a 2 cm. wide zone of white alteration, the rest of the rock being relatively unaltered Nipissing diabase.

Several thin- and polished-sections of the alteration and veins from the Hecla mine were examined with the microscope. Additional information on the mineralogy and paragenesis of the veins was obtained from polished-sections of a vein from the Kirk Budd mine in Block 8 of Gillies Timber Limit.

The surface rocks exposed on the Hecla claim are the Lorrain granite and Nipissing diabase but the contact relationships as shown on maps by W. G. Miller are incorrect. No silver or cobalt production is known from the Hecla mine. Since nothing is known about the sub-surface geology at this mine, it is impossible to relate the specimens collected for laboratory work to either contact of the diabase sill with the granite.

Vein Mineralization

The veins[1], as seen from specimens on the dump, average about 1 cm. in width and consist predominantly of chalcopyrite, pyrite and carbonate with minor quartz. Hematite was seen in one of the veins occurring as small inclusions in quartz. Minor malachite is present on the weathered surfaces. Inclusions of wall rock completely altered to pennine are also present.

Quartz (SiO_2)

The quartz occurs in anhedral to euhedral crystals enclosed in carbonate and was the first mineral to crystallize. Vein specimens from prospect pits in the Nipissing diabase at the north end of Kirk Lake (lot 1, Con. X, Lorrain Township) show euhedral crystals of quartz projecting out from the wall rock into the carbonate which occupies the central portion of the vein (Figure 12). This feature is displayed to a lesser extent in samples from the Hecla mine. Quartz commonly forms a narrow zone along the edges of a vein, an occurrence also seen in specimens from the Hecla mine.

There were evidently two periods of deposition of quartz, separated by the deposition of hematite. This is illustrated in Figures

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[1] Only those veins occurring in the Nipissing diabase sill are discussed. Consequently, this does not represent a complete description of the mineralogy of this mine.

13 and 14 which show clearly the inclusions of hematite arranged around a subhedral crystal of quartz and enveloped in a second generation of quartz. It is thought that the two periods of deposition of quartz were very closely associated with each other, no appreciable time interval separating them.

Hematite (Fe_2O_3)

Minor hematite was seen in a thin-section of one of the Hecla veins. It occurs as inclusions (up to 0.16 mm. in length) in quartz and carbonate but its relationship to the sulfides was not observed. A study of a vein in the Nipissing diabase from the Agaunico mine in lot 15, Con. I of Bucke Township, consisting of specularite, chalcopyrite, goethite, quartz and carbonate, showed that the specularite was later than the chalcopyrite (Bourne, 1950, pp. 5-9). However, in the Hecla vein, the deposition of hematite appears to have preceeded the deposition of the sulfides. Its close association with quartz and its mode of occurrence in the latter mineral suggest that the hematite was deposited after the first deposition of quartz but before the second.

Pyrite (FeS_2)

Pyrite and chalcopyrite commonly constitute up to 75 per cent of the veins with chalcopyrite slightly in excess of pyrite; in some veins, sulfide mineralization is negligible. Pyrite occurs in anhedral to subhedral grains (Figure 15) and was the first sulfide to crystallize.

Chalcopyrite ($CuFeS_2$)

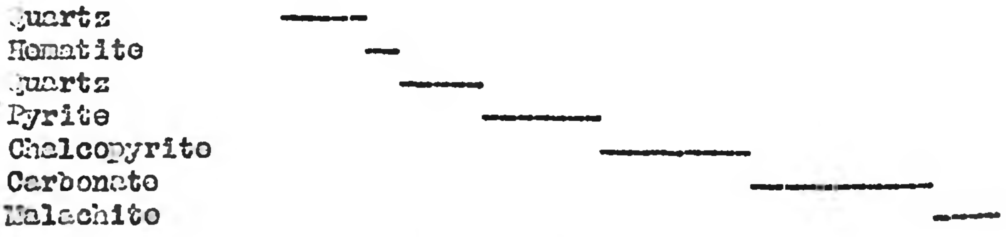
Chalcopyrite occurs in anhedral masses and veinlets traversing the pyrite grains but does not replace the latter mineral to any great extent (Figure 16). It is closely associated with but earlier than the carbonate and is altered on the weathered surface to malachite.

Carbonate

Carbonate is the dominant gangue mineral. It is fine-grained, white on the fresh surface but weathers to a grey or chocolate brown, possibly indicating an iron content. It was the last mineral to crystallize.

There are several patches of pennine in the veins (Figure 17), presumably representing completely chloritized wall rock fragments. Some of the quartz crystals contain inclusions of pennine, the latter occurring in rosettes and sheave-like forms, all showing anomalous blue interference colours.

Listed below in tabular form is the paragenetic sequence as determined from the sections examined:



Diabase

The relatively unaltered diabase consists mainly of pyroxene and labradorite with minor amounts of primary hornblende, titaniferous magnetite, pyrite, quartz, biotite and apatite; the texture is ophitic. Labradorite has been slightly altered to sericite, and pyroxene to secondary hornblende, the other constituents being unaltered. Some of the biotite is deuteric but much appears to be primary. The primary hornblende occurs in well-developed euhedral crystals showing good cleavage and although in some cases partly enclosed in biotite, it does not alter to the latter mineral. Such an occurrence is illustrated in Figure 18.

White Band of Alteration

Although the white bands of alteration at the Hecla and Temiskaming mines are similar in many respects, there are one or two differences. Generally speaking, the white band in the Hecla specimens averages 1.5 cms. in width, being slightly wider than the corresponding black zone although the contacts are gradational. It shows up well on the weathered surface where it is pale green in colour. Quartz, biotite, pyrite and apatite remain unaltered while titaniferous magnetite has altered to leucoxene and titanite.

The plagioclase laths are very badly altered to a fine-grained, granular aggregate of epidote and clinozoisite with minor sericite. The alteration products epidote and clinozoisite are the dominant feature of this zone and are illustrated in Figure 19. They completely obliterate the polysynthetic twinning but preserve the lath-shape of the plagioclase crystals. The ferro-magnesian minerals have altered to a fine-grained mexture of magnesium-rich carbonate, clinozoisite and epidote with but very minor amounts of exuded magnetite; this association is again conveniently termed "saussurite". Much of the carbonate occurs in small but well-developed and recognizable grains. A common feature of the "saussurite" assemblage is the occurrence of black spots which measure up to 0.035 mm. in length by half as much in width. Under high magnification (320X) these spots appear to be aggregates of very fine-grained epidote and clinozoisite. These spots are white in reflected light lending added weight to the above determination.

In the alteration of the ferro-magnesian minerals, conclusive evidence is present to show that the secondary hornblende and not the pyroxene or biotite gives rise to the "saussurite" assemblage. This is illustrated in Figure 20. Many cases were seen where remnants of hornblende showing its characteristic cleavages are completely engulfed in "saussurite" while biotite is unaltered. In no instance does pyroxene alter to "saussurite" without first altering to hornblende. Clearly, then, the alteration of the ferro-magnesian minerals in the white zone is as follows:

$$\begin{tikzcd} & \text{Biotite} & \\ \text{Pyroxene} \arrow[r] & \text{Hornblende} \arrow[u] \arrow[r] & \text{"Saussurite"} \end{tikzcd}$$

Examination of the slides in reflected light indicates that the "saussurite" as a whole, but more particularly the epidote and clinozoisite, gives the white colour to this band of alteration. Two other observations are worthy of note. The first is the paucity of exuded magnetite in the alteration of the ferro-magnesian minerals to "saussurite", a deficiency probably inherent in the original pyroxene. The second is the great abundance of epidote and clinozoisite from the alteration of the plagioclase, sericite being of little importance. As at the Temiskaming mine, the ophitic texture is well preserved in the white band of alteration.

Black Band of Alteration

In the specimens collected from the Hecla mine dump, the black band of alteration averages slightly greater than 1 cm. in width and is generally black or a dark shade of brown in colour. Quartz, pyrite and apatite persist unaltered in this zone and titaniferous magnetite has been more thoroughly altered to leucoxene and titanite forming a grid-like structure (Figure 21). Biotite occurs in a surprisingly fresh form in this zone although some is bleached and evidence is available to show it is altering to pennine. It is very unlikely that any biotite was formed in this zone through alteration or recrystallization.

As at the Temiskaming mine, the black zone is characterized by the presence of pennine chlorite, the alteration product of both the feldspar and ferro-magnesian minerals; the pennine gives the black colour to this band of alteration. Associated with the pennine, especially in the alteration of the ferro-magnesian minerals, are notable amounts of carbonate. The feldspar has a faintly fresher appearance than in the corresponding white band probably due to recrystallization to oligoclase. Associated with the pennine in the alteration of the plagioclase are minor amounts of clinozoisite but in all probability these represent unreplaced material from the white zone. The ophitic texture has been obliterated in the black band of alteration. This is partly due to crystallization of the pennine in sheave-like masses and partly to the fact that pennine replaces both the ferro-magnesian and feldspar minerals tending to obscure grain boundaries. Once again, it is well to note the sequence of alteration for the ferro-magnesian minerals:

$$\begin{tikzcd}
& \text{Biotite} \arrow[rr] & & \text{Pennine} \\
\text{Pyroxene} \arrow[r] & \text{Hornblende} \arrow[u] \arrow[r] & \text{``Saussurite''} \arrow[r] & \text{Pennine plus Carbonate}
\end{tikzcd}$$

As mentioned above, conclusive evidence is present to show that the alteration to "saussurite" and thence to pennine plus carbonate springs from the hornblende and not the pyroxene or biotite. As at the Temiskaming mine, evidence is shown in the slides that the chlorite zone is encroaching on the inner edge of the "saussurite" band. The lack of any large-scale veinlets of chlorite cutting the "saussurite" suggests rather quiet replacement of the latter mineral assemblage. Table 2 on the next page illustrates the complete alteration sequences for the constituent minerals of the diabase at the Hecla mine:

TABLE 2

Sequences of Alteration at the Hecla Mine

Fresh Diabase	White Band	Black Band
Labradorite ↘ Sericite (sparse)	Labradorite ↘ Epidote and Clinozoisite (sericite)	Epidote and Clinozoisite ↘ Pennine
Pyroxene ↘ Hornblende	Hornblende ↘ "Saussurite"	"Saussurite" ↘ Pennine and Carbonate
Titaniferous Magnetite	Titaniferous Magnetite ↘ Leucoxene and Titanite	Leucoxene and Titanite
Biotite	Biotite	Biotite ↘ Pennine
Quartz	Quartz	Quartz
Pyrite	Pyrite	Pyrite
Apatite	Apatite	Apatite

Summary of the Alteration at the Hecla Mine

Since much of the material which might be included under this heading would be undue repetition of what was included under the summary of the alteration at the Temiskaming mine, attention will be focused on a few salient points only. As mentioned previously, the spatial location of the specimens from the Hecla mine in the Nipissing diabase sill is unknown. Hence, it is difficult to appraise the significance of this alteration assemblage as far as vein mineralization is concerned.

The dominant feature of the white band of alteration is the great amount of epidote and clinozoisite formed through the alteration of the plagioclase. Although most of the feldspar laths have been too badly altered to determine their original composition, they do not appear to be more calcic than medium labradorite, or about the same composition as at the Temiskaming mine. It is concluded, therefore, that the solutions must have been fairly rich in lime to produce the the epidote-clinozoisite assemblage, a richness which may account for the relative abundance of titanite in the alteration of titaniferous magnetite. The introduction of potassium for the formation of sericite is unlikely since labradorite can contain slightly more than 1 per cent K_2O which was probably enough to account for the minor sericite present. The second point of interest is the scarcity of exuded magnetite in the alteration of hornblende to "saussurite" and from "saussurite" to pennine chlorite. For example, there are no concentrations of magnetite in the Hecla slides comparable with that illustrated in Figure 11, taken from one of the Temiskaming slides. As mentioned previously, this deficiency in iron was probably inherent in the original pyroxene.

SHAG SILVER MINE

Introduction

The Shag Silver Mines Limited was formed to develop the Reinhardt claim under Cross Lake in lot 2, Con. V of Coleman Township, a claim which had hitherto been unexplored. The property is being developed from the former Cross Lake O'Brien shaft. Mr. Carl Reinhardt is the owner of the property and Mr. Leo J. O'Shaughnessy is the mine operator. One small, but very rich ore shoot, part of the O'Brien Cross Lake No. 1 vein, was mined in 1949 when 94,335 ounces of silver were produced. The writer spent one morning underground with Dr. Thomson and Mr. O'Shaughnessy and collected several specimens showing the alteration which is extremely well-developed at this mine, particularly on the 270-foot level at co-ordinates 3100 feet south, 6150 feet east. The specimens studied in the laboratory were collected from this location which is about 280 feet above the lower contact of the sill with the "Keewatin".

The rocks on the west and east sides of Cross Lake are separated by the Cross Lake Fault which strikes northwesterly into Bucke Township and southeasterly through Kirk, Chown and Goodwin Lakes. Although the dip of the fault and the displacement along it are in doubt, it is known that the east side has gone up relative to the west side. The Nipissing diabase outcrops on the east side of Cross Lake and is underlain by "Keewatin" rocks. A thin wedge of Cobalt conglomerate is exposed on the

270-foot level between the diabase and the "Keewatin" rocks.

The samples collected for laboratory work are complicated by the presence of several subsidiary veinlets, each one being less than ½ cm. wide and all of which have their own alteration envelopes. Thus the alteration effects of several narrow veinlets are superimposed on the alteration bands adjacent to the main vein, tending to obscure the general relationships.

Diabase

The diabase at this locality of the Shag Silver mine corresponds to the quartz norite phase of Satterly. It is characterized by the presence of enstatite - now largely altered to hornblende - and plagioclase feldspar. The latter has been severly altered to sericite but its original composition does not appear to have been more calcic than medium labradorite. Enstatite was identified by its positive character, faint pleochroism, parallel extinction and 2V. Some of the enstatite has altered to hornblende and thence to biotite. Minor amounts of apatite, pyrite, and titaniferous magnetite are also present. Quartz comprises less than 1 per cent of the rock and occurs as isolated grains. No olivine was seen. Some of the hornblende has apparently altered to talc, the latter poikolitically enclosing laths of feldspar. The significance of this latter alteration is not known. As at the former two mines, the ophitic texture of the diabase is well developed.

White Band of Alteration

The white bands of alteration average close to 1½ cms. in widt although all contacts are gradational. The main factor obscuring the alteration sequences at this mine is the presence of much coarse-grained carbonate, epidote and clinozoisite. Where this assemblage is well-developed (as at the veinward edge of the white zone) the ophitic texture of the diabase has been partly destroyed; at the outer edge of the white zone, the ophitic texture is well preserved. Generally speaking, the alteration sequences in this band are similar to those at the former two mines. Pyrite, quartz and apatite remain unaltered in this band while titaniferous magnetite has altered to leucoxene. Hornblende, the alteration product of enstatite, has altered to a fine-grained mass of carbonate grains with granular epidote and clinozoisite ("saussurite"), the two latter minerals giving the white colour to this band. The epidote and clinozoisite occur as very small black spots, similar to those described at the Hecla mine (page 33); their white appearance in reflected light is striking. On the outer edge of this band, the plagioclase laths are completely altered to a medium-grained felt of sericite flakes. Towards the black band, the feldspars have been recrystallized to albite.

Black Band of Alteration

In the specimens examined, the black band of alteration averages 2 cms. in width and occupies its normal position between the vein and white band. Once again, it is characterized by the presence of chlorite which corresponds optically to pennine although not all of it shows the anomalous blue interference colours characteristic of this mineral. Quartz and pyrite persist unaltered in this band while titaniferous magnetite has been further altered to leucoxene and titanite. Apatite was not seen in the sections examined. The plagioclase has been recrystallized to untwinned albite with but few flakes of carbonate and sericite. Some of the albite is traversed by veinlets of coarse-grained carbonate.

Although partial recrystallization has obscured some features of the alteration, it appears evident that the chlorite and associated carbonate represent the final alteration products of the ferro-magnesian minerals. Furthest out from the vein, the chlorite occurs as anhedral plates and masses whereas closer to the vein the chlorite is rather well crystallized, occurring as slender laths. This latter occurrence is attributed to recrystallization. Both types are invariably associated with carbonate, similar to the other two mines previously described.

Except for the different colour of the chlorite in these sections, the above alteration sequences at the Shag Silver mine correspond closely with those at the Temiskaming and Hecla mines. However, superimposed on the normal white zone-black zone sequence is an assemblage of coarse-grained carbonate, epidote and clinozoisite (Figure 22). Some of the carbonate grains measure 0.56 mm. in width. Individual grains of epidote and clinozoisite measure up to 0.5 mm. long and commonly show a zonary structure as illustrated in Figure 23. This coarse-grained assemblage is concentrated both in and close to the black band where it is associated with chlorite and albite, and becomes less frequent towards the outer edge of the white band. It itself does not form a separate zone but occurs as patches in the two bands of alteration. Its presence completely destroys the ophitic texture. It is interesting to note that the coarse-grained epidote and clinozoisite are not noticeably white in reflected light; it is the fine-grained epidote and clinozoisite formed through the alteration of the ferro-magnesian minerals in the white zone which give the colour to the outer band.

The occurrence of this assemblage of coarse-grained epidote, clinozoisite and carbonate seems better accounted for by partial recrystallization rather than by introduction of material. Its association with albite supports this viewpoint. Some of the coarse-grained carbonate occurs in narrow veinlets which traverse laths of albite possibly indicating some introduction of carbonate after recrystallization. However, none of the main veins contain epidote or clinozoisite. Where the chlorite is associated with this coarse-grained mineral assemblage, it (the chlorite) occurs as subhedral laths accompanied by coarse-grained carbonate. This fact leads the writer to suspect that the chlorite has been partially recrystallized. To sum up, the coarse-grained nature of the epidote-clinozoisite-carbonate assemblage, the crystalline character of the chlorite, the presence of albite, and the lack of epidote and clinozoisite in the main veins, all point to partial recrystallization having taken place, the labradorite (and sericite) recrystallizing to albite and the "saussurite" to the coarse-grained assemblage and chlorite.

Although, as mentioned above, the relationships between the two bands of alteration have been somewhat obscured by recrystallization, there is sufficient evidence to indicate that here also the black band is replacing the corresponding white band. It is instructive to note that even adjacent to the narrowest of the subsidiary veinlets (some of which measure 1 mm. in width) the same relationship holds true. Shapeless masses of chlorite can be seen engulfing areas of "saussurite" prior to replacing them. The occurrence of some of the chlorite in distinct veinlets suggests that here the conditions of hydrothermal replacement were somewhat more "violent" than at the other two mines where the lack of chlorite veins suggests replacement under more static conditions.

Table 3 on the next page illustrates the sequences of alteration for the constituent minerals of the diabase at the Shag Silver mine:

TABLE 3

Sequences of Alteration at the Shag Silver Mine

Fresh Diabase	White Band	Black Band
Labradorite ↘ Sericite	Sericite	Sericite ↘ Albite
Enstatite ↘ Hornblende ↘ Biotite	Hornblende ↘ "Saussurite"	"Saussurite" ↘ Pennine and Carbonate plus recrystallized Epidote-Carbonate-Clinozoisite
Titaniferous Magnetite	Titaniferous Magnetite ↘ Leucoxene and Titanite	Leucoxene and Titanite
Apatite	Apatite	—
Quartz	Quartz	Quartz
Pyrite	Pyrite	Pyrite

Summary of the Alteration at the Shag Silver Mine

Except for the greater amount of recrystallization in the specimens from the Shag Silver mine, the alteration sequences are similar to those described from the Temiskaming and Hecla properties. Quartz, pyrite and apatite persist unaltered through the two bands while titaniferous magnetite alters to leucoxene and titanite, behaviours identical with the other localities. Another similarity is in the alteration of the ferro-magnesian minerals.

$$\begin{tikzcd}
 & & \text{Biotite} \arrow[rr] & & \text{Pennine} \\
\text{Enstatite} \arrow[r] & \text{Hornblende} \arrow[ur] \arrow[rr] & & \text{"Saussurite"} \arrow[r] & \begin{array}{l}\text{Pennine, Carbonate} \\ \quad\text{plus} \\ \text{recrystallized} \\ \text{Epidote-Clinozoisite-} \\ \text{Carbonate}\end{array}
\end{tikzcd}$$

The above sequence is very similar to those at the other two mines, excepting the original composition of the pyroxene. In each case, pennine and carbonate represent the final alteration product of the pyroxenes, "saussurite" being an intermediate stage. The lack of exuded magnetite in the alteration of enstatite to hornblende and from hornblende to "saussurite" is inevitable since enstatite contains very little iron. Undoubtedly, some of the "saussurite" in the white band recrystallized to give the coarse-grained epidote-clinozoisite-carbonate assemblage.

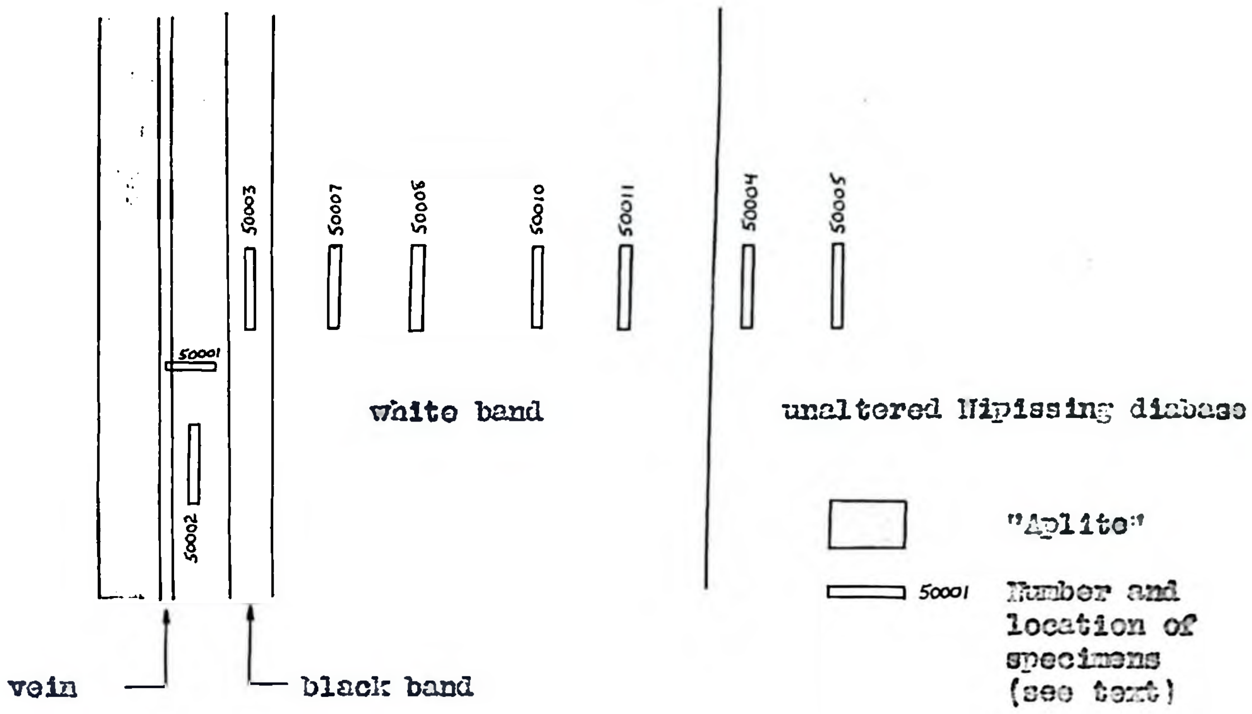
In the specimens from the Shag Silver mine, the feldspars first altered to sericite in the white band and then recrystallized to albite in the black band. The ophitic texture of the diabase persists to within the white zone but is obliterated in the black zone due to recrystallization.

"APLITE" AND VEIN AT HOUND CHUTES

Introduction

The writer and Dr. Thomson examined a narrow "aplite" dike cutting an outcrop of Nipissing diabase about 600 feet north of the power plant at Hound Chutes in Block 25 of Gillies Timber Limit. In the centre of the "aplite" is a carbonate vein up to 3 cms. wide which strikes 43°Ast. and dips vertically. The carbonate (mainly dolomite) is grey in colour and in places contains fragments of red "aplite". The contact between the vein and "aplite" is sharp and distinct as illustrated in Figure 24. No silver or cobalt mineralization was seen in this particular vein or "aplite" but cobalt mineralization has been reported from another "aplite" less than 75 feet west.

Up to about 1½ cms. from the "aplite" the diabase is darker than normal. This is followed outward by a zone 16½ cms. wide of white alteration which appears to pass through a very narrow zone of black alteration into the unaltered Nipissing diabase. The existence of this outer zone of black alteration is questionable as no laboratory evidence could be found to verify its presence. Indicated in the diagram below, are the representative specimens which were collected and examined with the microscope.



(Plan)

Diabase

The relatively unaltered diabase which forms the host rock for the vein exhibits a peculiar mottled appearance on the weathered surface, illustrated in Figure 25. On the basis of field evidence this was attributed to a glomeroporphyritic texture - a segregation of the labradorite laths and micrographic intergrowth into clots (see Tyrrell, 1948, p. 95) - which was subsequently confirmed with the microscope. As a result, the ophitic texture common to the diabase of the other localities (Temiskaming, Hecla and Shag Silver mines) is not seen in the specimens from Hound Chutes. The diabase consists mainly of secondary hornblende with clusters of labradorite laths and patches of micrographic intergrowth. Titaniferous magnetite, pyrite, biotite and apatite are minor constituents of the diabase. The feldspar laths, including the feldspar associated with quartz in micrographic intergrowth, have been badly altered to sericite with minor amounts of epidote and clinozoisite. The hornblende presumably represents the alteration product of original pyroxene, none of the latter being present in the slides examined. Apatite occurs in long needles occassionaly 0.9 mm. in length and is closely associated with quartz. Some of the biotite may be primary but much is deuteric in origin.

White Band of Alteration

The white band is 16½ cms. wide with an overall grey colour but examined closely it has a distinct mottled red appearance due to the presence of finely divided hematite in the feldspar. The laths of plagioclase can be distinguished with the aid of a hand lens. Figures 26 and 27 show the "aplite" and vein cutting the Nipissing diabase, the white zone standing out particularly well.

No change in mineral composition is noticeable until slide 50010 is reached (see Table IV), that is, slightly inside the outer edge of the white band. Here, the red coloration of the feldspar first becomes apparent, pennine is the only ferro-magnesian mineral present, and sericite has begun to alter to albite giving the feldspar laths a fresher appearance; the texture is unchanged from that of the relatively unaltered diabase. Titaniferous magnetite has begun to alter to leucoxene while quartz, apatite and pyrite remain unaltered. Micrographic intergrowth is still plentiful. Abundant carbonate is associated with the pennine. The latter two minerals occur in anhedral masses and veinlets between and around the feldspar laths.

In the next slide inward, 50008, the feldspar is recrystallized albite, pennine and carbonate represent the ferro-magnesian minerals, and titaniferous magnetite has completely altered to leucoxene preserving the grid-like structure (Figure 28). Quartz and micrographic intergrowth are sparse and there are several laths of apatite and grains of pyrite. As a result of recrystallization, the grain size has increased slightly.

In the innermost slide of the white zone, 50007, quartz and micrographic intergrowth are absent. The rock is composed entirely of albite, chlorite and carbonate, leucoxene and minor apatite. The albite is very fresh in appearance except for the dusting with hematite. Due to recrystallization, the texture in this slide is entirely different from that of the unaltered diabase.

Two general trends of alteration in the white band emerge from the description above. The first is the gradual diminution in quantity of quartz and micrographic intergrowth as one goes from the outer to the inner edge of this band. The second is the gradual change in the plagioclase from labradorite in the unaltered diabase through sericite to albite at the inner edge of the white band. The change in texture is due to recrystallization. It will be noticed that the white colour of this band is not due to the presence of "saussurite". Examination of this series of slides indicates that the white colour is due to the increasing abundance of feldspar, especially the recrystallized albite, and the mottled red colour to the presence of finely divided hematite in the feldspar.

Black Band of Alteration

A specimen from the black band of alteration was kindly donated by Dr. Thomson. Its mineralogical composition is listed in Table IV and it can be seen that it presents anomalous features. Titaniferous magnetite is completely unaltered, quartz is more abundant than in 50007, the feldspar is oligoclase-andesine, and the ferro-magnesian minerals are represented by hornblende which has altered slightly to "saussurite" - an assemblage of fine-grained carbonate, epidote and clinozoisite. It resembles very closely the unaltered diabase, typified by slide 50005. Its origin might well be explained by recrystallization except for the texture which in places is ophitic.

"Aplite"

The red coloration reaches its maximum development in a band 2 or 3 cms. wide adjacent to the vein. Here, the rock is composed dominately of plagioclase feldspar determined optically to be albite. Pennine and carbonate are closely associated and occur in narrow veinlets and irregular masses around the feldspar grains. Much of the carbonate has been introduced. Quartz, micrographic intergrowth of quartz and feldspar, and apatite are absent, pyrite remains unaltered and titaniferous magnetite is represented by leucoxene.

Thus there is a complete sequence (neglecting the black zone) of mineral changes from unaltered diabase to a rock which otherwise would be described as magmatic in origin. The texture of the fresh diabase persists to about the middle of the white band where it is modified by recrystallization.

In hand specimen, there is a thin seam of chloritic material between the vein and "aplite". In thin section, this seam averages 1.5 to 2.0 mm. in width and consists of chlorite, quartz, carbonate, titaniferous magnetite and a few cubes of pyrite. The chlorite occurs as bladed crystals either singly or in aggregates between which the quartz occurs as fine-grained interstitial material. Titaniferous magnetite - now almost entirely altered to leucoxene - occurs as irregular masses and veinlets cutting the groundmass.

The above mineral sequences are listed in Table 4 on the next page:

TABLE 4

Sequences of Alteration at Hound Chutes

Fresh Diabase	Outermost White 50011	50010	50008	Innermost White 50007	Black Band	"Aplite"
Labradorite ↘ Sericite	Sericite	Sericite (some albite)	Sericite ↘ Albite	Albite	Oligoclase	Albite
Augite ↘ Hornblende ↘ Biotite	Hornblende ↘ "Saussurite"	"Saussurite" ↘ Pennine and Carbonate	Pennine and Carbonate	Pennine and Carbonate	Hornblende ↘ "Saussurite"	Pennine and Carbonate
Sericite } Quartz } graphic	Sericite } Quartz } graphic	Sericite } Quartz } graphic	Sericite } Quartz } graphic (sparse)	-	-	-
Titaniferous Magnetite	Titaniferous Magnetite	Titaniferous Magnetite ↘ Leucoxene	Leucoxene	Leucoxene	Titaniferous Magnetite ↘ Leucoxene	Leucoxene
Apatite	Apatite	Apatite	Apatite	Apatite	Apatite (sparse)	-
Pyrite	Pyrite	Pyrite	Pyrite	Pyrite	Pyrite	Pyrite
Quartz	Quartz	Quartz	Quartz	Quartz	Quartz	Quartz

Summary

Detailed laboratory work regarding the origin of the "aplite" has substantiated the view of hydrothermal replacement first advocated by Bastin (1935), a similar origin being postulated by Goodspeed (1939, p. 7) for "aplite" dikes in the Cornucopia district, Oregon. It is for this reason, following Bastin, that the word aplite is enclosed in quotation marks to distinguish it from a rock similar in appearance formed by true magmatic processes. Omitting for the moment the black zone of alteration which shows anomalous variations, there is a gradual transition in mineral composition from diabase to "aplite", replacement sequences which are listed in Table 4. These mineral changes reach their maximum development adjacent to the vein where albite is the dominant constituent and the red coloration is most apparent. It seems clear, then, that the "aplite" dike is a product of hydrothermal replacement outward from a fracture, rather than of straight magmatic origin. The mineralogy moreover differs from a normal aplite, which contains essential quartz.

There are several differences in the alteration at Hound Chutes as compared with the alteration at the Temiskaming, Hecla, and Shag Silver mines. The first is the presence of hematite and therefore a red coloration at Hound Chutes. The second concerns the differences in mineralogical composition in the white zone, tabulated below:

	Temiskaming Mine	Hound Chutes
Feldspar	sericite with more or less epidote and clinozoisite.	sericite on the outer edge, albite on the inner edge. Increasing abundance of albite towards the inner edge.
Ferro-magnesian minerals	"saussurite" plus magnetite.	"saussurite" on the outer edge only; mainly pennine and carbonate.
Titaniferous magnetite	leucoxene	leucoxene
Colour due to	"saussurite" especially epidote and clinozoisite.	albite

However, it is instructive to note that the alteration sequences in both localities are, broadly speaking, the same. For example, the alteration of the ferro-magnesian minerals at the Temiskaming mine is as follows:

$$\begin{tikzcd}
{} & {} & \text{Biotite} \arrow[rr] & & \text{Pennine} \\
\text{Augite} \arrow[r] & \text{Hornblende} \arrow[ur] \arrow[rr] & & \text{"Saussurite"} \arrow[r] & \text{Pennine and Carbon}
\end{tikzcd}$$

Similarily, at Hound Chutes, hornblende has altered to "saussurite" and thence to pennine and carbonate which, however, are much more widespread. Titaniferous magnetite has altered to leucoxene at both localities. Recrystallized albite (or oligoclase) does not appear at the Temiskaming, Hecla, and Shag Silver mines until the black zone whereas at Hound Chutes albite is the dominant constituent of the white band, increasing in abundance as the vein is approached. However, the general sequence of alteration of the feldspars is similar, namely:

labradorite ⟶ sericite ± epidote and clinozoisite ⟶ albite

The second main difference is that albite gives the white colour to the band at Hound Chutes whereas epidote and clinozoisite ("saussurite") do the same at the other localities.

> It appears, therefore, that in the main silver-producing areas at Cobalt and South Lorraine, wall-rock alterations bordering the veins are similar in most respects to those observed at Elk Lake and Gowganda, but only in a few places are they accompanied by strong hydrothermal oxidation and the development of red coloration in the diabase, i. e., the formation of 'aplite' or 'red rock'. (Bastin, 1935, p. 730).

Summary of the Alteration at Butte, Montana

Before proceeding to a description of the mechanics of wall rock alteration, I shall insert a brief summary of the wall rock alteration along the ore-bearing veins in the quartz monzonite at Butte, Montana. Although not precisely the same, the alteration effects in these two mining camps are very similar. This can be seen by comparing Figure 1 of this thesis with Figure 1 on page 5 of the 1948 paper by Sales and Meyer.

> At Butte, successive zones of sericitized and argillized quartz monzonite occur around every ore-bearing fracture regardless of its size, attitude, or relative age. The two types of alteration always occupy the same relative position; sericite adjacent to the ore-bearing vein, clay minerals always between the sericitized rock and fresh quartz monzonite, except where overlap of alteration effects between adjacent fissures has eliminated the lower grade mineralogical products, as is the case in much of Butte's Central zone of pervasive sericitization. (Sales and Meyer, 1948, p. 1).

The argillized zone at Butte shows three phases: a white kaolinite-rich portion in contact with the sericitized zone, a dark band of montmorillonite-rich and nontronite plus allophane-hisingerite-bearing plagioclase and hornblende alteration adjacent to fresh monzonite, and a lighter green "mixed clay" band between. As at Cobalt, the contacts between all the phases are intergradational.

According to Sales and Meyer (1949, p. 466), replacement of the wall rock by vein minerals has been the dominant process of vein formation at Butte. The growth of a vein, therefore, is essentially the final stage of the alteration process. Where quartz and pyrite form the marginal facies of a vein, they encroach by replacement on the wall rock silicates.

CHAPTER III

MECHANICS OF HYDROTHERMAL ALTERATION

There are two different opinions regarding the mechanics of hydrothermal alteration; one is championed by T. S. Lovering, the other by R. H. Sales. In the East Tintic district, Utah, Lovering recognizes five stages of hydrothermal activity, each stage being induced by a different solution.

> The replacement ores commonly have a casing of pyritic jasperoid which in turn is surrounded by an envelope of hydrothermal dolomite. Sericite is abundant close to the ore and clay-mineral alteration is common locally at the outer edge of the jasperoid. This zonal arrangement is probably the result of different solutions which followed the same path at different times. (Lovering, 1949, p. 1).
>
> It is often tacitly assumed that the hydrothermal alteration associated with ore deposits is essentially contemporaneous with ore deposition - that the different mineralogical zones in the surrounding rocks may be regarded as reaction rims representing the diminishing activity of the powerful solutions that deposited the ore. This interpretation contrasts with that which ascribes the various alteration zones to differing solutions whose periods of activity have been separated by appreciable time intervals. The evidence in the Tintic district has led the writer and his collaborators to the latter view. (Lovering, 1949, p. 3).

The other viewpoint - that of one solution causing the entire alteration was expertly presented by Dr. Sales in a discussion given at the meeting of the A. I. M. E. held at the Colorado School of Mines. Since the evidence at Cobalt favours this latter mode of origin, I have made free use of Dr. Sales' paper in the following, modifying his conclusions to fit the Cobalt occurrence. In Figure 31, A-A represents

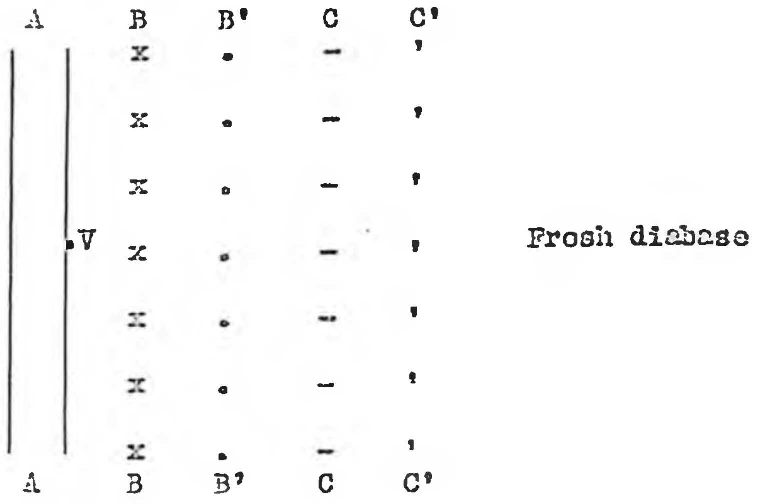


Figure 31

a joint or quartz-carbonate vein in the diabase sill with attendant alteration bands as they occur at Cobalt and as were described previously in this thesis. Under hydrothermal attack, at a given moment of time, we may assume the chlorite zone to have advanced to B-B and the "saussurite" zone to C-C. As long as the wall rock is under solution attack, the zones cannot remain stationary but must move outward from the conduit, the chlorite zone invading the inner edge of the "saussurite" zone, and the latter encroaching on fresh diabase. At the end of hydrothermal activity, we can assume the zones to have migrated to B'-B' and C'-C' respectively. The limiting factor on the final widths of the two zones is the length of time over which hydrothermal activity occurs, although as pointed out by Sales, "it is conceivable that changes in the chemical composition of the solution from time to time might have an effect upon the comparative widths of individual zones".

It is obvious, however, that at any given moment chlorite and "saussurite" are forming simultaneously at their respective fronts but at the expense of earlier formed minerals at the veinward edge of the next zone (or fresh diabase) ahead. In spite of this encroachment of one zone upon the next, we are not justified in concluding that the white band is the earlier of the two bands of alteration. Collectively, the chlorite zone from V (Figure 31) to B' and the "saussurite" zone from B' to C' were formed during the same period of time, that is, during the period of time over which hydrothermal alteration was active.

In summation, then, the wall rock diabase is unstable against solution attack. The chlorite zone becomes the stable zone and represents the finished product; the "saussurite" band is the "preparation" zone and represents the zone of breakdown of the minerals caused by the attacking solution. Obviously, the "saussurite" zone must migrate outward as long as the solution attack continues.

Although this mechanism was proposed by Sales to explain the wall rock alteration along veins in the quartz monzonite at Butte, it is likewise eminently suited to explain the alteration along joints and quartz-carbonate veins in the Nipissing diabase sill at Cobalt. Wherever the alteration is seen, the two bands always show the same spatial relationships: chlorite zone adjacent to the vein or fracture and "saussurite" zone between the chloritized rock and fresh diabase except where overlap of alteration effects between adjacent veins or fractures has eliminated the lower grade mineral assemblage. No faulting or other evidence of any time break separated the development of the two bands. Consequently, the writer favours the above mechanism to account for the observed alteration rather than the one proposed by Lovering which does not appear to be applicable to explain this type of alteration at Cobalt.

SUMMARY AND CONCLUSIONS

As the laboratory work carried out on this problem progressed, the writer was reluctantly forced to conclude that this thesis must serve only as a preliminary survey of the wall rock alteration along joints and veins in the Nipissing diabase sill at Cobalt. As such it has raised a great many more questions than it has answered. This, however, is inevitable in a report of this kind. For this reason, each locality has been described separately rather than one description embracing the four localities. This has made this thesis unnecessarily long perhaps, but under the circumstances it was considered the best plan of attack.

Omitting for the moment the "aplite" at Hound Chutes, certain general features of the alteration common to the other three localities have emerged from this work:

(1) This type of wall rock alteration is very consistent from the upper to the lower contact of the sill and also over wide horizontal extent. Joints and veins in the sill are characterized by a black band adjacent to the joint or vein and a white band between the black band and fresh diabase. These two alteration bands always show this same spatial relationship except where overlap of alteration effects between adjacent veins or fractures has eliminated the lower grade mineral assemblage.

(2) The inner band is characterized by the development of chlorite whi gives the black colour to this band. The chlorite is invariably associated with carbonate. The plagioclase feldspars have been altered to

pennine or in more extreme cases (e. g. Shag Silver mine) they have been recrystallized to albite. The black band represents the higher grade mineral assemblage.

(3) The outer band is characterized by the development of "saussurite" - an assemblage consisting of epidote, clinozoisite, carbonate plus or minus sericite and magnetite. The first two minerals give the white colour to this band of alteration. It represents the lower grade mineral assemblage.

(4) Contact relationships indicate that the chlorite zone is encroaching on the "saussurite" zone. This, however, does not mean that any time interval separated the development of the two bands of alteration - they are essentially contemporaneous and were formed from the same hydrothermal solution.

(5) The geological situation of a joint or vein in the diabase sill appears to have had a noticeable effect on the subsequent alteration. For example, specimens from near the lower contact (Shag Silver mine) are characterized by a greater abundance of epidote and clinozoisite than are specimens from near the upper contact of the sill (Temiskaming mine). The specimens from the Hecla mine are intermediate in this respect.

(6) The alteration bands are genetically connected with the veins and their metallic content. Whether the alteration along a productive vein or ore shoot is always different from that along an unproductive vein is, as yet, unknown.

(7) It is tentatively concluded that the hydrothermal solutions causing the alteration were slightly alkaline and were characterized by the

presence of calcium, magnesium, potassium, and the carbonate radical although the abundance of each varied in different parts of the sill.

Similarily, from the study of the vein and "aplite" at Hound Chutes, certain features have emerged:

(1) Detailed examination with the microscope indicates that the "aplite" is a product of hydrothermal replacement rather than of straight magmatic origin, and cannot be considered a true aplite as defined by Johannsen (1939).

(2) Generally speaking, the alteration sequences adjacent to the vein and "aplite" at Hound Chutes are similar to those at the Temiskaming, Hecla, and Shag Silver mines. The main difference is that at Hound Chutes the solutions were strongly oxidizing, converting ferrous silicates to hematite and hence a red coloration.

(3) It seems reasonable to conclude that both the "aplite" and vein were formed from the same solution, the vein forming during the final stages of hydrothermal activity. Where metallic mineralization is present in the vein, the sequence would be "aplite", then the vein, and finally metallic mineralization. It is interesting to note that in the highly productive area of Cobalt there are no occurrences of aplitic material whereas in the Elk Lake region where "aplites" are abundant, silver mineralization is much less prominent.

It will readily be seen that much more work is necessary before a complete understanding of this problem is achieved. As Cobalt is at present experiencing a "boom", it is possible that many of the mines with extensive workings in the diabase will be pumped out enabling a more extensive suite of specimens to be collected. It is the writer's opinion that the exact location of all specimens must be known; specimens from mine dumps would be of little value in a more detailed description of this type of alteration. If possible, this should be done in conjunction with a detailed examination of the sill itself. By doing so, the effects of the different phases of the diabase on the subsequent alteration might be eliminated. From this, one might be able to determine whether the alteration along a productive vein is different from that along an unproductive vein, information of extreme importance in exploration.

The importance of a complete understanding of wall rock alteration cannot be minimized. First, there is the scientific importance which is a long range viewpoint as far as finding new orebodies is concerned. And second, there are the practical applications which involve a study directed toward the nature of rock alteration accompanying the deposition of ore minerals.

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DESCRIPTIONS OF PLATES

PLATE I

Figure 1. Specimen from the Hecla mine showing the alteration. Collected from the dump at the shaft. Scale is divided in inches.

a - quartz-carbonate vein
b - black band
c - white band

Figure 9. Seam of pennine chlorite between calcite vein and diabase. Temiskaming mine. Crossed nicols. X17½.

cv - calcite vein
p - pennine

PLATE II

Figure 10. Titaniferous magnetite, epidote and clinozoisite grains, carbonate (cv). Temiskaming mine. White band of alteration. Crossed nicols. X72.

Figure 11. Exuded magnetite in pennine. Temiskaming mine. Black band of alteration. Ordinary light. X72.

PLATE III

Figure 12. Euhedral crystals of quartz projecting out from the wall rock into the carbonate which occupies the central portion of the vein. From a prospect pit at the north end of Kirk Lake.

Figure 13. Occurrence of hematite in quartz. Hecla mine. Ordinary light. X50.

PLATE IV

Figure 14. Occurrence of hematite in quartz. Hecla mine. Crossed nicols. X6½.

Figure 15. Occurrence of pyrite in the vein. Hecla mine. Ordinary light. X72.

ch - chalcopyrite
py - pyrite

PLATE V

Figure 16. Occurrence of chalcopyrite in the vein. Hecla mine. Ordinary light. X72.

ch - chalcopyrite
py - pyrite

Figure 17. Inclusion of pennine in the vein. Hecla mine. Crossed nicols. X6½.

PLATE VI

Figure 18. Relation of biotite to hornblende. Hecla mine. White band of alteration. Ordinary light. X72.

Hb - hornblende
Bio - biotite

Figure 19. Epidote-clinozoisite alteration of plagioclase feldspars. Hecla mine. White band of alteration. Ordinary light. X72.

PLATE VII

Figure 20. Relation of biotite and hornblende to "saussurite". Hecla mine. White band of alteration. Ordinary light. X72.

Hb - hornblende
Bio - biotite
Sau - "saussurite"

Figure 21. Titaniferous magnetite altered to leucoxene but preserving the original grid-like structure. Hecla mine. Black band of alteration. Ordinary light. X72.

PLATE VIII

Figure 22. Assemblage of coarse-grained carbonate, epidote and clinozoisite. Shag Silver mine. Crossed nicols. X72.

cv - carbonate
ep - epidote
cl - clinozoisite

Figure 23. Zoned epidote-clinozoisite crystal. Shag Silver mine. Crossed nicols. X72.

PLATE IX

Figure 24. Contact between the vein and "aplite" at Hound Chutes. Crossed nicols. X17½.

Figure 25. Weathered surface of the Nipissing diabase at Hound Chutes. Notice the mottled appearance. The scale is 12 inches long.

PLATE X

Figure 26. Photograph of the vein and "aplite" at Hound Chutes. Notice the white band of alteration. Looking northeasterly.

Figure 27. A closer view of the vein and "aplite" at Hound Chutes. Notice the white band of alteration and the mottled appearance of the weathered surface of the diabase. The scale is 6 inches long. Looking northeasterly.

PLATE XI

Figure 28. Titaniferous magnetite now largely altered to leucoxene but preserving the original grid-like structure. Hound Chutes. Slide 50006. Ordinary light. X72.

Figure 29. Rapids on the Montreal River at Hound Chutes.

PLATE I

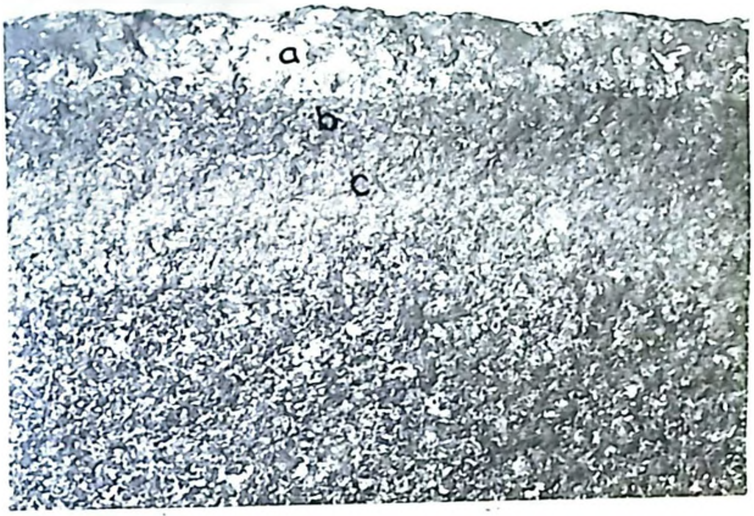

Figure 1

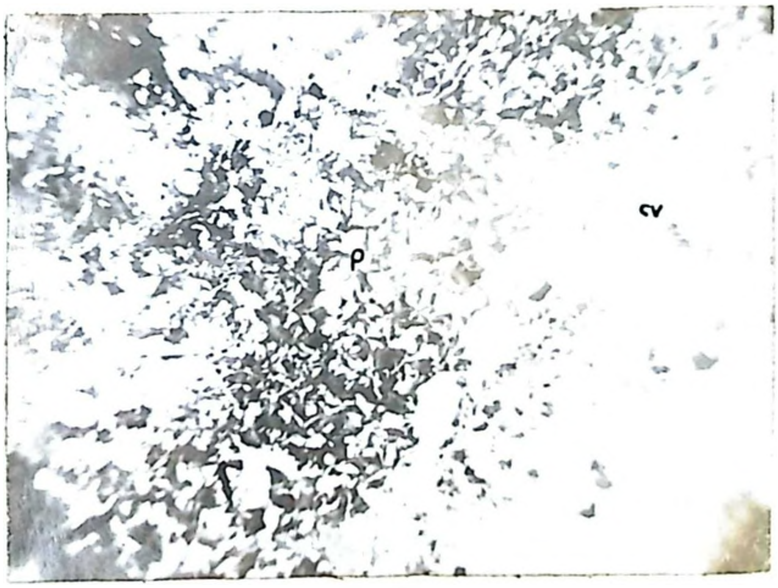

Figure 9.

PLATE II

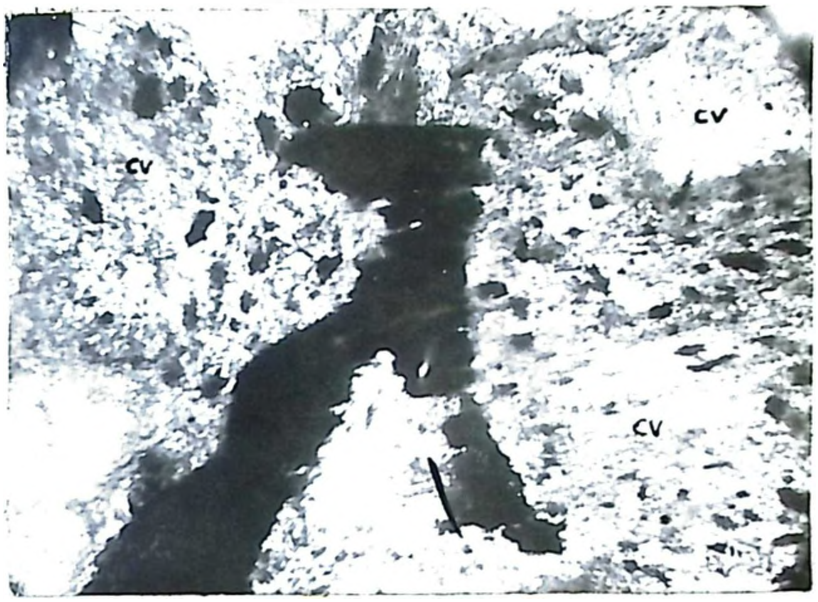

Figure 10

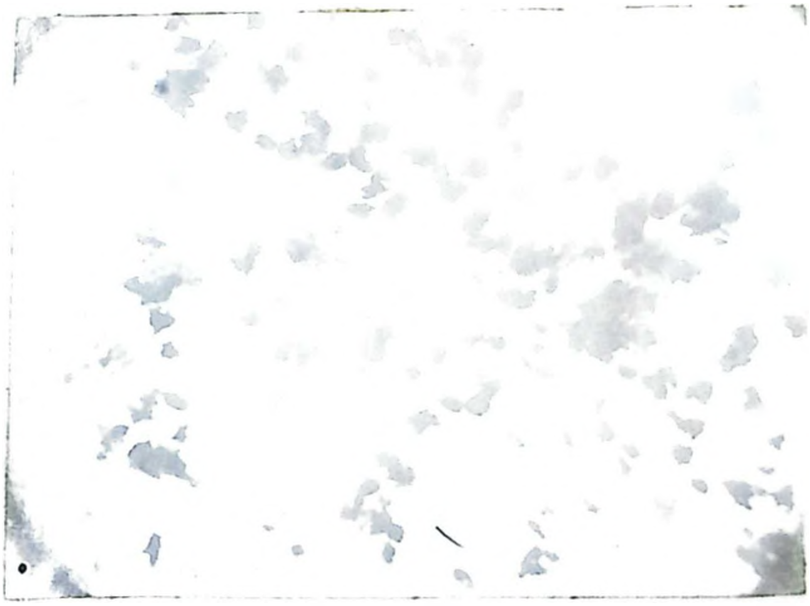

Figure 11

PLATE III

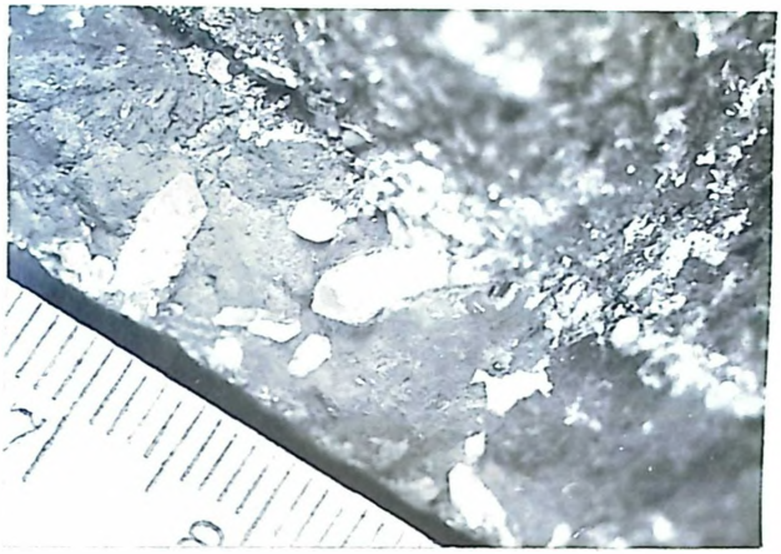

Figure 12

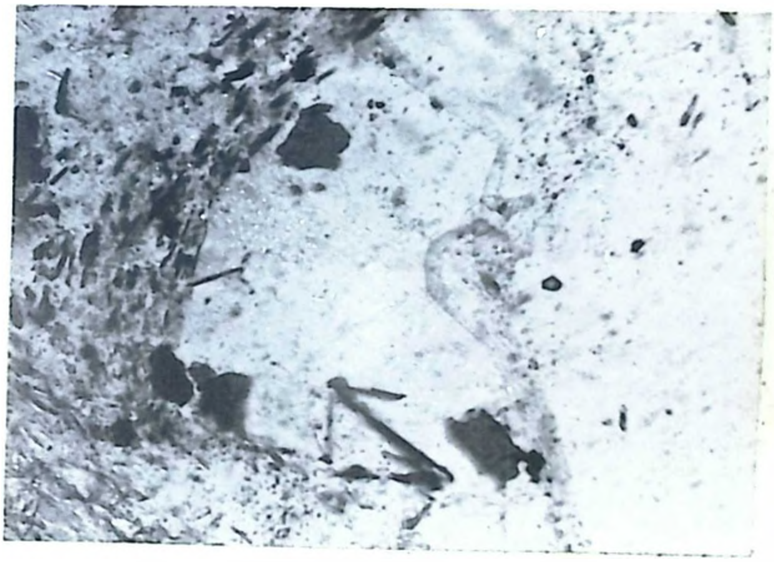

Figure 13

PLATE IV

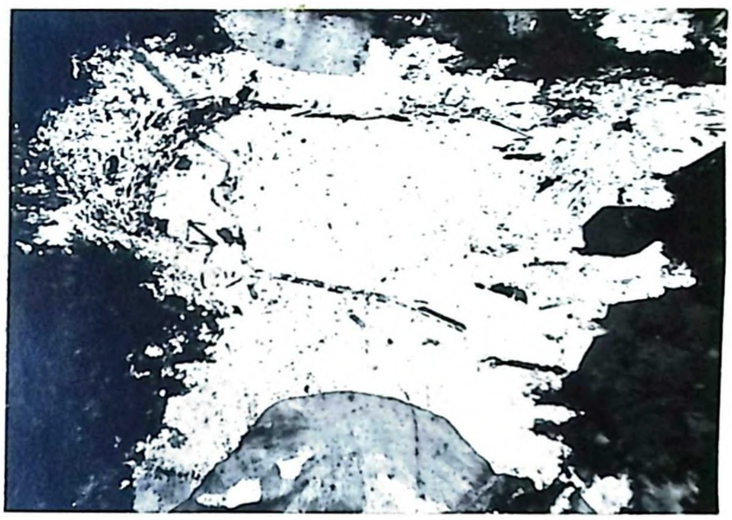

Figure 14

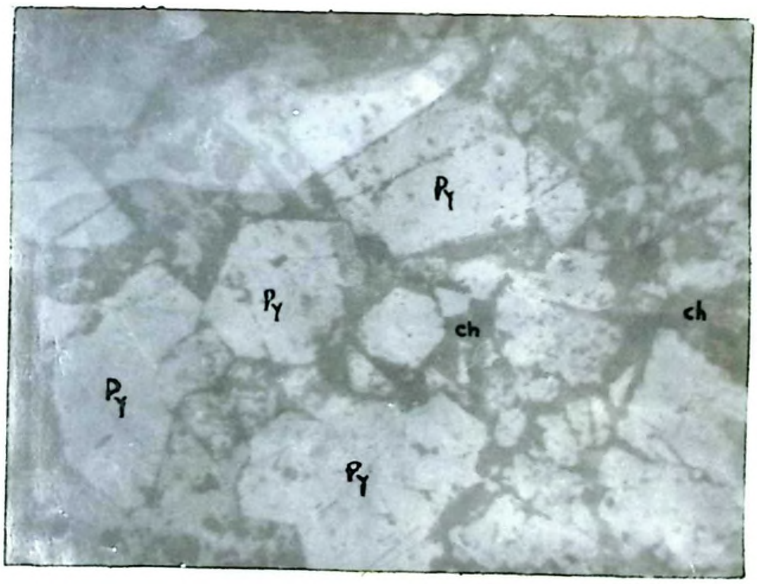

Figure 15

PLATE V

Figure 16

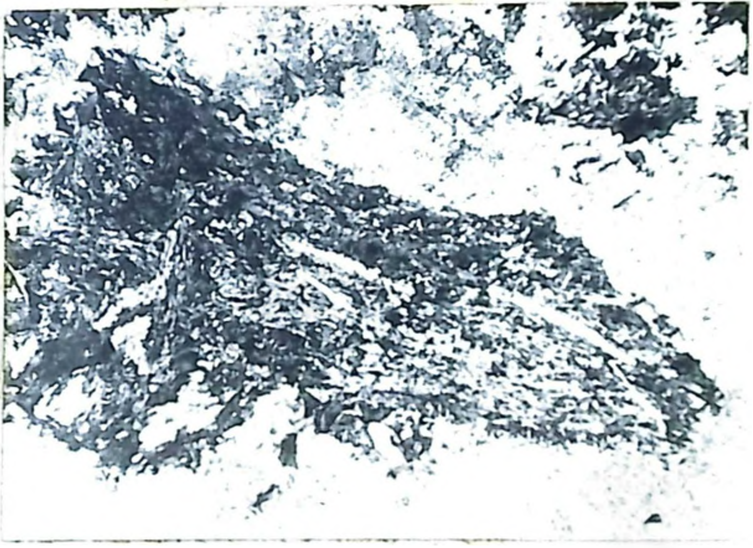

Figure 17

PLATE VI

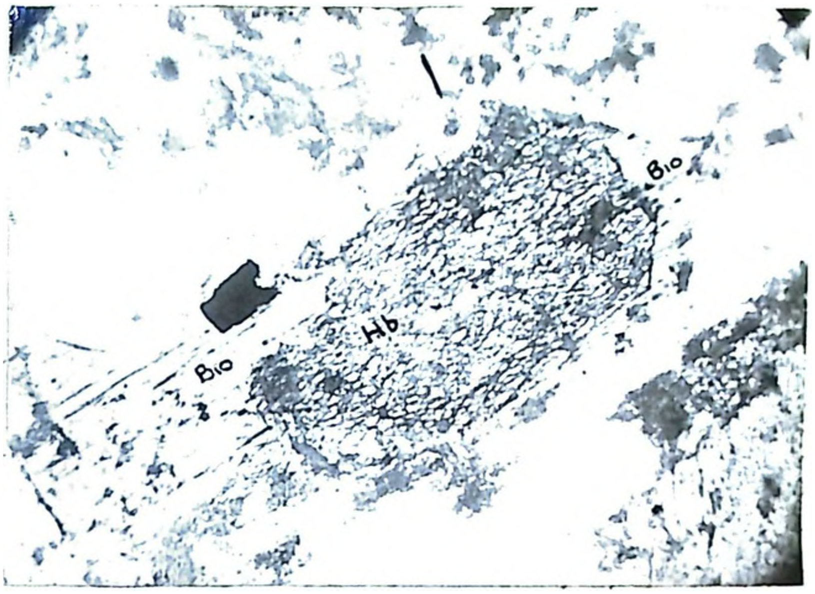

Figure 18

Figure 19

PLATE VII

Figure 20

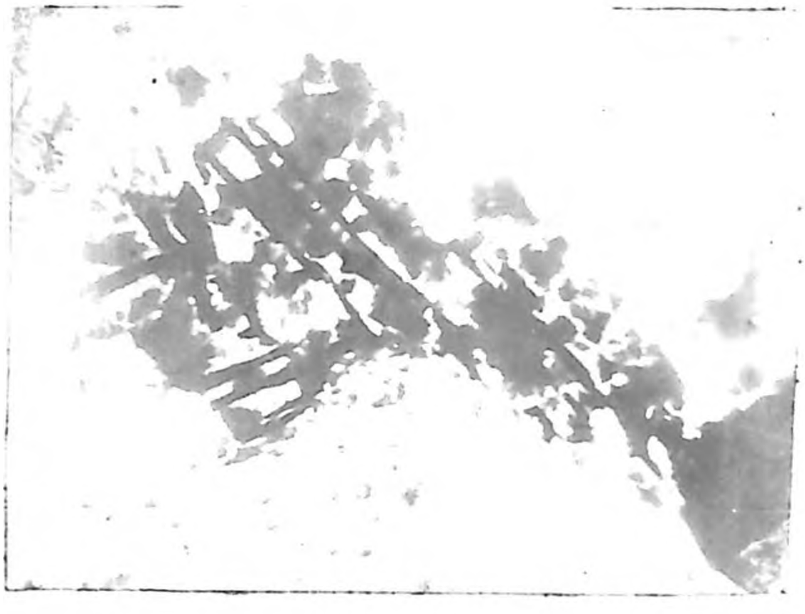

Figure 21

PLATE VIII

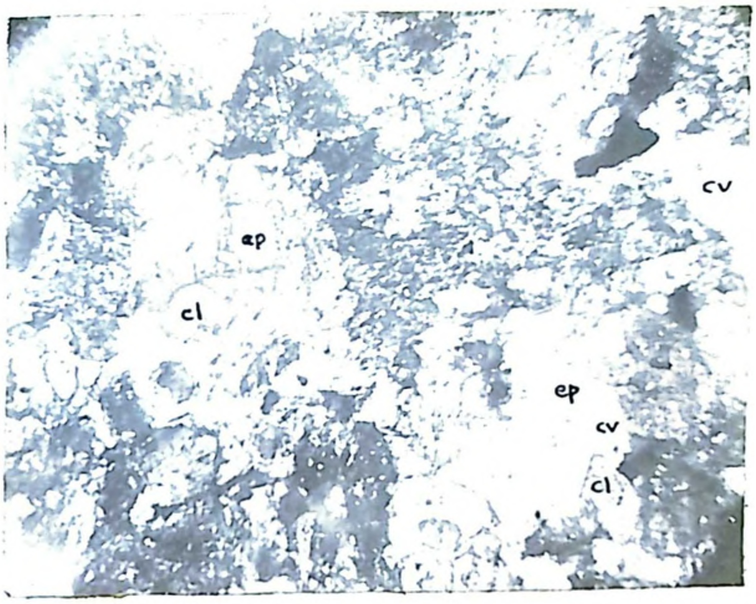

Figure 22

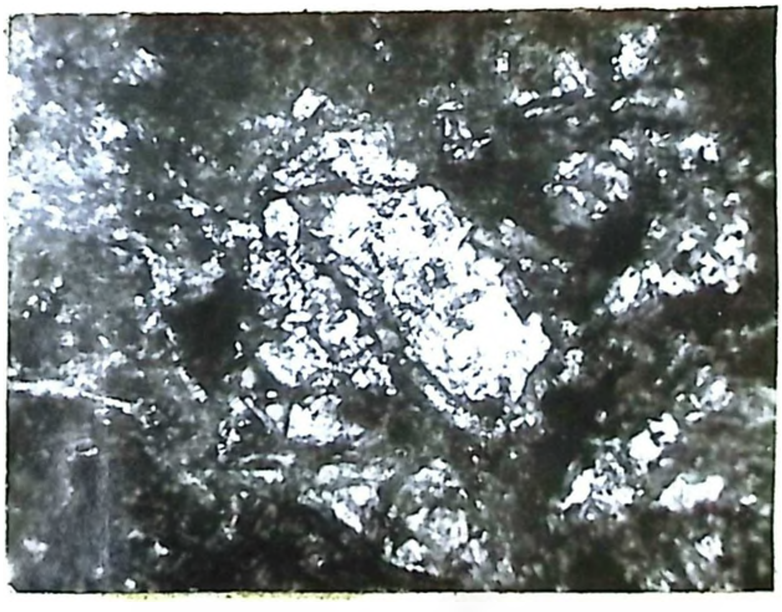

Figure 23

PLATE IX

Figure 24

Figure 25

PLATE X

Figure 26

Figure 27

PLATE XI

Figure 28

Figure 29