CANADA
DEPARTMENT OF MINES
HON. T. A. CRERAR, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

BUREAU OF ECONOMIC GEOLOGY
GEOLOGICAL SURVEY

MEMOIR 190

Geology and Mineral Deposits at the Mine of B. C. Nickel Mines, Limited, Yale District, B.C.

BY
H. C. Horwood

OTTAWA
J. O. PATENAUDE, I.S.O.
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1936

Price, 10 cents No. 2414

CANADA

DEPARTMENT OF MINES

HON. T. A. CRERAR, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

BUREAU OF ECONOMIC GEOLOGY

GEOLOGICAL SURVEY

MEMOIR 190

Geology and Mineral Deposits at the Mine of B. C. Nickel Mines, Limited, Yale District, B.C.

BY

H. C. Horwood

OTTAWA
J. O. PATENAUDE, I.S.O.
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1936

Price, 10 cents No. 2414

CONTENTS

Illustration

Geology and Mineral Deposits at the Mine of B.C. Nickel Mines, Limited, Yale District, B.C.

INTRODUCTION

The nickeliferous sulphide deposits owned by B.C. Nickel Mines, Limited, are in hornblendite that outcrops on the ridge between Stulkawhits and Emory creeks. The property, which includes one hundred and seventeen claims and fractions, may be conveniently reached by a 7-mile road up Stulkawhits creek from Choate on the Canadian Pacific railway or by pack trail up Emory creek. Choate is 6 miles up Fraser river from Hope and 95 miles by rail from Vancouver.

The writer made a reconnaissance examination of the surrounding territory[1] in June and July 1935, and was ably assisted by J. M. Cummings, T. C. Gibbs, J. W. McCammon, G. S. Armstrong, G. M. Rhodes, B. I. Nesbitt, and G. S. Williamson. In October the surface showings and the underground workings were examined in detail. Mr. C. B. North, engineer in charge of operations at the mine, materially assisted the examination by placing all maps and mine data, as well as camp facilities, at the disposal of the writer. E. Merrett, foreman, and B. S. Brown, engineer, were also of considerable assistance.

The property has been described by C. E. Cairnes[2] in 1924, by W. E. Cockfield and J. F. Walker[3] in 1933, in an unpublished manuscript by W. E. Cockfield[4] in 1934, and in annual reports of the Minister of Mines of British Columbia[5]. The writer is particularly indebted to Mr. Cockfield for permission to use his manuscript, as much of the data here present, especially on surface geology, were taken from this work.

The first discovery of nickel-bearing pyrrhotite in this region was made in 1923 by a trapper, Carl Zofka, who located what is now known as the Pride of Emory showing. Prospecting work carried on during the years 1923 to 1931 resulted in the location of a number of other showings. B.C. Nickel Company, which did part of this work, was reorganized in 1933 to permit prospecting and development work on the present extensive scale.

The area is within the Coast Range system of mountains and has the rugged topography so characteristic of their southern and eastern borders. The rainfall is heavy, especially in spring and autumn, after and before the snow. In winter heavy falls of snow at the higher elevations make transportation difficult. The ridge on which the property is

[1] Horwood, H. C.: Bureau of Economic Geology, Paper 36-4, 1936.
[2] Cairnes, C. E.: Geol. Surv., Canada, Sum. Rept. 1924, pt. A, pp. 100-106.
[3] Cockfield, W. E., and Walker, J. F.: Geol. Surv., Canada, Sum. Rept. 1933, pt. A pp. 62-68.
[4] Cockfield, W. E.: Unpublished report, 1934.
[5] Annual Reports of the Minister of Mines, B.C., 1923 to 1935.

located is rugged and has steep to precipitous slopes down to the creeks. The creeks have a steep gradient, and in their upper reaches, in the vicinity of the deposits, have narrow, sharply cut valleys. Stulkawhits creek drops about 3,000 feet in 5 miles. The road from Choate to the mine climbs from 220 feet on the Cariboo highway to 3,530 feet at No. 1 tunnel, in approximately 7 miles.

GEOLOGY

The rocks in the vicinity of the mine may be divided on the basis of age into six groups. Starting with the oldest these groups are: (1) late Palæozoic schists; (2) diorite, granodiorite, and granite of early Mesozoic age; (3) Cretaceous (?) conglomerate; (4) hornblendite of late Mesozoic age; (5) diorite and quartz diorite of late Mesozoic age; (6) Recent Fraser River gravels. Although only the first, the fourth, and the fifth groups are shown on the map of the property the other three will also be summarily described.

The map (Figure 1) is published by the courtesy of B.C. Nickel Mines, Limited. Except for a few minor alterations by W. E. Cockfield the geological boundaries are all plotted as located by the staff of the company.

LATE PALÆOZOIC SCHISTS

The schists are altered sedimentary and volcanic rocks, and in the vicinity of B.C. Nickel Mines, Limited, are almost entirely sediments. They are largely quartz-hornblende or quartz-biotite schists that probably were originally shaly sandstones. They are fine grained, dull grey or grey-green, and quite schistose, and contain from 60 to 80 per cent quartz, up to 15 per cent hornblende, up to 25 per cent biotite, and minor amounts of chlorite, andesine, magnetite, and garnet. An inclusion in the hornblendite on the summit of the ridge between Texas and Emory creeks has a higher percentage of quartz than is usual in most of the rock. The schists of volcanic origin are almost invariably fine-grained, greenish, hornblende schists of andesitic or dacitic origin. They are made up of about 60 per cent hornblende, 20 per cent quartz, 10 to 15 per cent andesine, and minor amounts of biotite, magnetite, and epidote. In one place the rock contains large amounts of chlorite and carbonate. The series has been folded, metamorphosed by intrusive rocks of Mesozoic age, and now occurs, for the most part, as large roof pendants in the batholithic mass.

DIORITE, GRANODIORITE, AND GRANITE OF EARLY MESOZOIC AGE

The earliest Mesozoic intrusives outcrop in a band paralleling Fraser river between the mine and the river, and in a roughly circular mass southwest of the property. The Fraser River band is a highly sheared and altered rock, generally almost white in colour, which varies from quartz diorite to granite. The southwestern mass is a grey-pink gneissic diorite made up almost entirely of andesine-labradorite and augite. The grey-pink diorite also occurs in two small outcrops on the road between No. 1 and No. 2 tunnels and in the 512-foot crosscut in the mine. These two bodies, believed to be inclusions in the hornblendite, were too small to plot on the map.

CRETACEOUS (?) CONGLOMERATE

Conglomerate, believed to be of Cretaceous age, outcrops in a long, narrow band that crosses Stulkawhits creek about 2 miles from its mouth. It overlies the early Mesozoic intrusives and the late Palæozoic schists. It is made up largely of materials derived from the intrusives, but also contains a few pebbles or boulders of volcanic and sedimentary origin.

HORNBLENDITE OF LATE MESOZOIC AGE

The hornblendite mass that contains the nickeliferous sulphide deposits is the next youngest formation in the region. It occupies an irregular area of approximately 1½ square miles and is intrusive into the late Palæozoic schists. Data obtained in mine workings and in diamond drill cores indicate that the entire mass has a steep north-northeast plunge. This point will be discussed in the paragraph on structure. Although its relation to the conglomerate is not known it is thought to be younger, as the surrounding diorite which is believed to be closely associated with it in age and origin intrudes the conglomerate. Hornblendite is the principal rock type of the mass, but variations to pyroxenite are common. On the surface it weathers readily to a reddish brown dirt that mantles most of the outcrops and renders accurate determination of the surface geology very difficult. The hornblendite varies from medium to very coarse grained, is dark greenish black in colour, and is made up almost entirely of hornblende. Hypersthene is a common minor constituent, magnetite, chromite, and sulphides are almost invariably present, and augite and labradorite occasionally occur.

Almost all the pyroxenitic variations are associated with the nickeliferous sulphide deposits and with them are believed to have segregated from the hornblendite. The principal pyroxene present, the orthorhombic variety hypersthene, gives the pyroxenitic rock a greyish bronze appearance that is quite distinct from the colour of the hornblendite. Every variation from a pure pyroxenite made up of hypersthene to a pure hornblendite exists, but the end members are relatively uncommon. In addition to hypersthene and hornblende the normal pyroxenite occasionally contains augite and olivine. Magnetite and chromite are usually present, and the sulphides pyrrhotite, pentlandite, and chalcopyrite are always important constituents. In one or two places there is a variation to an olivine-bearing rock that has the composition of a pyroxene dunite.

Although some hornblende has been developed by the reaction of the magma with hypersthene during crystallization of the rock, most of it is a primary product of crystallization and has been very little altered. Variations from pyroxenite to hornblendite are due to segregation rather than to partial alteration of the hypersthene. In general the order of crystallization of the various minerals was as follows: (1) magnetite and chromite; (2) olivine; (3) hypersthene; (4) augite; (5) hornblende; (6) labradorite; (7) sulphides. Small grains of magnetite and chromite, which were not differentiated in thin section, occur with somewhat rounded crystal faces and have been found included in hypersthene crystals. Olivine occurs in large grains that have been rounded and corroded by the later hypersthene. Small fractures with serpentine and magnetite criss-cross the olivine and indicate some alteration. Hypersthene occurs as large, well-formed grains that in most places have been rounded where they adjoin hornblende or sulphides. Augite, a rare constituent, appears to have formed after the hypersthene as it includes and corrodes crystals of this mineral. Hornblende, the last important silicate to crystallize, occurs in large and small hypidiomorphic crystals that surround and corrode the earlier minerals. Labradorite was noticed in only a few localities and there its interstitial nature between crystals of hornblende attest its later formation. The sulphides form interstitial material in all types of the basic intrusive, but are present in important amounts only with the pyroxenite or the hornblende pyroxenite. They were the last minerals to crystallize as they surround and corrode the earlier minerals and have been deposited along cleavage planes and in cracks across individual grains. Except for very fine selvages, too small to be determined mineralogically, the sulphides have produced no alteration in the silicates.

The basic intrusion is believed to be an early segregation from the magma that produced the surrounding later diorite. This point will be discussed after the diorite has been described.

DIORITE AND QUARTZ DIORITE OF LATE MESOZOIC AGE

The diorites are normally medium- to coarse-grained, light grey rocks that are typical of the Coast Range batholith. Locally, especially in the vicinity of the hornblendite, they have basic facies that may be classed as norites and gabbros. They occur as bodies of irregular shape intruding the hornblendite. Along their contacts with hornblendite they usually contain more than normal amounts of femic material and are rather fine grained. The normal diorite contains 60 to 65 per cent andesine, 5 to 15 per cent quartz, 10 to 30 per cent hornblende, 5 to 15 per cent biotite, and accessory magnetite, apatite, and pyrrhotite. In some places, adjoining areas of schist, the rock contains up to 15 or 20 per cent garnet that has undoubtedly been formed by assimilation of the schist. In other near-contact zones the rock grades into gabbro. In some places, near hornblendite, the diorite becomes gabbroic, but in general it grades into norite. The typical norite has about 65 per cent labradorite, 25 per cent hypersthene, 10 per cent hornblende, and accessory magnetite. Augite is occasionally present in small amounts. With a decrease in hypersthene and an increase in hornblende the rock becomes gabbro.

Dykes, which are thought to be the last evidences of activity in the magma that produced the hornblendite and the diorite, cut both these rocks. The dykes are believed to be closely related in time and origin to the intruded rocks, as they were injected during a period of fracturing but before a later fissure-filling and replacement mineralization that is believed to be genetically related to the diorite. They are of two varieties, an early basic type and a later more acidic type. The basic type occurs as fine- and coarse-grained black rocks made up of about 75 per cent hornblende and hypersthene, 25 per cent andesine or labradorite, and accessory magnetite. Hornblende is usually more abundant than hypersthene. This type of dyke, because of its resemblance to hornblendite, has been regarded as evidence that the hornblendite intruded the diorite. Its later origin than both these rocks was not previously recognized. The later more acidic type is a medium-grained, light grey diorite made up of 30 per cent hornblende and 70 per cent andesine. It has been found cutting the basic type in the same fracture plane and is believed to be complementary and of practically the same age.

HORNBLENDITE, DIORITE, AND DYKE, RELATIONSHIPS

The hornblendite, the diorite, and the later dykes are all believed to have originated from the same magma. The diorite cuts the hornblendite, has fine-grained margins along contacts with it, contains inclusions of it, and is, therefore, younger. The diorite and the harnblendite are similar mineralogically, as both contain hypersthene and hornblende of identical appearance. The diorite has contact facies that show striking similarities to both the hornblendic and the pyroxenitic variations of the basic intrusive. These similarities are strongly suggestive of a common origin for diorite and for hornblendite.

The short time interval between the intrusion of the basic rock and the diorite is also indicative of a common origin. The brevity of this interval is indicated by the lack of development of joints or faults in the hornblendite before intrusion of the diorite. Had joints and faults been present before the diorite was intruded, the diorite masses would probably have been guided by these structures. The lack of structural control is evidenced by the irregular shape and unordered distribution and arrangement of the diorite masses.

The minor development of fine-grained margins along the diorite intrusions suggests that the hornblendite had only partly cooled before emplacement of the diorite. It is believed that the basic rock is an early segregation of the magma that produced the diorite.

The dykes are believed to be genetically related to the hornblendite and to the diorite as they occur in cracks in these intrusives and are mineralogically very similar to them. They were intruded before the late fissure filling and replacement sulphide veinlets were formed and, therefore, must be closely related in time to the major intrusions.

The hornblendite mass probably extends to considerable depths as it intruded the schists after differentiating from the dioritic magma. However, the intrusion of the later diorite would undoubtedly tend to reduce the size of the hornblendite. This is suggested in the underground workings where masses of diorite occupy large areas in the basic rock, but the diorite could not be mapped in detail on the surface due to the mantle of overburden, so its variation in size from the surface down to the tunnel levels could not be ascertained. The hornblendite masses may decrease in size and pinch out at some unknown depth, but the hornblendite outcrops from the summit of the ridge to the bottom of the valley of Stulkawhits creek, a vertical range of over 1,000 feet, and should go much deeper.

RECENT FRASER RIVER GRAVELS

The youngest formation in the region is composed of gravel beds with some interbedded sands. These deposits form benches along Fraser river and were deposited by the river in post-glacial time when the river channel was over 100 feet above its present level. The gravels are well exposed on the mine road a short distance from Fraser river.

STRUCTURE

The structural features may be divided into primary, which includes all structures due to intrusion, and secondary, due to movements after intrusion.

Primary structures are illustrated in the underground geology. The hornblendite body has been intruded by many irregular masses of diorite that are probably connected either laterally or at depth with the main batholithic mass. Data from underground workings and diamond drill records show that the intrusion of the diorite was not controlled by any structural features in the hornblendite. It cuts through the rock, and in a couple of places across bodies of sulphide, in a manner so irregular that the only apparent control was the force of intrusion.

The position of the hornblendite on the surface and underground strongly suggests that it has a steep plunge to the northeast or north-northeast. As drift and weathered rock prevent accurate mapping of diorite bodies on the surface it is not known if the diorite masses have a similar plunge.

Some of the ore-bodies, particularly the two on the 3,800 crosscut and the 3,800 crosscut west, have a steep north-northeast plunge apparently parallel to that of the hornblendite mass. Other bodies, which appear to be arranged practically vertically, have not yet been completely defined.

Secondary structures, produced by tensional movement after the emplacement of the hornblendite and probably after the intrusion of the diorite, include faults and joints. They are believed to be later than the main diorite intrusions as the positions of the latter are not controlled by any such features and because faults and joints have been found cutting both hornblendite and diorite. They also cut across bodies of sulphides.

The strike of most of the faults is between north 15 degrees west and north 35 degrees east. The faults are normal faults and have a trend direction that is not confined within narrow limits. As any one block did not move the same amount throughout its entire length, stresses, set up normal to the fault planes on the east and west sides of the block, produced a few minor faults and many joints that, in general, have an east-west alinement. The direction of these minor faults lies outside of the 50-degree angle noted above. Faults that lie within this angle may be divided into two groups, those dipping east and those dipping west. As there are approximately four times as many east-dipping faults, and as these contain more crushed rock and gouge than the west-dipping type, it appears that most of the movement is down to the east. The dip of both types varies between wide limits but averages about 55 degrees.

A fault occurs on the east side of the small ore-body in the west end of the 3,900 crosscut. It strikes north 5 degrees west, dips 70 degrees east, and displaces the ore-body so that unmineralized hornblendite is brought into juxtaposition with massive sulphide. Drag structures in the fault clearly indicate that the eastern block has moved down relative to the western block. As data on the amount of displacement are lacking the position of the displaced part of the ore-body cannot be definitely ascertained. The narrow zone of gouge in the fault plane suggests that the displacement is less than 100 feet. As there is no evidence of lateral movement the sulphide mass should be found down to the east on the eastern side of the fault.

The paucity and minor nature of west-dipping faults indicate that movement along them is relatively unimportant.

Many of the faults and joints have been filled by small diorite or gabbro dykes or by veinlets of sulphides.

MINING DEVELOPMENT

The nickeliferous sulphide bodies have been located and developed by surface trenching, by magnetometer work, and by drifting, crosscutting, raising, and diamond drilling. Surface work includes open-cuts on sulphide outcrops and open-cuts and trenches across mineralized zones outlined by the magnetometer survey. This survey explored the ground in the neighbourhood of the two tunnels and outlined several small bodies of sulphides and several larger bodies that contain magnetite.

The two tunnels have been driven west from the Stulkawhits Creek side of the ridge into the hornblendite. No. 1 tunnel, at 3,530 feet elevation, is 4,629 feet long and has a western portal on the Emory Creek side of the ridge. No. 2 tunnel, at 3,275 feet elevation, is 2,321 feet long and almost parallel to No. 1 tunnel.

No. 1 tunnel has seven crosscuts which total 7,145 feet in length. In the following description the number of the crosscut in each case indicates its distance from the eastern portal. The 512-foot crosscut has been driven 3,360 feet north through massive hornblendite without picking up any ore. At its extremity a branch runs off to the northeast for 380 feet. The 1,600-foot crosscut has been driven 405 feet to the north. The last 155 feet are in an important sulphide body. A raise at 265 feet from the main tunnel is being driven on the east side of the crosscut. The 1,900-foot crosscut runs north from the main tunnel for 740 feet. A small body of sulphide was opened up in a short, 95-foot, branch crosscut that runs east. The 3,200-foot crosscut runs north from the only bend in the main tunnel. Although some sulphides were noticed at 220 feet no body of any importance was found. The 3,400-foot crosscut runs southwest and west for 560 feet to join the 3,800-foot crosscut and cuts three sulphide bodies for a total combined length of 188 feet. One of these is long and narrow and is followed closely by the workings. Its width has been determined by four short branch crosscuts totalling 98 feet. A raise is being driven on the west side of the first body to explore it toward the surface. The 3,800-foot crosscut has been driven for 313 feet south and for 205 feet west to explore two sulphide masses and is in these masses for a total distance of 108 feet. A raise is being driven in the body that lies at the junction of this crosscut and the west extension of the 3,400-foot crosscut. The 3,900-foot crosscut runs north for 256 feet and then west for 132 feet and cuts two small masses of sulphide. Three short branch crosscuts, totalling 65 feet, explore these masses and intersect a third very small body.

No. 2 tunnel did not open up any important ore-bodies and has only one short crosscut 55 feet long. A small mass of sulphide on the north side of the tunnel has been picked up in a diamond drill hole.

In October 1935 no work was being done in No. 2 tunnel. As the drifting program in No. 1 tunnel was almost complete work was being concentrated in the raises. The object of the work was to establish stations at 150 feet and 300 feet above No. 1 tunnel level and to delimit the sulphide masses on these levels by drifting and diamond drilling.

A thorough and extensive diamond drilling program has been employed to outline the sulphide bodies below the surface outcroppings and above and below their locations in the tunnels and crosscuts.

The company estimates of ore, as outlined by the development work described above, total over 1,000,000 tons that average 1·3 per cent nickel and 0·4 per cent copper. The company plans to outline another million tons before beginning construction of an aerial tramway and a mill. The proposed tramway will follow Stulkawhits Creek valley from the mine to the Canadian Pacific railway near Choate. If the necessary ore is found it is the intention of the company to erect a mill at the railway. The proposed mill will have a capacity of about 1,000 tons a day, and will make a sulphide concentrate suitable for smelting.

At present, power for the property is furnished by a small hydro-electric plant built by the company on Stulkawhits creek. The capacity is limited by the small areal extent of the drainage basin and by seasonal rainfall. A small dam is used for storage purposes and assists materially in regulating the flow.

MINERAL DEPOSITS

The mineral deposits are masses of sulphides irregularly distributed in the hornblendite. They occur as massive bodies that have up to 50 or 60 per cent sulphide and contain over 1 per cent nickel, and as disseminations of no economic interest. Small sulphide veinlets cut both types of deposits, but are of importance only where they enrich the massive sulphide bodies. The term "ore" is applied by the company to deposits that contain at least 1 per cent nickel. The principal sulphides are pyrrhotite, pentlandite, and chalcopyrite.

On the surface and on the No. 1 tunnel level the most promising bodies have been found in two localities, first in the neighbourhood of the 1,600- and 1,900-foot crosscuts and second around the 3,400-, 3,800-, and 3,900-foot crosscuts. Where not cut off by diorite or by faults these bodies appear to grade into the disseminated type. Although of rather irregular cross-section many of them have a long dimension that appears to parallel rather closely the steep north-northeast plunge of the hornblendite mass.

Disseminated deposits are extensive in the two localities mentioned above and they occur associated with the massive sulphide bodies and as separate segregations. They include, in these sections, at least 50 per cent of what has been mapped as hornblendite. The apparent concentration of both massive and disseminated deposits into two zones, when considered with the plunging nature of ore-bodies and hornblendite, suggests that these zones, both toward the surface and down the north-northeast plunge, are favourable locations for the search for other sulphide bodies. Elsewhere in the hornblendite the disseminated deposits occupy a much smaller percentage of the rock.

Sulphide veinlets cut massive sulphides, disseminated bodies, hornblendite, and, in places, the diorite. In the latter they are usually quite small, usually a fraction of an inch wide; elsewhere they vary up to 2 or 3 inches in width. They appear to be most numerous and widest in the more massive deposits.

Another type of mineral deposit, in which magnetite and minor amounts of chromite are the principal metallic minerals, was located in several places by magnetometer surveys near the surface above the north end of the 512-foot crosscut of No. 1 tunnel. This type of deposit, originally believed to contain sulphides, has been examined in a few open-cuts on the surface.

Small quartz veins occur in fractures and fault planes in the hornblendite, in the diorite, and, to a minor extent, in the dykes. They are usually small, seldom over 4 inches wide, and are barren of metallic minerals. The finely granular texture of the quartz and the common development of drusy structures indicate that the veins are relatively low-temperature deposits and were thus formed considerably later than the sulphide veinlets mentioned above.

As the ore-bodies so far located are similar in character a description of a few of them will suffice.

The Pride of Emory outcrop, the original discovery, is a rusty bluff some 30 feet high on the Emory Creek slope at elevation 4,150 feet. The deposit does not extend to the level of No. 1 tunnel at 3,530 feet, but lies 360 feet above and 200 feet north of a point in the tunnel 3,200 feet from the east portal. Surface stripping, diamond drilling, and magnetometer work have outlined a body that measures 60 feet by 130 feet on the surface, has a depth of 260 feet, and contains, according to company estimates, about 200,000 tons of sulphides that average 1·6 per cent nickel and 0·35 per cent copper. On the surface the deposit is a rusty mass of sulphides that is crossed by a fracture system that strikes north 20 degrees east. It appears to be surrounded by coarsely crystalline hornblendite.

The Brunswick showings are on the Emory Creek slope between elevations of 3,800 and 3,900 feet. The continuations of two of them have been found on the 3,400- and 3,800-foot crosscuts and in inclined diamond drill holes above and below the level of the crosscuts. These bodies are irregular in outline both on the surface and in the mine workings. They appear to have a well-defined north-northeast plunge of 65 or 70 degrees. The plunge of the other bodies has not yet been satisfactorily determined, but is believed to be steeper. The larger sulphide body in the 3,400-foot crosscut has a proved vertical length of 260 feet and, according to company records, approximately 45,000 tons of ore that contains 1·49 per cent nickel and 0·50 per cent copper. The sulphide mass at the south end of the 3,800-foot crosscut has, according to company estimates, 200,000 tons that average 1·10 per cent nickel and 0·35 per cent copper. The body in the 3,800-foot crosscut west has, according to the company, over 64,000 tons that contain 1·40 per cent nickel and 0·60 per cent copper.

Other important bodies lie to the east of the Brunswick showings. A sulphide mass at the end of the 1,600-foot crosscut contains, according to the company, about 90,000 tons that average 1·14 per cent nickel and 0·40 per cent copper. At the end of the crosscut the ore is rather massive and has over 60 per cent sulphides in places. Some of this concentration is due to the presence of chalcopyrite of replacement origin. The body is cut off on its northwestern side by diorite.

The showing in No. 1 tunnel between 1,305 and 1,430 feet from the eastern portal is more disseminated than those mentioned above. However, as company estimates indicate approximately 1·0 per nickel, it has been classed as ore.

Other bodies that have been located on the surface or underground are similar to those described. Company estimates of ore in October 1935 totalled over 1,000,000 tons, averaging 1·3 per cent nickel and 0·4 per cent copper. The presence of other elements, some of which may be of economic importance, has been ascertained in a few samples. Analyses made by the Mines Branch of eighteen samples of ore taken from several different sulphide bodies gave an average of 18·38 per cent iron, 1·89 per cent nickel, 0·14 per cent cobalt, 0·31 per cent chromium, 10·87 per cent sulphur, 0·70 per cent copper, and only a trace of arsenic. Two other assays of massive chalcopyrite and pyrrhotite had small amounts of silver. Although the average content of gold, platinum, palladium, or cobalt cannot be calculated, the fact that 25 tons of representative ore from the 1,600-foot crosscut carried 0·02 ounce of gold, 0·08 ounce of platinum and palladium, and 0·13 per cent cobalt indicates that these metals are important.

Surface exposures of sulphide masses weather to a rusty, gossan-like mass that, on account of the amount of silicates present, seldom forms a solid capping. In places, especially on small cliffs along the road where construction has stripped the overburden from nickel-bearing rock, greenish white stains and crusts of the hydrous nickel sulphate, morenosite, $NiSO_4 \cdot 7H_2O$, have been found.

MINERALOGY

The massive and disseminated sulphide bodies have the same mineralogical associations and relations; the later veinlets, although possessing some qualitative similarities, have distinctive textural characteristics. The former contain the following minerals, listed in order of abundance:

Pyrrhotite	Fe_nS_{n-1}
Pentlandite	(Ni, Fe) S. and violarite $(Ni, Fe)_3S_4$
Chalcopyrite	$CuFeS_2$
Magnetite	Fe_3O_4 and chromite $FeCr_2O_4$
Pyrite	FeS_2
Sphalerite	Zns
"Limonite"	Fe_2O_3 nH_2O
Linnæite?	Co_3S_4

In deposits where the sulphides are relatively massive and make up about 50 per cent of the rock there is about four times as much pyrrhotite as pentlandite. Chalcopyrite, magnetite, and chromite each make up about 2 or 3 per cent of the rock. The other constituents are rare.

The massive deposits vary from rather fine to coarse grained and have textural features suggestive of segregation origin. The sulphides occur as irregular grains or aggregations of grains around crystals of hypersthene and hornblende, and undoubtedly crystallized after the silicate minerals. In places the silicates present plane crystal faces to the sulphides, but usually they are rounded and apparently corroded. Many small blebs of pyrrhotite occur within crystals of the rock minerals and indicate that the sulphide was present before the silicates crystallized. Besides occurring as interstitial material and as blebs, the sulphides were noticed along cleavage planes and occasionally in cracks across the silicates. The sulphide-silicate rock may be likened to a porphyry in which the hypersthene and hornblende are phenocrysts and the sulphides groundmass. Where the phenocrysts are in excess the groundmass occurs as separate interstitial grain aggregations.

Although alteration of the silicates is practically lacking there appears to be a very slight amount along contacts with the sulphides where thin selvages of a secondary mineral have been developed. The selvages are so small that the contained mineral cannot be identified, even under the highest power of the microscope. This alteration was probably produced by the small amount of aqueous material that would be present in the magma under normal conditions of crystallization.

The metallic minerals have in general the following crystallization sequence: (1) magnetite and chromite, (2) pyrite, (3) pentlandite, (4) pyrrhotite, (5) chalcopyrite, and (6) sphalerite. Both magnetite and chromite occur as small crystals or as rounded grains scattered through the sulphide bodies and the hornblendite-pyroxenite. They are present in much larger amounts in the ore-bodies and afford additional evidence of the segregation origin of the sulphide masses. The chromite was not distinguished from the magnetite in polished section, but its presence is attested by chemical analyses. Both minerals occasionally occur within the silicate minerals and were the first to crystallize from the magma.

Rounded and corroded grains of pyrite occur surrounded or included by pyrrhotite or pentlandite and are probably of earlier origin. The mineral is present in very minor amounts as it was noticed in only a few of the polished sections.

Although most of the pentlandite is believed to have crystallized before the pyrrhotite some of it is undoubtedly later. The earlier variety occurs as crystals within the pyrrhotite and in places appears to have been slightly corroded and replaced along cleavage planes. Elongate, vein-like masses in the pyrrhotite appear to be of later origin. It is probable that the crystallization interval for pentlandite started before and finished after the pyrrhotite. In one section small needles projected out into the pyrrhotite from a narrow crack and were undoubtedly formed by solutions. As there was little or no pentlandite associated with the later replacement veinlets it is probable that the needles were deposited by solutions that formed as the end product of the silicate-sulphide magma.

Pyrrhotite, the most abundant sulphide, almost invariably occurs as grains or aggregates of grains surrounding crystals of the gangue minerals. In the 1,600-foot crosscut some of the ore is a coarse-grained, crystalline aggregate of gangue minerals, pyrrhotite, and pentlandite, that contains up to 12 per cent nickel. The pyrrhotite and the enclosed pentlandite make up about 60 per cent of the rock. They appear to have crystallized in place, as both sulphides and gangue minerals have a texture similar to that of other coarse-grained igneous rocks.

Chalcopyrite occurs as large grains with the pyrrhotite and as later aggregations that appear to have replaced the earlier sulphides. It is probable that some of the chalcopyrite had crystallized before the end of the crystallization period of the pyrrhotite. Where associated with pentlandite its relations are analogous to those of pyrrhotite. Although in places the copper mineral is plentiful, in general it occurs only in occasional grains.

A grey mineral, believed to be sphalerite, occurs in very minor amounts as small, rounded grains in chalcopyrite, and as small veinlets cutting chalcopyrite, pyrrhotite, and pentlandite. As it was noticed in only two or three sections and is not represented in any of the chemical analyses it is of rare occurrence.

A hard white mineral with variable anisotropism is believed to be the cobalt mineral linnæite. As it was noticed in very minor amounts in only one section, determinations were not conclusive. It occurs as small, irregular needles or stringers cutting both pyrrhotite and pentlandite. The presence of appreciable amounts of cobalt in the ore is a point in support of the determination.

The disseminated sulphide bodies have a mineral content and mineralogical relationships that are identical with those of the massive type. The percentage of sulphides is variable, usually under 20 per cent, and the nickel content under 1 per cent. The isolated interstitial arrangement of the sulphide grains further attests their presence in the rock before consolidation.

Sulphide veinlets of fissure-filling and replacement origin cut massive sulphide bodies, disseminated deposits, the hornblendite-pyroxenite, and the intrusive diorite, and are undoubtedly of later age than the sulphides of segregation origin. Chalcopyrite is by far the most abundant sulphide; pyrrhotite is present but usually in minor amounts. In the massive sulphides many of the veinlets are over an inch in width and appear to be the source of a large percentage of the chalcopyrite present. Most of the veinlets in the diorite are only a fraction of an inch wide. Replacement structures are well developed in both hand specimen and polished section. Although the veinlets have produced practically no alteration, included grains of both pyrrhotite and pentlandite appear to be rounded and corroded. Many minute veinlets cut gangue minerals as well as the pyrrhotite. The veinlets are of economic importance only where they enrich the massive sulphide bodies.

Secondary minerals are present near the surface in the sulphide bodies. Violarite, $(Ni,Fe)_3S_4$, is secondary after pentlandite as it occurs in bands bordering cracks and cleavage planes in that mineral. Some pentlandite crystals from specimens close to the surface have been almost entirely altered and can only be recognized by the presence of the original cleavage planes. Limonite, $Fe_2O_3\ nH_2O$, occurs as narrow, sinuous veinlets that cut both sulphide and gangue minerals. It has been developed from the pyrrhotite. Both minerals have been formed by the action of supergene waters on the sulphide bodies after they had been exposed by erosion.

The gangue minerals are all normal constituents of the basic rock that contains the deposits. The rock has been termed a hornblendite or a hornblende pyroxenite according to its two major variations. In the massive sulphide bodies hypersthene is the principal silicate, whereas away from the ore-bodies hypersthene is subordinate to hornblende. This concentration of the heavier, earlier forming hypersthene with the sulphides parallels the association of magnetite, chromite, and sulphides, and is indicative of segregation. Other gangue minerals that are present in small amounts include olivine, augite, biotite, and labradorite. They occur only in restricted sections and are not characteristic of the rock as a whole.

GENESIS OF THE SULPHIDES

It has been pointed out in different parts of this report that the massive and disseminated bodies of sulphides are probably of segregation origin and that the later sulphide veinlets have been formed by fissure filling and replacement.

The variation or gradation from what have been termed massive sulphide bodies to disseminations and to hornblendite with minor amounts of sulphides is a factor that is indicative of a segregation origin. Where not cut off by diorite or by faults the sulphide bodies grade out into material that contains pyrrhotite, pentlandite, and chalcopyrite, but cannot be classed as ore. These disseminations show similar gradations to a rock in which the minor amounts of sulphides are undoubtedly of primary origin.

The concentration of magnetite and chromite either with the sulphide or in separate bodies is further evidence of segregation. The disseminated masses and the normal hornblendite also contain accessory magnetite and chromite, but in much smaller amounts than the sulphide concentrations. These two oxides generally occur as idiomorphic grains and were the first minerals to crystallize from the magma. Their concentration at certain loci can be explained only by segregation. As sulphide masses are usually associated with a higher percentage of magnetite and chromite than is normal in the hornblendite, they also are probably of segregation origin.

The association of hypersthene and massive sulphide bodies is another fact suggestive of segregation. The hypersthene in the normal hornblendite is very minor in amount and occasionally completely lacking. The fact that it has a higher specific gravity than hornblende indicates that, under suitable conditions, its segregation is a normal process. Its association with magnetite and chromite is corroborative evidence.

The time relationship of basic intrusive, sulphide masses, and diorite, clearly indicates the early origin of the mineralization. Hornblendite and massive and disseminated sulphide bodies have been intruded by irregular tongues and bodies of diorite. This relationship proves that the sulphides were in place before the intrusion of the diorite. Therefore, they could not have been produced by the diorite and must owe their origin to some process genetically related to that of the hornblendite.

The complete lack of structural control for both the sulphide bodies and the later dioritic intrusives is a factor indicating an origin for the sulphides that is independent of structure. The lack of the development of any structural features in the hornblendite until after the intrusion of the diorite is attested by the irregular shape and disposition of the intrusion. The fracturing and faulting that are present undoubtedly developed after the injection of the diorite as they are evident in both early basic and later acidic rocks.

Textural features indicate that the sulphides were the last minerals to crystallize. They are present as interstitial grains or aggregates of grains between the silicates and have characteristics that are similar to sulphides known to have been primary constituents. The sulphides vary in grain size with the associated silicate minerals and possess a fabric comparable with that of such a mineral as quartz, which is the last to crystallize from a magma. The occurrence of veinlets and films of sulphides in cracks and along cleavage planes in the silicate minerals is not necessarily evidence against a segregation origin as such textures are known to occur in rocks where sulphides are primary constituents[1].

The almost complete lack of any alteration in the silicates associated with the sulphides in the massive or disseminated bodies is an additional point in favour of a segregation origin. Very thin selvages, so small that their mineralogical content could not be determined under the high power of the microscope, were the only evidences of any change. They were produced probably by a small amount of aqueous material that is normally present in all igneous rocks. Much of the alteration, minor as it is, is usually associated with the late sulphide veinlets that will be mentioned below.

The disposition or arrangement of the sulphide masses is strongly indicative of a segregation origin. The bodies are separate and unrelated and come to an end in relatively short distances down the plunge, as well as laterally. The plunge, which is approximately 65 to 70 degrees to the north-northeast, parallels that of the hornblende mass and is the long axis for both the sulphide bodies and the country rock. This parallelism strongly suggests that most of the segregation took place at some locus well below the present position of both sulphides and hornblendite, and that these segregates were intruded simultaneously. As the silicates are not crushed or broken to any appreciable extent much of the separation must have taken place in the liquid state before intrusion. The shape and arrangement of the sulphide masses cannot be explained by segregation after emplacement.

After the emplacement of the hornblendite with its segregations of sulphides, oxides, and silicates, and after the intrusion of the diorite, the

[1] Newhouse, W. H.: "Opaque Oxides and Sulphides in Common Igneous Rocks"; Bull. G.S.A., vol. 47, 1936, pp. 1-52.

region was affected by some movement due to tensional stress. This stress resulted in the development of joints, faults, and narrow shear zones. Before the effects of the stress were complete, or during a short period of temporary stability, small dykes of basic and acidic nature were intruded along lines of weakness. These intrusives were also fractured to a minor extent.

After dyke intrusion and fracturing a late stage of sulphide mineralization produced small fissure-filling or replacement veinlets along fractures and faults. These veinlets are generally under an inch wide. They appear to be wider and more numerous in fractures in sulphide bodies rather than in the hornblendite or the diorite. It is possible that some of these veinlets were formed after the intrusion of the diorite but before the injection of the dykes. Some of the sulphides at least are later than the dykes as they occur in fractures in them. The sulphides in these veinlets are believed to be genetically related to the dioritic intrusives.

The development of small, barren, drusy quartz veins in the faults and shear zones followed the last sulphide mineralization. Their fine-grained and drusy nature suggests relatively low-temperature conditions and they were probably formed a considerable time after the sulphide veinlets. They are the last representatives of igneous activity and mineralization in the region.