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GEOLOGICAL REPORT 18

CALUMET ISLAND AREA

PONTIAC COUNTY.

by

F. Fitz Osborne

QUEBEC

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1944

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PONTIAC COUNTY

by F.Fitz Osborne

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CALUMET ISLAND AREA

PONTIAC COUNTY

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INTRODUCTION

Location and Previous Work

Calumet island, lying between two channels of the Ottawa river, is about sixty miles above Ottawa. The village of Bryson is on the Quebec mainland facing the island and is only a short distance south of the sole bridge crossing to the island. Campbell's Bay, north of Bryson, is opposite to, and may be reached by a ferry from, Calumet Island village.

The steeper slopes of the island are wooded, but the clay bottoms and sand and gravel terraces are farmed. There is some lumbering, but agriculture is the principal industry. Mining, on the ground now held by Calumet Mines, Limited, has been carried on at intervals for many years, and a few prospect pits have been put down elsewhere with the hope of finding occurrences of zinc-lead ore.

Calumet island is within an area mapped by Ells (1), and the occurrence of lead and zinc minerals is noted in his report. Goranson (2) later mapped the geology of the island and described the occurrences of ore. More recently, a diamond-drilling campaign by Calumet Mines, Limited, has made available much additional information regarding the ore deposit and the surrounding rocks. It was felt that much might be learned from a detailed study of the drill cores and, while this work was in progress, advantage was taken of the opportunity to re-study the geology of the southern part of the Island. An interpretation of the rocks, and of the relationship of the orebodies - somewhat at variance with the views expressed by Goranson - is presented herein.

The successful development of the zinc and lead ores at Balmat and Edwards, in the State of New York, in the part of the Laurentian shield there, and the history of the successful operation of the Tétreault mine, in Montauban township, Portneuf county, Quebec, make it particularly desirable to determine the mode of occurrence of the ore minerals at Calumet in order to assist in the development of criteria whereby prospecting for base-metals in the Laurentian area may be assisted. The zinc-lead ores at the localities mentioned show similarities in their occurrence, but, at the same time, there are significant differences, and a knowledge of these is particularly important in searching for deposits of such ore elsewhere. At Balmat and Edwards, an impure dolomite layer intercalated in a dominant limestone series is the host for the ore. At Tétreault, the ore is principally in a pod of carbon-

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(1) ELLS, R.W., Geology of Portions of Pontiac, Carleton, and Renfrew Counties; Geol. Surv. Can., Rept. No.977, 1907.

(2) GORANSON, R.W., Calumet Island, Pontiac County, Quebec; Geol. Surv. Can., Summ. Rept., 1925, Pt.C, pp.105-124.

ate rock that was protected and enclosed by non-carbonate rocks. At Calumet Mines, the greater dimensions of the orebodies were fixed by a layer of fissile biotite gneiss, and carbonate rocks had a subordinate to negligible role in determining the disposition of the orebodies. The influence of structure in determining channel-ways for metallizing solutions is important in all the properties mentioned. A prospector, therefore, should search for rocks that are sufficiently different from those surrounding them that they could have acted as a channel for metallizing solutions.

Acknowledgments

Dr. Paul Armstrong, Consulting Geologist for Calumet Mines, Limited, co-operated in the work by allowing the writer access to all the geological information concerning that property. René Béland, assistant, was employed principally in draughting, and rendered efficient service. Pierre Mauffette made a study of thin sections of the principal rocks of the deposit, this work being carried out in the petrographic laboratory, McGill University. W.W. Moorhouse, graduate student at Columbia University, assisted in the mapping of the Calumet Mines property, but the writer is solely responsible for the divisions used in mapping.

GENERAL GEOLOGY

The oldest rocks belong to the Grenville series. Quartzites and garnetiferous gneisses, which in many localities form an important part of the Grenville series, are not abundant at Calumet, but crystalline limestones occur in force. The complete determination of the structural position and original character of some of the rocks must await data from the mapping of a large nearby region. The suggestion is offered here that the Grenville rocks consisted originally of clastic argillaceous sediments with intercalated beds of limestone and with carbonate present also as an impurity in the associate sediments. Dominantly carbonate rocks with minor clastic zones near their base overlay the clastic rocks. The assumption that the limestone members were originally higher in the series than the clastic members is based on two facts. In the marginal note to the regional geological map (1) of the district, Ells states that the limestones are near the top of the 'Archaean', and in the region of the type locality for the Grenville series in Quebec, the limestones appear to be higher in the series than the clastic beds, now represented by quartzite and gneisses. The section at Calumet may be visualized, therefore, as originally a series of muds and more or less calcareous shales passing by intercalation and gradation into a relatively pure limestone. During the subsequent history of the rocks, the limestones have been the only ones to retain many of their original characteristics.

The limestones have been extensively recrystallized, and in some localities they have been silicated, with the formation of diopside, tremolite, and related minerals. Practically all traces of the original bedding surfaces have been destroyed, and, instead, a well-defined schistosity and foliation, commonly defined by the silicate layers, has been formed. The pseudo-bedding structures

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(1) Pembroke Sheet; Geol. Surv. Can., Map No.122, Pub. No.660, 1906.

are in the main parallel to the nearest contact with the silicate rocks, and have been emphasized by replacement along the surfaces of movement, so that a layered effect is visible. An observer lacking experience with the Grenville rocks might easily mistake the structure for bedding. On the east, or Quebec mainland, side of the island, the foliation or layering dips at relatively low angles eastward and the limestones structurally overlie the mass of silicate rocks that form the main part of the southern half of the island. The limestone band may be traced around the southern end of the island to the western, or Ontario, side, where the dip is approximately the same as on the eastern side, but where the limestones pass beneath rather than over the silicate rocks. Limestones also pass beneath the silicate rocks on the north end of the area mapped. These relationships suggest that the southern part of the island is a close and overturned fold. If the suggestion of the relative positions of the carbonate and silicate bands is correct, the structure is an anticline overturned to the west. The distribution of the limestones in the area mapped is suggestive of a synclinal structure, and the structure may indeed be such if, in this part of the Laurentian region, clastics overlie limestones. Examination of the areal map prepared by Ells (1) shows that the structure is probably a minor one and that the principal structure on the island is the overturned drag fold. This probability is strengthened by the fact that Ells' map shows limestone bands with two trends, with a structural vertex near Calumet island.

The clastic sediments have been drastically altered. Near the limestones they have been converted to amphibolites of various types. Some have the feather structure found in the thin-layered amphibolites derived from impure limestones elsewhere in the Grenville sub-province, but many of them are some other variety of amphibolite. One important variety contains relic carbonates, but such rocks are subordinate to hornblende and biotite gneisses derived from these and related rocks. The less calcareous members of the series have been altered to micaceous rocks, of which the rusty-weathering gneisses found associated with the limestone are characteristic examples. The fissile micaceous rocks were, however, altered by the penetration of granitic magma with formation of medium to fine grained, moderately leucocratic gneisses, for which the term 'migmatite' is appropriate. The hill known locally as 'the mountain' on the southeast side of the island, Plate I-A, is composed of such granitic gneisses, derived from the argillaceous rocks, together with darker coloured migmatites derived from originally amphibolitic rocks. Aerial photographs of the mountain, Plate II-A, show the almost complete nose of the structure defined by the etching of the beds of diverse composition. Similar alternation of beds may be found elsewhere, particularly near the northern part of the area mapped; but in a band extending southeastward across the island, the layered character of the rocks has been destroyed and the rocks have been converted to a medium-grained, rather basic gneiss characterized by abundant glistening hornblende and a prevailingly dark colour. Some of these rocks have a schistosity parallel to that of the anticlinal structure, but most of them have been recrystallized along shear surfaces that strike east and west and dip steeply north, so that, over a large area, the east-west strike prevails; but even in many of the outcrops of these rocks, relic structures belonging to the earlier deformation may be found.

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(1) <u>Op. cit</u>.

Intrusive masses of pink granite are quite common, but most of them are small. Injections of pink granite in lit par lit fashion into gneisses are found, particularly in certain zones in, and along the edges of, the mass of silicate rock near its contacts with the limestones. In some places, the pink granite forms injections along the east-west-striking shear structures.

The granitization of some of the rocks has been so complete that they have been converted to light-coloured migmatites which resemble granite orthogneisses in most respects. Such rocks have hornblende and biotite as dark minerals, with some garnet. The dominant constituents are, however, quartz and feldspar. Except for their field relationships, such rocks might be mistaken for a moderately contaminated granite, but their origin by replacement of the adjacent formations makes it clear that they have been developed from older Grenville rocks by migmatization. Such migmatites are particularly well developed in and near the property of Calumet Mines, Limited, where a prominent band occurs below the principal ore horizon and several bands above it.

Several small stocks of Morin or Buckingham gabbro occur in the limestones near Bryson. One large mass forms the backbone of the ridge that flanks the east side of the Ottawa river from Bryson for some distance north. A small dyke of gabbro trends across the structure of the limestone and cuts both limestones and migmatites on the island and the limestones near Bryson. A dyke of diorite porphyry or diabase cuts the ore at the Calumet Mines property. Small dykes of lamprophyric habit cut the ore zone and are found also in a few other localities in the region. They are post-ore and more remarkable for their persistence than their thickness.

The geological history may be summarized as follows:

(1) Grenville sedimentation of clastic and impure carbonate beds followed by limestone.

(2) Folding and overturning of the Grenville series. Formation of amphibolite and gneisses.

(3) Migmatization of the rocks, yielding a pseudomorph of the older structure.

(4) Migmatization, controlled by the east-west shearing, tending to obliterate the earlier structure.

(5) Injection of Buckingham gabbro.

(6) Injection of pink granite with accompanying diopsidation.

(7) Injection of aplites and pegmatites.

(8) Formation of ore at Calumet Mines property.

(9) Injection of lamprophyre and diabase dykes.

(10) Erosion.

(11) Deposition of Lower Palaeozoic rocks (evident on north part of island.)

(12) Faulting.

(13) Erosion.

The Precambrian history of the region is very complex, and it is possible that some of the metamorphic effects recorded above as consecutive were part of one and the same episode. The field evidence, however, supports the sequence of events outlined. Very little of the Palaeozoic and younger history is evident in the southern part of the area. Dr. W.B. Mather informed (1) the writer of an occurrence of Lower Palaeozoic limestones under marshy ground on lot 9, range I, Calumet island. This is the only occurrence of such sedimentary rocks on the southern part of the island. Although faults are known to have displaced Palaeozoic rocks in the Ottawa valley and are probably present near Calumet, no direct evidence of them was noted in the field.

STRUCTURAL GEOLOGY

The relatively small area mapped in detail on Calumet island prevents more than a suggestion to be made concerning the structure. The scale of the map by Ells (2) of the large area near the island does not lend itself to recording data useful for determining details of structure, and the more detailed map of the island by Goranson (3) has no dip and strike symbols. In addition, the rocks of the island have an exceptionally complex history, so that many original structures have been obliterated or modified.

The most conspicuous structural feature is the banding shown by the rocks on the eminence locally known as 'the mountain', near the southern tip of the island. The aerial photographs and traverses show that this hill is composed of alternating bands, 50 to 100 feet thick, of fine-grained, rather leucocratic biotite gneiss, and fine-grained, more mafic hornblende-biotite gneiss, and that these form an overturned fold whose axis pitches to the east at about 20°. If, as suggested above, the limestones originally overlay the silicate rocks, the fold is an anticline overturned to the west. In any case, the limestones on the east side of the island dip at low angles to the east, as do those on the west side of the fold. The distribution of the limestones suggests that the outcrops of them along the two channels of the river about the island are due to drag folds related to a larger structure.

The original fold structure has been modified, and the gneisses and original amphibolites have been much sheared, so that medium-grained hornblende and hornblende-biotite gneisses have been formed. These gneisses are well developed from lot 8 of ranges I, II, III, and IV, northward. Foliation and schistosity strike northwest and east-west. The east-west shearing direction is the younger and in places may be seen developing at the expense of the northwestward-striking schistosity. Despite the presence of shears, older schistosity parallel to what is probably bedding may be detected in many of the outcrops. The old schistosity conforms in general to projections of the structural trends of the fold on the 'mountain'.

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(1) Oral communication.

(2) <u>Op. cit</u>.

(3) Geol. Surv. Can., Summ. Rept., Pt. <u>C</u>, 1925.

The edge of a batholith of granite crops out east of Campbell's Bay. Along its west border it is in reality a lit par lit injection complex in which the schistosity, which is nearly vertical, strikes N.20°W. Granitic material belonging to this intrusive has injected the shear planes in the hornblende and biotite gneisses.

From the examination of the exposures, one gets the impression that a great many of the gneisses have been formed by a 'blocky' type of adjustment in which the foliation has been developed as a result of movement between crustal blocks of small dimensions, and that the zones of gneisses with consistent direction of foliation have allowed adjustment in the crust much as would clean-cut faults at higher levels, that is, under less pressure. Such an explanation would account for the narrowness of belts of gneiss with consistent foliation and for the way in which the zones tend to ramify and turn along other adjustment surfaces.

The conditions during metamorphism were so rigorous at Calumet that profound changes were brought about in the rocks. In places, parts of the rocks were dissolved and re-precipitated, resulting in segregation of minerals; elsewhere, bands of originally sedimentary material were converted to granite gneisses by introduction and re-arrangement of constituents. The operation of this process results in the formation of migmatites or synthetic rocks, and it is certain that some petrologists would consider all the gneisses 'migmatites'; but for purposes of this report only the part of the Grenville series that has been converted to a granite gneiss is termed migmatite.

One significant structural element remains to be mentioned and that is the direction of elongation of crystals, of axes of plication, and of similar linear features. Over practically all the island, the direction of elongation is east and west and the pitch is 20° to 30° to the east. The constancy of the direction is really remarkable when the diversity of attitude of structural features such as schistosity, bedding, and foliation is considered. The joints, however, show a close relationship to the lineation. It would add considerably to the complexity of this report to discuss in detail the applications of the data related to the lineation in working out the structure of the area, and for that reason it is omitted. The purpose of this paragraph is, therefore, to place on record the fact that a pronounced and consistent direction of elongation is present.

PETROLOGY

For purposes of discussion, the rocks may be treated in three principal sections, which are: (1) the silicate rocks of the Grenville series and the gneisses formed by their shearing; (2) the carbonate rocks of the Grenville series; and (3) the igneous rocks. In addition, another category of rocks which includes migmatites, rocks which retain evidence of their sedimentary origin but are due to the action of magmas or derivatives of magmas, must be mentioned. On the areal map accompanying this report, twelve formations are shown. Many more units than this were observed in the field, but difficulties of presentation make it necessary to combine them, and several similar kinds of rocks are grouped as one formation. Even within the formations shown on the map there are gradations, but the principal rocks are as indicated. In considerable measure, too, the units are grouped to bring out the principal structural features of the area.

The Grenville paragneisses probably did not originally have so great a diversity of composition as the present character of the rocks would suggest. It is the writer's belief that the part of the Grenville series that gave rise to the rocks at Calumet originally consisted of impure argillaceous sedimentary rocks interbedded with bands of more limy or magnesian character, some of which approached limestone in character. The purer calcite and dolomite rocks resulted from the recrystallization of the limy beds, probably with the addition of MgO in the case of the dolomites. Undoubtedly, the silicate impurities now represented by the contact-metamorphic minerals caused some loss of CO_2, but, in the main, there is little evidence that the composition of the carbonate rocks has been drastically altered.

Metamorphism of the purer clayey beds gave rise to biotite schists. Hornblende was formed in minor amount. The biotite schists were fissile and so were open to penetration by solutions pervading the rocks. Some of the solutions carried sulphides of iron, so that pyrite and pyrrhotite were deposited. This is the reason for the common rusty weathering of these rocks. The limestones were apparently relatively impermeable to solutions, whereas the intercalated fissile schists offered paths by which the solutions could penetrate, and so the rusty-weathering gneisses in the limestones were formed.

Recrystallization of beds that were intermediate in composition between the purer argillaceous and the limy types took a somewhat different course. The CO_2 was for the most part expelled and the lime and magnesia promoted the formation of pyroxene and amphibole, along with medium calcic plagioclase. Various types of amphibolites resulted. In some, relic carbonates are found; in others, the rocks consist entirely of silicates. The amphibolites lack the schistosity found in the biotite gneisses, and resemble diorites in texture and structure, although a gneissic structure is faintly visible in many outcrops. They were not so permeable to solutions as the biotite gneisses.

Amphibolites form the selvages of some of the biotite gneisses in limestone, and, in other places, the biotite gneisses grade into amphibolites where more lime was present in the original sediments.

The differences between the biotite gneisses, the amphibolites, and the calcareous rocks were accentuated by recrystallization accompanying shearing. The amphibolites yielded dark-coloured hornblende or hornblende-biotite gneisses, whereas the biotite gneisses, which were not abundant, tended to lose their identity and be converted to gneisses of granitic aspect. The limestones were not drastically altered lithologically.

Differences in the physical characters also determined differences in the susceptibility to injection and granitization. The biotite gneisses were easily altered, and some of them yielded granite gneisses with or without garnet. These rocks betray their composite origin in retention of old internal structures. Many of the amphibolites were not so amenable to injection and yielded composite gneisses only along their contacts with other rocks and along zones of strong shearing.

Lit par lit granitic injections are found in the Grenville formations other than limestone. In some places, the injected granitic material is pink and in others grey or buff. The injections are, in the main, very regular and tend to follow the foliation.

Crystalline Limestones

The crystalline limestones are the most easily recognized members of the Grenville series in the vicinity of Calumet. Dolomitic and serpentine-bearing varieties are common. Some layers contain much diopside, and relatively large masses of white diopside rock occur in a number of places. The diopside rock is particularly well exposed along the river channels, where the limestone that formerly enveloped it has been eroded away. Besides serpentine and diopside, phlogopite, tremolite, chondrodite, sphene, and chlorite are of sporadic occurrence. Brucite is common as an accessory mineral in parts of the band flanking the southern part of the island on its eastern side. In some places, the brucite is sufficiently abundant that the brucite-bearing bands have been considered as a possible commercial source of magnesia.

The limestones are medium to coarse grained. The flow layers developed by the deformation cut across bedding structures and have controlled the recrystallization to such an extent that the layering may easily be mistaken for bedding. The layering is not without its structural significance, for near silicate rocks it is normally parallel to the contact between these and the crystalline limestone. Farther from the contacts, the structure is less regular and may be replaced by very irregular flow layers developed in consequence of the plastic yielding of the limestone.

Gypsum and anhydrite were noted in the cores from deep drilling at the Calumet Mines property. Their significance will be discussed in the section on that property.

Gabbro

Rocks of gabbro type are found on the mainland to the southeast of the island, and in small volume also on the island itself. The gabbro is prevailingly dark green and of medium granularity, but lighter-coloured, coarse-grained facies were seen in some places. The fine grain of much of the gabbro makes it difficult to distinguish this rock from the hornblende gneisses, especially where, as in wooded areas, it is poorly exposed. For that reason, some of the hornblende gneisses are included with gabbro as a separate colour on the map.

Besides the large mass of gabbro that extends from Bryson northward on the east side of the Ottawa river, two small stocks cut the limestone west of Carswell's quarry and a dyke of the rock is exposed near the north end of Bryson village. An outcrop of similar rock was seen on Calumet island on the projected trend of this dyke.

It was recognized in the field that the gabbro is far from uniform in character, but its general resemblance to the basic facies of the Morin, or Buckingham, series is so close that it may be correlated with the latter with fair assurance.

Granite

The edge of a large mass of pink granite crops out northeast of Campbell's Bay. In places, the rock is strongly gneissic, with many inclusions; elsewhere, it is porphyritic - some was seen with phenocrysts of microcline two inches in diameter. Dykes and sills of a similar pink granite crop out on Calumet island and along the contact between the gabbro and the limestone near Bryson.

A dyke of pink granite cuts gabbro near the highway to Campbell's Bay, at a point half a mile north of the bridge to Calumet island. Although the dyke is narrow, it has an alteration zone 100 feet wide bounding it, across which the gabbro has been converted to a granular diopside rock, with veins of quartz and occasional crystals of phlogopite.

Several occurrences of fine grained, pink granite were seen on Calumet island. The largest, in and near lot 6, ranges I and II of Calumet island, is stock-like, with vertical or outward dipping contacts, in which respect it differs from the mass near Campbell's Bay. It is doubtful whether all the pink granites should be grouped together as related, but in default of evidence, one way or the other, they are all indicated in one colour on the accompanying map. Setting aside the uncertainty of the correlation of the stock and some other small masses on the island, the granites can be assigned to the acidic part of the Morin, or Pine Hill, series.

Diabase and Lamprophyre Dykes

Lamprophyre dykes, one to two feet thick, were observed to cut the ore in drill holes at the Calumet Mines property. The dykes are persistent and can be correlated between successive rows of holes. A few similar dykes were observed elsewhere on the island.

A diabase dyke is shown on the plan of the Calumet Mines property. In places, it is of the nature of a diorite porphyry, but in its central portion it has the typical ophitic or diabasic texture. Some drill holes pass through ore into the dyke, which is devoid of mineralization and thus probably is post-ore. One other diabase dyke was observed on lots A and B, South range, Calumet island.

The relative ages of the diabase and lamprophyre dykes are not known, but the lamprophyres are probably older than diabase.

ECONOMIC GEOLOGY

Summary of Conclusions

Intensive exploration, mainly by diamond drilling, has disclosed bodies totalling more than one million tons of ore containing lead, zinc, gold, and silver on the property of Calumet Mines, Limited.

Exploration in other parts of the area, almost entirely limited to test-pitting and other surface work, has failed to reveal any important indication of the presence of similar ore shoots.

The regional geology is favourable to the occurrence of deposits of mica and of feldspar, but no deposits of these minerals worthy of special mention have been discovered.

Brucite-bearing limestones are found in the area. Brucite, hydrous magnesium oxide, is a possible commercial source of magnesia and of magnesium metal. Interest in the known brucite deposits of this area has for the present been overshadowed by the discovery and development of larger deposits elsewhere in Quebec.

Zinc and Lead

Calumet Mines, Limited

The occurrence of zinc-lead ore on lots 9, 10, 11 and 12 of range IV, Calumet island, has been known for many years, and sporadic attempts have been made to exploit the deposits. In 1912, a gravity mill was erected, but it was operated for only a short time and has since been destroyed by fire. In 1926, the British Metals Corporation (Canada), Limited, took an option on the property, unwatered some of the old workings, and trenched part of the surface. The results of their examination were reported as disappointing and the option was not exercised.

In 1937, Calumet Mines, Limited, acquired the property and started an extensive campaign of diamond drilling under the supervision of Dr. Paul Armstrong. This work was still in progress at the time of the writer's examination of the property and adjacent parts of the island.

These occurrences of zinc and lead mineralization have been mentioned in several of the Annual Reports of the Commissioner of Crown Lands for Quebec, in reports of the Quebec Bureau of Mines, and in reports of the Geological Survey of Canada.

The best description is by Goranson, in the Summary Report of the Geological Survey of Canada for 1925. A summary is given in the report on zinc and lead deposits in Canada by Alcock (1), which includes a complete bibliography of references to, and descriptions of, the property.

Workings on Calumet Mines Property

A large block of ground on the island has been staked or purchased by, or is under option to, Calumet Mines, Limited, but their work has so far been concentrated on lots 9, 10, 11, and 12 of range IV. (Map No.550). The geology of that section of the property only is discussed here.

The early work on these lots was directed toward the exploration and exploitation of a number of scattered occurrences of zinc and lead minerals, and a tendency has grown up to refer to these occurrences as separate entities. For the sake of clarity, therefore, the geographical setting on lots 9, 10, 11, and 12 may first be outlined. All the old shafts and most of the open pits are water-filled, but three shafts were pumped during the writer's stay on the property and some of the other working had been unwatered earlier by the British Metals Corporation.

The Bowie workings are on the southern half of lot 9 and consist of two open pits with a rub of rock separating them, and a shaft, the latter being near the north end of the more northerly pit. According to report, the shaft is 52 feet deep and has some level workings extending from it. The old Bowie ground is separated from the other localities in which work was carried on by a creek and an east-west striking dyke of diabase, but the name Bowie has been given to orebodies found by drilling north and northeast of the Bowie pits.

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(1) Geol. Surv. Can., Econ. Geol. Ser. No.8, 1930, pp.121-126.

A considerable amount of work was done in past years near the present mine office of Calumet Mines, about midway across lot 10. The workings include a vertical shaft, the MacDonald, 87 feet deep with about 300 feet of level work, and, 100 feet southwest of this, an inclined shaft, known as the Lawn. Although there is no record of a connection between the two shafts, water pumped into the Lawn raised the level of that in the MacDonald. The Lawn pit is a shallow, open pit near the Lawn shaft.

The Russel shaft, near the middle of a stripped area on lot 11, is in reality an open cut deepened near its centre.

The principal workings on lot 12 are Ste-Anne workings and include the Galena pits, a shallow inclined shaft, and a deeper vertical shaft.

The numerous drill holes put down by Calumet Mines have shown that the Bowie, MacDonald, Lawn, Russel, and Ste-Anne workings are on parts of the one main mineralized formation, and that this increases in apparent thickness at the surface as it is followed northward from Bowie ground toward Ste-Anne.

Very small pits form a parallel line 200 feet east of the line just described and were apparently put down in an attempt to develop ore on a subsidiary mineralized zone. At most, sulphide mineralization over a width of a few inches was found.

The Belgian pit is about midway of the length, and near the north limit of, lot 11. This shallow open-cut was made on a small mineralized streak in amphibolite. Drilling around the Belgian pit did not disclose any other shoots of ore at this horizon.

The Longstreet is an inclined shaft about 1,500 feet east of the Lawn shaft and near the north boundary of lot 10. It was sunk on a reportedly high-grade lens of galena. Although some trenches and pits north and south of it may have exposed other parts of the mineralized zone, closely-spaced drill holes did not disclose ore at this horizon.

Thus, the work to date has revealed one main northerly-trending ore-bearing formation, along which parts of orebodies and minor ore-shoots have been found in the Bowie, Russel, MacDonald, and Ste-Anne areas. Subsidiary mineralization occurs along a parallel zone to the east, at higher horizons. In a few places, the higher zones contain minor ore-shoots, but the difficulty of searching for them, coupled with their generally small size, makes them less economically important than those in the main zone, i.e., in the biotite gneisses and injected biotite gneisses.

Origin of Deposit

Goranson's views on the genesis of the orebodies may be summarized as follows: A mass of amphibolite derived from gabbro or diorite but with inclusions of limestone was sheared along planes striking slightly west of north and dipping steeply east. Metasomatism along the main shearing zones, which he considers two in number, produced drastic biotitization, alteration of the amphibolite, and the formation of ore-shoots. Where the shear zones encountered carbonates, the typical 'contact metamorphic' silicates were formed by metasomatism.

The writer's views on the origin of the ore, based on a detailed mapping of the surface exposures and the examination of 80,000 feet of diamond-drill core, are different from those advanced by Goranson. Briefly, the writer believes that the principal ore-shoots are in a regionally metamorphosed and metasomatized argillaceous member of the Grenville series underlying a rather massive amphibolite (derived from sedimentary rocks) which was resistant to shearing and was possibly metasomatized by the ore-bearing solutions. The principal ore-shoots are in the more argillaceous band, which strikes N.20°W. and dips 30°E. The structural control of the position of the shoots was complex, but it is believed that a direction parallel to the regional lineation is important.

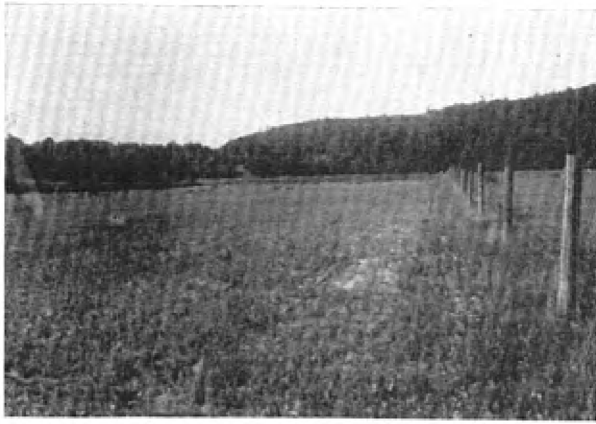
Furthermore, the writer believes that, at the surface, the length of the favourable zone is less than suggested by Goranson.

General Structural Relationships

The orebodies of Calumet Mines, Limited, are contained within an inclined cylindroid (elliptical cylindre) of rock whose position is shown schematically on Figure 1. The cylindroid is significant in that many of the rocks within it are different from those elsewhere on the island. Several forces have contributed to the making of the cylindroid. To the east, a rather massive layer of amphibolite shows an eastward bow in its outcrop, and this bow has protected the formations lying to the west. The mineralized area is thus in a 'pressure shadow'. On the west or footwall side of the cylindroid, a layer of granitic migmatite shows an abrupt change in its strike and so forms a bow convex to the west. The migmatite is apparently somewhat transgressive in its disposition, and the meta-sedimentary rocks of block B (Figure 1) may be equivalent to those of block A containing the ore shoots, although the two blocks are different in kind of metamorphism.

One effect of the introduction of the migmatite was to drag the south end of the amphibolite to the east, to form a toe, beneath which are some of the important orebodies.

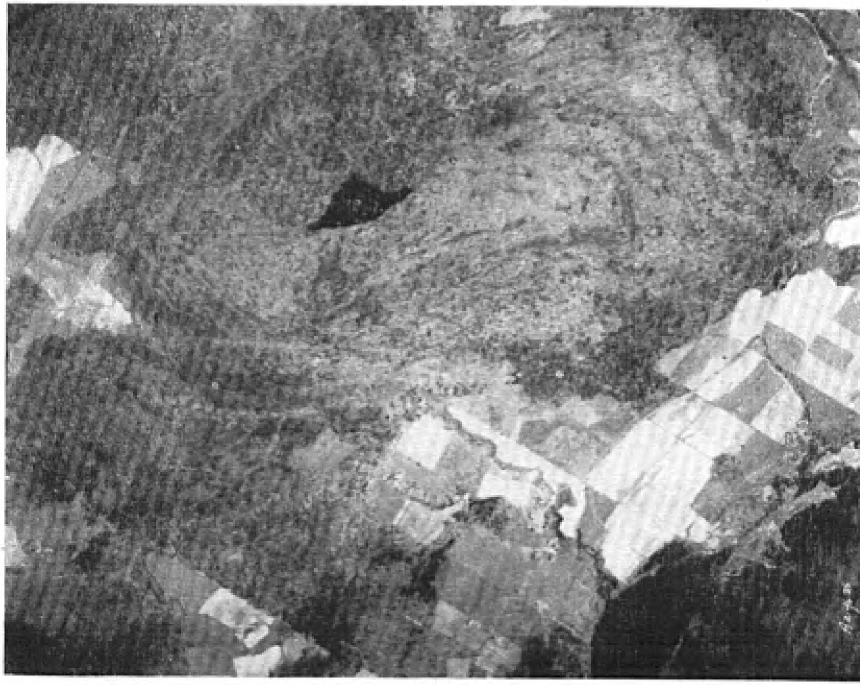
The trend of the lineation, i.e., the direction of alignment and of the axes of drag folds, is east to east-southeast, and the pitch is 25° to 30°. This direction is shown in the smaller structures in the rocks and exerts some control on the shape of the orebodies, but drilling has shown that the orebodies are on another trend. This trend is N.45°-65°E., and its origin is uncertain. A few minor, vertical joints strike in this direction. Since it is parallel to the minor diameter of the elliptical cross-section of the cylindroid, it is suggested that it may be a direction of tension. The post-ore diabase dyke previously referred to, which strikes approximately parallel to the trend of the lineation and is nearly vertical, appears to swing toward the diagonal direction, i.e., the trend of the orebodies, and to die out as it enters the amphibolites. Inasmuch as there is no evidence for the operation of major stresses between the time of emplacement of ore and the injection of the diabase, it is reasonable to assume that the stress directions remained unchanged and that a fracture that did not extend through the amphibolites guided the metallizing solutions to the biotite gneiss. The presence of such a concealed opening below the ore horizon would explain the presence of the orebodies along the direction of their actual trend.



A.—The "Mountain", Calumet island. Sand and clay-covered agricultural land in foreground.

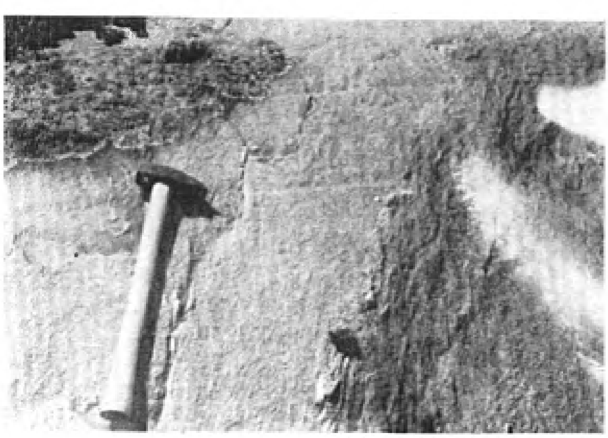
B.—Calumet Mines and vicinity. Pricipal mine workings are on east side of clearing, east of Ottawa river. (Number is on northeast corner.).

(Photo Civil Aviation, Ottawa)



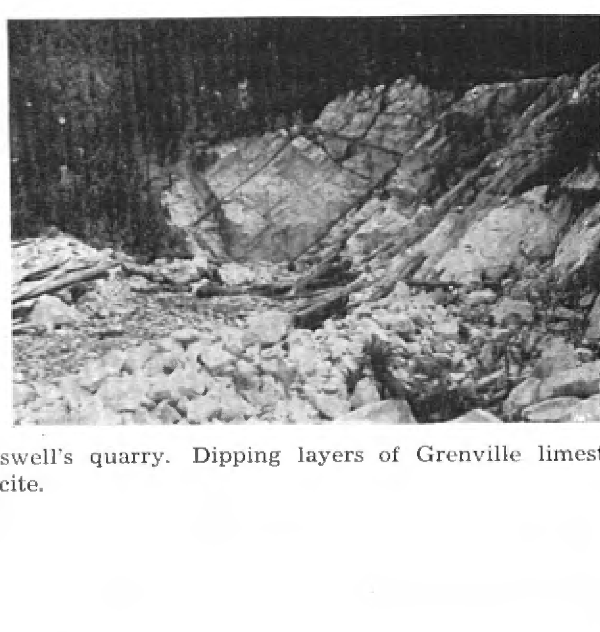
A.—Fold structure on the "mountain". The darker areas are in small swamps which occupy depressions etched along beds. (Number is on south.).

(Photo Civil Aviation, Ottawa)



B.—Medium-mafic hornblende gneiss, showing crenulation characteristic of many exposures.

A.—MacDonald shaft, Calumet Mines, Limited. Principal underground work is in this vicinity.



B.—Carswell's quarry. Dipping layers of Grenville limestone with brucite.

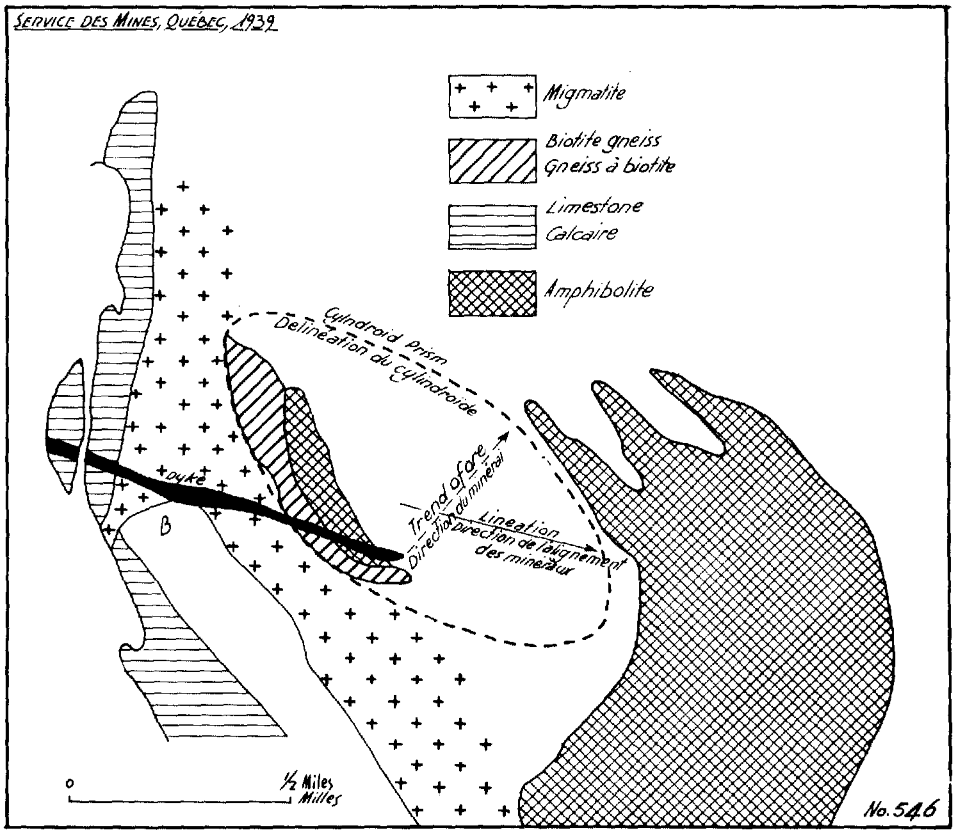


Figure 1.- General relationships of ore zone.

The geological setting from the Ottawa river eastward may be described as follows: A series of rocks strike N.15°W. and dip 30°E. Limestones with intercalated amphibolites and rusty-weathering gneisses crop out near the river. The zone of dominant limestones is followed eastward, and is structurally overlain, by a layer of amphibolitic rocks and hornblende gneisses. These in turn are overlain by a highly granitic migmatite containing relic sedimentary structures. This layer is somewhat cross-cutting in its structural relationships, and is, in the vicinity of the ore-bodies, followed upward by the biotite gneisses and injected biotite gneisses with irregular amphibolite masses and the ore shoots. The ore-bearing layer is succeeded upward by the rather massive carbonate-bearing and clotted amphibolites. This main amphibolite mass is somewhat broken up by zones of minor alteration.

The eastern or hanging-wall margin of the amphibolite is against a mass of intermediate migmatite which probably represents a layer similar in original character to the biotite gneiss, but which has been more granitized than the latter. This is succeeded to the east by hornblende gneisses which, in turn, are followed by a zone of porphyroblastic amphibolites and amphibole rocks which are similar in many respects to the massive carbonate and clotted amphibolites, although they have been more metamorphosed than the hanging-wall amphibolites. This upper porphyroblastic amphibolite is overlain by hornblende gneisses and intermediate migmatites. The exact disposition of these latter mentioned rocks has not yet been disclosed by drilling, and the surface is covered with overburden.

Petrography

A detailed examination of sixty thin sections made from drill cores of typical rocks disclosed a wide variety of minerals and mineral associations. The observations with the microscope are in accord with the interpretation of the geology offered here, which is based largely on the work in the field.

The microscope shows a number of diverse mineral associations in the biotite gneiss near the ore, and the diversity can only be interpreted as evidence of an original heterogeneity. Several points call for comment. The plagioclase, other than that in the pegmatites, is commonly more calcic than albite; oligoclase and andesine are common. Cordierite and anthophyllite, an association antipathetic to lime, are found in a few places, but elsewhere the lime-bearing association, diopside-tremolite, is found. Biotite and a phlogopitic biotite are present and are probably the most characteristic of the silicate minerals. Uniaxial (rhombohedral) carbonates, both iron-bearing dolomite and calcite, are abundant, particularly near lead and zinc mineralization. The carbonates are apparently post-silicate in age, and in part they preceded the metallic minerals. No incontrovertible evidence of 'old' carbonates can be seen in the biotite gneisses proper.

Garnet and quartz, with biotite, are found with chalcopyrite in positions that indicate that this association fringes the orebodies.

The various mineral associations offer a problem of considerable scientific interest, but, for its solution, the study of many additional thin sections would be necessary and it is difficult to justify the expense and time this would involve.

In places near the ore, the silicates have been altered to chlorite and talc, and scapolite - which is widely developed - has been converted to wilsonite. Barite has been found as a gangue mineral.

Diopside, tremolite, pargasite, hastingsite, hornblende. plagioclase, orthoclase, microcline, anorthoclase, sillimanite, and spinel can be identified in the drill cores from various places on the property. No thin sections were cut from specimens in the assayed ore-sections, and it is probable that much of the amphibole here termed tremolite is pargasite.

Grenville Limestone

Grenville crystalline limestones crop out in a band extending along the shore of the Ottawa river west of the mine property. The limestones are medium to coarse grained, with dolomitic and high-lime bands. Some bands contain diopside as discrete grains or as aggregates, and also other silicates, such as serpentine and phlogopite.

The bedding of the limestone has been largely obliterated, and pronounced shear structures take its place. This shearing is parallel to the bands composed of silicate minerals and, as shown by a drill intersection, the dip is about 30° east.

A narrow band containing disseminated sphalerite was observed in the limestone exposed near the high-water mark of the river, in the southern part of lot 9. The zone, which may be traced for more than one hundred feet, is on the continuation of a nose of migmatite which extends southward from the main mass of migmatite. Although there is no evidence that the occurrence has any economic value, it is significant that the sphalerite is along the continuation of the channel opened by the migmatite, and, furthermore, that disseminated sphalerite was encountered in a drill hole 3,000 feet east of the exposure and at about the same distance below the upper limit of the limestone as the exposure near the river.

The drilling revealed the interesting fact that, at several horizons, the limestones contain anhydrite and gypsum. Some of the anhydrite is mauve coloured and coarsely-crystalline, but a medium-grained, pale violet anhydrite and calcite aggregate is more common. The adjacent limestone contains silicates and has the normal texture of the crystalline limestones. Study of thin sections supports the view that the sulphate has been introduced and has replaced the limestone. Later, some of the anhydrite has been replaced by gypsum which in part has been deposited in small fibres and in part has migrated through the rock to deposit in veinlets. The gypsum is not restricted to the limestone, but occurs also in the basic silicate rocks below the ore horizon.

Granite Migmatite

A migmatite that shows relics of sedimentary structure underlies the biotite gneisses. The rock is thoroughly granitic in appearance and, were it not for the sedimentary structure and the presence of sporadically-distributed garnet, it might be mistaken for a grey biotite-granite gneiss. The migmatite is cut by thin sills of pink granite and by pegmatite dykes.

The structure most characteristic of the migmatite is a plane foliation and schistosity, which is parallel to the local structure except where, near the south end of the ore zone, the migmatite swings to the east and appears to cross the biotite gneiss and to replace part of it.

Biotite Gneiss and Injected Biotite Gneiss

The principal ore shoots on the property of Calumet Mines are in a biotite gneiss that has, in places, been injected by granitic material and metasomatized. The least altered varieties of the rock are fine-grained, thinly-layered gneisses that resemble some hornfels in appearance and consist of quartz, orthoclase, and plagioclase, with biotite as the characteristic ferromagnesian mineral, although varieties with amphibole, either hornblende or anthophyllite, occur. In places, these rocks grade into fine-grained amphibolites by decrease in quartz and orthoclase, and increase in hornblende and plagioclase. The amphibolites are irregularly distributed and possibly now proxy for originally heterogeneously-distributed limy beds in the sediments. The amphibolitic layers were apparently less susceptible to the injection and metasomatism that converted many of the biotite gneisses to paragneisses of the injection type. It is exceedingly difficult to separate the effects of solutions producing granitization from those of the more conventional metasomatic type. In granitization, quartz and orthoclase were introduced. During the metasomatism, quartz was formed abundantly, so much so that lenticles of practically pure quartz are found in many places. The fibrolite variety of sillimanite accompanies dark-brown biotite, actinolite, pargasite, and various other amphiboles. Other minerals observed are scapolite and its alteration product, wilsonite, zoisite; and, rarely, cordierite. During the late stages of metasomatism, some of the plagioclase was altered and some carbonate introduced.

Structure.- As shown by the diamond drilling, and by the outcrop, the biotite gneiss strikes N.15°W. and dips about 30°E. Although, as a whole, the body has a fairly regular tabular form, the drilling has shown that the thickness is much greater in some places than in others. Thus, in the Ste-Anne section of the property, the thickness may be as much as 300 feet, whereas it is only a few tens of feet where cut in some of the drill holes.

On a small scale, the biotite gneisses are crumpled and, in the main, the axes of the crumples pitch about 30° east. However, the scale of the crumpling or folding is small in comparison with that of the overlying amphibolites. Also, the amphibolitic layers within the biotite gneiss are not only less sheared than the gneiss but are less crumpled and injected.

Amphibolite

The upper side, or hanging-wall, of the zone containing the principal orebodies is a rock of heterogeneous type that may be termed amphibolite. The drill cores show that such rock forms an almost continuous mass extending over the ore zone.

The amphibolites are thinly and markedly-layered rocks, or they are massive. Schistosity is developed along the margins of the mass and in one or two interior zones, but, in the main, is much less apparent than in the hornblende gneiss and hornblende-biotite gneiss.

Several varieties of amphibolite may be differentiated in logging cores, and in some instances it is possible to correlate varieties appearing in one core with those in core from holes nearby; but in general, the varieties are so intimately mingled that correlation is impossible.

One variety is a clotted-appearing rock containing hornblende, biotite, pyroxene, medium-calcic plagioclase, scapolite, and a little quartz. Another is characterized by hornblende, plagioclase, and abundant carbonate; the carbonate may be in layers, suggesting it is an original constituent, or in veinlets, suggesting it was introduced. One variety of the rock contains so much biotite it has been termed 'biotite amphibolite'.

Structure.- Plotting of data from drill cores shows that the amphibolites are a somewhat crumpled plaque. Fold structures are much more open than in the biotite gneisses, and in places this structure is replaced by a lineation pitching 30° east. Also, in contrast to the biotite gneisses, the amphibolites are not sheared, except in a few local zones.

Porphyroblastic Amphibolite

Near the edges of the carbonate and scapolite (hanging-wall) amphibolite mass - and in some places within the main mass - a variety of amphibolite, characterized by larger crystals (porphyroblasts) of either biotite or hornblende, occurs. Some of the porphyroblastic rocks are massive, but others are faintly schistose. These latter are the more sheared representatives of the normally massive amphibolites, their schistose structure being the result of increased efficacy of the shearing stress. The porphyroblastic amphibolites pass by gradation through porphyroblastic gneisses to hornblende gneisses. The latter are much more schistose and have a larger content of light-coloured minerals. Although there were probably some differences in the original compositions of the amphibolite and hornblende gneiss, some of the present differences may be attributed to addition of material, particularly granitic injections, to the hornblende gneisses.

In a few places, metasomatic rocks, consisting almost entirely of coarse or fine amphibole, are found. One variety consists of spinel and amphibole.

Intermediate Migmatite

A belt of an intermediate migmatite is found above the main amphibolite mass. The rock has the appearance of a grey granite gneiss and consists of quartz, orthoclase, plagioclase, hornblende, and biotite. Irregular structures are characteristic, and, in a few places, structures that may represent original schistosity and bedding show a pattern somewhat similar to that of the biotite gneisses, suggesting that the migmatite is granitized biotite gneiss, originally similar to the normal biotite gneiss. Somewhat similar migmatites were formed from the hornblende gneisses.

Secondary Ore Shoots

Although the principal ore shoots are within the one layer of biotite gneisses, subordinate shoots occur at other horizons. Aside from certain occurrences of disseminated sphalerite, all these subordinate shoots are above the main ore horizon. One is in the carbonate and clotted amphibolites. It is marked by an alteration zone of variable thickness or in places by a carbonate vein up to two inches thick, and here and there carries sphalerite and galena over a length of a few feet. The ore shoot mined from the Longstreet shaft is at a still higher horizon, but although some indications of the activity of solutions are found on the projection of this shoot, the drilling failed to disclose important ore elsewhere at the Longstreet horizon.

The evidence at hand would indicate that these minor zones, although moderately continuous, are economically unimportant. In general, they are along planes of weakness in the amphibolites, planes that were also loci along which pegmatites were injected and migmatizing solutions spread. The amphibolites 'fringe out' near the end of the body and it is quite possible that orebodies may be found in the fringe. The upper ore shoot at the Bowie, according to one interpretation of the drill cores, might be an orebody in such a position.

Structural Control of Ore-Shoots

In any ore deposit, it is important to establish the relationships of the orebodies to the structural features. Although the structural relationships will be more easily determined as the body is mined, nevertheless the relatively closely-spaced drill holes on the Calumet property serve as a substitute for actual underground work in determining the control exercised by structure. The disability attached to the use of data from drill holes is that the condition found in a core may be local, whereas, in the body open for mining, the average condition may be determined.

The main ore shoots are contained within one layer of rock, which has a change in strike. At the north, the strike is approximately north-south and the dip 30° east, but at the south end of the ore-zone the strike swings to N.45°W. and the dip is northeast. It is the structure of the biotite gneisses that determined the tabular character of the orebodies and their east or northeast dip of 25° to 30°. The presence of the favourable horizon fixes the most important structure of the deposits. The layering is parallel to the regional schistosity, and the minor orebodies are parallel, or approximately parallel, to the main orebodies.

Although the principal control on the shape of the orebodies has been due to the heterogeneity of the formations and the presence of one more permeable to solutions than the rest, the orebodies are not continuous in the generally favourable horizon. Instead, the ore is in shoots. In part, the presence within the favourable formation of rocks amenable to replacement by the ore-bearing solutions may have caused a localization of ore deposition, but the replaceable parts of the formation were acted upon by the same forces as were the other rocks, and their disposition determined thereby. An analysis shows that the edges of orebodies are in general along a direction slightly south of east or due east. Furthermore, axes of larger warps (folds) in the amphibolites trend in the same direction. The same trend is shown by axes of minor folds, in the direction of elongation of minerals, and in the strike of the diabase dyke (Figure 2). This direction of lineation, or b direction, is rather uniformly found over most of the island, and it can be concluded that it is more than a local structure. Thickness contours on orebodies reflect the same direction to such an extent that it is reasonable to suggest that the folding along the b axis has determined the distribution of ore shoots.

Another direction is apparent on the Bowie orebodies, where the strike of the formation deviates from north. It is apparent from the map that the amphibolite, the hanging-wall of the biotite gneisses, has, on its south end, been dragged to the east, probably along the zone of migmatites below the biotite gneisses. The principal Bowie orebodies lie beneath the 'toe' formed by the eastward drag on the south end of the formation. The Bowie bodies lie along a line trending N.60°E., and it is possible that a fracture or opening in this direction allowed the penetration of solutions to the biotite gneiss horizon. Although the b direction is reflected in some features of the Bowie, the N.60°E. direction is of major importance. There is no evidence in the rocks on the surface for the presence of a channel-way in such a direction. While the suggestion that there is such a direction appears reasonable, it must be regarded as purely speculation.

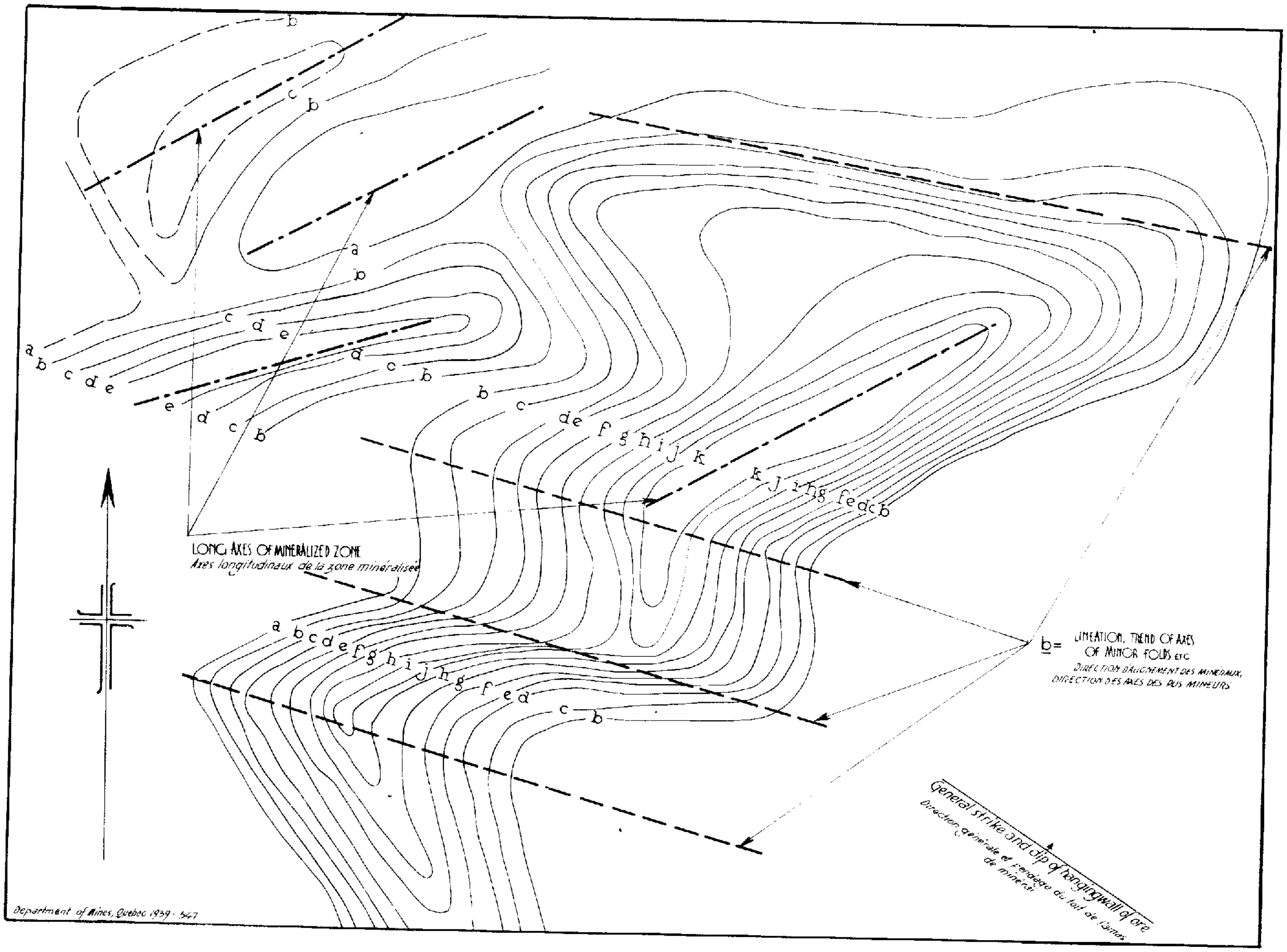


Figure 2.- Structural control of ore shoots.

Geophysical Exploration

Before Calumet Mines embarked on their diamond-drilling programme, an electrical survey, employing the Schlumberger self-potential method, was made of a large central portion of the property. This survey yielded negative results, summed up as follows by Dr. Paul Armstrong (1): "Evidently, most if not all of the equipotential contours resulting from the survey indicate the oxidizing activities, not of the orebodies but of the rusty-weathering biotite gneiss in which the ore occurs, the effect of the latter masking that of the ore".

Later, a magnetometric survey, using horizontal and vertical Askania instruments, was carried out by Dr. D.A. Keys, of McGill University. Commenting on the results obtained, Armstrong says (2); "Inasmuch as Professor Keys' results could be checked against the precise ore information obtained from drilling, it can be said that they were negative. However, his survey did indicate, with a good deal of accuracy, the contacts of amphibolite and biotite gneiss .... The ore body itself .... had no magnetic effect whatever".

Ore and Gangue

The core sections from the ore zone show contact-metamorphic silicates, with tremolite (and other amphiboles), diopside, light-coloured biotite, and dark phlogopite as the characteristic minerals. The assemblage is one ordinarily considered diagnostic of contact-metamorphic or pyro-metasomatic deposits, but no carbonate rocks that show the characteristics of the Grenville limestone have been found near the 'contact silicates'. The hypothesis that the lime and magnesia present in the so-called contact silicates were picked-up elsewhere is at least reasonable. Dolomite and iron-bearing carbonates are common with, and characteristic of, the ore, but the carbonates are in most places younger than the silicates, which supports the notion that the solutions were either originally rich in carbonate or else picked up the carbonate elsewhere than where the ore was deposited. The contention that there were originally carbonates in the biotite gneiss and these yielded the contact silicates cannot be ruled out, but the data available lead the writer to prefer the view that much, if not all of the carbonate was added by metasomatism. In amphibolite forming the hanging-wall of the ore zone, some of the carbonate is original, but some is younger than the silicates.

Other silicates present in addition to those mentioned above are talc and chlorite. Scapolite also is widespread, but in small amount, and its alteration product, wilsonite, is found in some places. Garnet and cordierite are rare. Graphite occurs in some of the schists. Barite was recognized as a gangue mineral.

The writer has not studied the metallic minerals, but has had access to an unpublished report on them by Dr. M. Haycock, of the Mines Branch, Department of Mines and Resources, Ottawa. The ore is a medium-grained aggregate of pyrrhotite, pyrite, marcasite, sphalerite, galena, with some 'grey copper', (tetrahedrite or tennantite) and, in some places, chalcopyrite and arsenopyrite.

(1) ARMSTRONG, Paul, The Exploration and Development of Calumet Mine, Quebec; Can. Inst. Min. and Met., Trans., Vol.XIIV, 1941, p.406.

(2) Op. cit., p.407.

Native gold has been reported. Outside of some uncertainty regarding the distribution of the gold, the ore offers no apparent difficulty in beneficiation. Large-scale mill tests on ore from below the zone of active circulation of ground-water will be necessary before a process for treating the ore can be finally worked out. Unfortunately, such ore is not available. All the tests to date have been made on pulp remaining from samples of core used for analysis.

In the subsidiary ore shoots formed outside the biotite gneiss, the dark micas, with carbonates, are the characteristic gangue minerals. The typical contact-metamorphic silicates are subordinate to the biotite or are lacking.

Genesis of the Ore

The solutions that were responsible for forming the deposits were the result of igneous activity and probably originated at considerable depth. The presence of disseminated sphalerite in the limestones, and the probability that this sphalerite is from the same source as that of the orebodies, suggests that the solutions communicated with limestones by at least some channel-ways. A deep-seated fissure may have guided the solutions for at least some part of their course, but, on reaching the biotite gneiss beneath the relatively impermeable layer of amphibolite, they spread laterally and formed the ore shoots in the biotite gneiss.

Little can be said concerning the magma that gave rise to the solutions. However, it is certain that the ore deposit is younger than the regional metamorphism and that the pink granite is the only granite that has such a relationship to the deformation. Within the ore zone itself, pink pegmatites are common. Some of the pegmatites are of the diopside-bearing type, suggesting contamination by reaçtion with limy rocks. Although the relationship of pegmatites to the 'contact sillicate' minerals is not clear, nevertheless, the sulphide minerals cut minerals of the pegmatites. Green microcline is characteristically developed, and the relationships suggest that the pegmatites are closely related to the ore. It may well be that 'contact silicates', ore, and contaminated pegmatites are from one source, and that source may well have been the pink granite.

The deposit is similar to the Tétreault and the Balmat and Edwards deposits in that all were formed at a high temperature, but in each the role of the limestone has been different. At Balmat and Edwards, the ore-shoots were formed in impure dolomitic limestones contained within more abundant, purer limestones; at Tétreault, the principal ore shoot is due to partial replacement of limestones; and at Calumet, the role of limestones is insignificant. All three deposits illustrate the importance of determining the structure.

Tonnage and Grade of Ore

The drilling has indicated more than one million tons of ore. Most of the orebodies have been delimited by closely-spaced drill holes, so that the tonnage may be regarded as certainly established. The writer has examined the data for ore-reserve calculations, and, although his conception of the ore sections between drill holes might differ, in plans, from that of the Company engineers, the final result would be substantially the same. Conservative assumptions were made in the calculations. An early detailed estimate gave 942,384 tons with ~~[illegible]~~ 2.51 per cent lead, 8.16

per cent zinc, and 0.036 oz. gold and 5.76 oz. silver per ton. Later drilling is reported to have indicated an additional 86,000 tons with 18 per cent combined zinc and lead, and $6.90 in gold and silver per ton. Except where the grade of ore was exceptionally high, no section thinner than eight feet was included in the calculation of the reserves, and in many places, beyond its assumed width, the ore was bounded by material of only slightly lower grade.

Aside from the ore actually shown by drilling, it is necessary to appraise the geological possibilities. These may be considered under various heads:

(1) Extension along strike.- As the map of the property shows, the biotite gneisses extend approximately the length of the drilled area, and the carbonate- and scapolite-bearing amphibolites extend a slightly greater distance than the biotite gneisses. At the north end of the mineralized zone, the biotite gneisses and the hanging-wall amphibolites lose their essential characteristics and their place is taken by granite gneisses and hornblende gneisses, respectively. The same situation is found south of lot 9. Goranson has suggested that the mineralized zone may be traced in that direction, but the quartz veins with sparse mineralization and the fine sulphide impregnations in the granite gneisses south of lot 9 are quite unlike the mineralization that constitutes the ore. Hence, the probability of ore of the same characteristics as that drilled occurring in the area north or south of Calumet Mine may be discounted.

(2) Extension down dip of formation, or pitch of the orebodies.- The structure containing the ore-bearing formations is sufficiently large that it may be expected to be continuous; also, the general structural features such as folds and lineation are sufficiently uniform that the ore-bearing horizon is likely to be persistent. The disseminated sphalerite in the limestone near the river, and the occurrence of similar material in a corresponding stratigraphic position in a drill hole 3,000 feet away, was mentioned previously. In addition, the deeper diamond-drill holes have cut the main ore-bearing horizon at a distance of about 3,000 feet from its outcrop, and have shown that, in that distance there is no appreciable change in the character of the country rock. These facts support the contention that the general conditions in the country rock are sufficiently uniform that, provided ore-bearing solutions had access to the favourable horizons, there is no reason to believe that the ore-bearing horizon is likely to be cut off.

(3) If, as postulated above, the ore solutions were conducted from depth to the horizon favourable for deposition along a concealed fissure, the occurrence of similar parallel fissures might have determined the position of other ore shoots. As explained above, however, the rocks containing the ore shoots are, structurally, a pipe-like mass or cylindroid, and, in a short distance east of the Calumet Mines property, they are covered by rocks that behaved differently in deformation. One mile from the outcrop of the ore, the ore horizon would be 3,000 feet below the surface. It is obviously not feasible to search for ore shoots at such depth unless the position of the channels can be inferred.

The occurrence of minor amounts of sphalerite a mile east of the Calumet Mines property might be taken to indicate that solutions carrying zinc passed that way. This evidence, however, is not helpful in the search for ore.

Other Properties

As a consequence of the recent operations on the property now owned by Calumet Mines, Limited, there have been renewed attempts to find other ore occurrences of the same type on the island. In past years, numerous trenches and pits have been dug through the overburden and, in a few places, short shafts have been put down or open cuts have been made in bed-rock. These relics of the early workings are to be seen in many places, particularly in the bands of rusty-weathering rocks. Recently, the activity has led to the staking of claims, procuring of options, and a small amount of diamond drilling and trenching. In general, the rusty-weathering rocks have been prospected. However, examination by the writer of both old and new workings failed to disclose any important indication of the presence of ore shoots. Iron sulphides are the only metallic minerals found consistently. On the south side of the Calumet Mines property, pits and open-cuts have exposed minor amounts of sulphides disseminated in the gneisses or in small, glassy quartz veins, and careful examination of these occurrences reveals the presence of sphalerite. This mineral was also seen in a narrow quartz vein north of Tancredia. However, the presence of such sphalerite is not necessarily indicative of an orebody, for the mineral is widely distributed in minor amount in many parts of the Laurentian region, particularly in the rusty gneisses. More significant guides to the orebodies are the structural and lithological units associated with the ore, but, on Calumet island, the rocks along a large part of what might be a favourable zone are concealed by drift. Much of this is too thick for test pitting, and the experience at the Calumet Mines property has shown the difficulties of outlining the orebodies by drilling. In view of these circumstances, blind drilling for orebodies cannot be recommended.

Brucite

Brucite has been found in the crystalline limestone at several places on both sides of the east channel of the Ottawa river in the vicinity of Calumet island. The occurrences have been described in reports by the writer (1) and by M.F. Goudge (2).

Occurrence

On Calumet island, the belt of crystalline limestone that flanks the east side of 'the mountain' is known to contain brucite from near the power house at the southern end of the island as far north as lot 3, range II Reserve. Most of the exposures are in the southern part of the belt, but brucite has been reported in drill cores from the peninsula opposite lot 3, in the north. Because of lack of exposures, it is difficult to trace the individual brucite-bearing layers, but they appear to be lenticular in form and to be separated from one another by non-brucitic layers.

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(1) Osborne, F. Fitz, Brucite; Que. Bur. Mines, P.R. No.139, 1939.

(2) Goudge, M.F., Preliminary Report on Brucite Deposits in Ontario and Quebec and Their Commercial Possibilities; Bureau of Mines, Dept. of Mines and Resources, Ottawa, Mem. Series No.75, 1939.

The brucite-bearing limestone on the mainland side of the river is found in a belt that extends from north of the Calumet Island bridge to near the southern limit of the town of Bryson. The northernmost exposures flank the east side of the road to Campbell's Bay and are of a coarse-grained limestone with very large granules of brucite and abundant rounded grains of serpentine. Magnetite also occurs replacing brucite. The dip of the beds is steep to the east, and the amount of pure brucite limestone is small. To the south, brucite is found as a constituent of the crystalline limestone in several outcrops in the village. In no place is any large section of brucite-bearing rock exposed, and until adequate work to determine the thickness, linear extent, and quality of the material is done, the possibility of utilization of the material as a source of magnesia, is in doubt. The limestone in this southern part of the belt dips to the east, but at a relatively low angle. The dip is not sufficiently steep that the top of a layer would be accessible for open quarrying on a reasonably large scale. Underground methods would be necessary, and the low dip would make such methods more difficult than on a steeper dip.

Brucite limestones are found on the west side of the road both north and south of Carswell's quarry, near the south limit of Bryson, and also on the east side of the road, in and near the quarry operated by Robert Carswell for lime.

Description of Mineral

Brucite, $Mg(OH)_2$, is a soft, white or buff coloured, mineral which crystallizes in the hexagonal system. Crystals are either platy or fibrous (nemolite). As it occurs here in the crystalline limestone, however, it is usually distributed through the rock in the form of more or less spherical granules, averaging perhaps one-eighth of an inch in diameter, and rarely as much as half an inch. Most of the granules have a concentric, or onion-like, structure, which is well seen on naturally - or artificially - etched surfaces. The mineral weathers more rapidly than the associated carbonates, giving a pitted surface on the exposure; also, it becomes chalk-white, by the formation of a surface coating of hydrous magnesium carbonate. These features are a considerable aid in prospecting for brucite.

Mode of Origin

The brucite limestone might have originated in either of two ways: (1) the magnesia was introduced into a limestone (containing little or no Mg) and deposited as brucite, or possibly as periclase (MgO) which was later hydrated to form brucite; (2) the brucite was formed by dissociation of magnesium-bearing carbonate already present in the limestone, and hydration of the MgO so produced.

Characteristics of the brucite limestone to be taken into consideration in a discussion of these alternatives are: (a) the brucite occurs as discrete granules, more or less uniformly distributed through the limestone; and (b) there is a tendency for the Mg:Ca ratio in the brucite limestone rock as a whole to approximate 1:1 (1).

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(1) The name pencatite has been given to a crystalline limestone containing brucite in which the Mg:Ca ratio is about 1:1 (Harker, A., Mem. Geol. Surv., London, 1904, p.150). Where calcite is in excess of brucite, the rock has been termed predazzite (ROGERS, A.F., Am. Jour. Sc., Vol.XLVI, 1918, p.582).

(1) Magnesia Introduced into the Limestone: On the east side of Calumet island, the brucite occurs in a belt of limestone that is in contact with younger igneous rocks. It is conceivable that the magnesia to form brucite was here introduced into the limestone by solutions related in origin to the igneous rocks, and that it was deposited directly as brucite, or as periclase that later became hydrated to brucite.

While such a mode of origin for the brucite is possible, it would not explain the uniform distribution of the mineral through the limestone, nor the fact that the Mg:Ca ratio in the rock as a whole approximates 1:1.

(2) Dissociation of Magnesium Carbonate Already Present in the Rock: Analyses of the least metamorphosed Grenville limestones indicate that, in large part at least, the rock was originally low in magnesia. Much of it, however, now contains a considerable amount of magnesia, present in dolomite $CaMg(CO_3)_2$, and the distribution of the dolomite bands suggests that many of them have been formed from the limestone as the result of metasomatism by solutions derived from igneous rocks that have intruded the limestone.

It is known that the dissociation temperature of dolomite is between that of calcite (higher) and magnesite (lower). Under favourable conditions, where the confining pressure is sufficiently low, it is believed that, in a belt of rock having the composition of dolomite, dissociation might proceed to, and stop at, the point where the molecule $CaMg(CO_3)_2$ breaks down to $CaCO_3$, MgO, and CO_2, the last escaping as a gas. If, then, the MgO were hydrated to form $Mg(OH)_2$, the resulting rock would be a brucite limestone consisting of calcite and brucite. The ratio Mg:Ca would be 1:1, and it would be expected that the brucite would be uniformly distributed through the rock. It may be pointed out, also, that, assuming contemporaneous hydration of the MgO, the calcite-brucite aggregate would have approximately the same volume as the dolomite from which it was derived, as shown by the following figures:

	$CaMg(CO_3)_2$	$(+H_2O) \rightarrow$	$CaCO_3$	+	$Mg(OH)_2$	$(+CO_2)$
Mol. wt.	184		100		58	
Sp. G.	2.85		2.72		2.4	
Mol. vol.	64.5		36.7		24.2	

If, on the other hand, periclase (mol. vol. 10.8) is formed first, with volume decrease and recrystallization, its subsequent hydration would give a volume increase of about 28 per cent:

	$CaCO_3$	+	MgO	$(+H_2O) \rightarrow$	$CaCO_3$	+	$Mg(OH)_2$
Mol. vol.	36.7		10.8		36.7		24.2

The rocks show no evidence for such an expansion. There remains the possibility that some of the brucite was rendered soluble and migrated into openings in the rock. If so, and if the openings were closely spaced, the bulk composition of the rock need not be changed greatly and the Mg:Ca ratio might still approximate 1:1.

An adequate explanation of the origin of the deposits must await more detailed field work and laboratory study, which must include not only the brucite limestone itself but all the rocks in its vicinity. For example, at several localities on Calumet island, stringers of dolomite intersect the limestone, and veinlets of the mineral seal cleavage cracks in the calcite adjacent to the brucite, and these may have a bearing on the origin of the brucite.

Feldspar and Mica

Apart from brucite, there has been little or no search for deposits of non-metallic, or 'industrial', minerals on Calumet island. A number of pegmatite dykes were seen by the writer in the course of the mapping, and it is possible that some of these might yield feldspar or mica of commercial grade. On one of these dykes, on the southeast side of the island, a pit has been sunk. The dyke cuts limestone, which is unusual, and the mica it contains is white muscovite.

Other Non-Metals

Non-metals, except for brucite, have not been exploited or searched for in the vicinity of Calumet island. A few occurrences of pegmatite were seen. The pegmatites might yield feldspar or mica, but no one of the occurrences is sufficiently outstanding that it deserves special mention. One pit has been sunk on a pegmatite in the limestone on the southeast side of the island. Not only is the occurrence of pegmatite in limestone unusual, but the pegmatite has white, rather than amber or black, mica.

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