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LACHUTE MAP-AREA, PART 3- MAGNESITE-DOLOMITE DEPOSITS, GRENVILLE TOWNSHIP, PART C

PROVINCE OF QUEBEC, CANADA

Department of Mines and Fisheries

Honourable ONÉSIME GAGNON, Minister L.-A. RICHARD, Deputy-Minister

BUREAU OF MINES

A.-O. DUFRESNE, Director

ANNUAL REPORT

of the

QUEBEC BUREAU OF MINES

for the Calendar Year

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JOHN A. DRESSER, Directing Geologist

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Part III—MAGNESITIC DOLOMITE DEPOSITS

GRENVILLE TOWNSHIP

by F. Fitz Osborne

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LACHUTE AREA

Part III.—MAGNESITIC DOLOMITE DEPOSITS

GRENVILLE TOWNSHIP

by F. Fitz Osborne

INTRODUCTION

Although deposits of magnesite are widely distributed in many geological formations throughout the world, the deposits of magnesite and magnesitic-dolomite near Kilmar, in the Lachute map-area, are the only commercial ones yet found in the Laurentian shield in Canada. The Kilmar deposits supply the raw material from which a varied series of refractories and other products are made. Such refractories are used in the reduction and smelting of ores and in the manufacture of steel, so that any expansion of the metallurgical industries will doubtless increase the demand for them. Hence it seems advisable to give a full description of the mode of occurrence of the ore in order, if possible, to assist the search for this useful mineral both here and elsewhere. In some localities, boulders of magnesite are found in the drift in such positions that they cannot be derived from any of the deposits yet discovered. Furthermore, the boulders are commonly of a higher grade of material than that yielded by the deposits being exploited. They may be a useful clue in the further search for magnesite.

History

The history of the discovery and exploitation of the Quebec magnesite deposits until 1916 has been given by M. E. Wilson (1). As early as 1900, the Rev. W. P. Boshart observed boulders of white glistening rock, unlike the common Grenville limestone, on lot 15, range IX of Grenville township. The material was analysed in the laboratories of the Geological Survey at Ottawa and proved to be magnesite. Messrs. Boshart and W. B. McAllister thereupon prospected the vicinity and were successful in finding magnesite *in situ*. Options on several lots were taken, and trial shipments of magnesite made, but the low price of the product, coupled with the high cost of transportation, made operations unprofitable, and accordingly they were abandoned.

In 1907, T. J. Watters, of Ottawa, organized the *Canadian Magnesite Company* to exploit a deposit on the north half of lot 18, range XI, Grenville. Later, the rights to the McPhee property, on lot 15, range IX, were acquired, and a 10-ton kiln erected to calcine the crude magnesite and so reduce transportation costs. It was necessary to haul by waggon

(1) Wilson, M. E., *Magnesite Deposits of Grenville District, Argenteuil County, Quebec;* Geol. Surv. Can., Mem. 98, 1917, pp. 17 and 18.

over poor roads to the railway at Calumet. The Canadian Magnesite Company was taken over by the *North American Magnesite Company* in 1914. In 1915, S. Melkman organized the *Scottish Canadian Magnesite Company* to operate the magnesite occurrences on lots 15, ranges X and XI, and in the following year a narrow-gauge railway was built to connect the property with the Canadian Pacific railway, thus providing better transportation facilities than had previously been available. In addition to the small kiln operated at the North American property, crude magnesite was shipped to cement plants in Hull and Montreal for processing.

In 1918, the *International Magnesite Company* took over operation of the Dobbie mine, on lot 13, range I, Harrington, and erected a vertical, wood-fired kiln of ten tons capacity. The Scottish Canadian Magnesite Company established the nucleus of the present plant of *Canadian Refractories, Limited,* and had it operating late in 1920. A short time later, the North American plant at Calumet was placed in service. This was built near the old mill of the nearby graphite mine.

In 1922, an agreement between North American Magnesite Producers and the Scottish Canadian Magnesite Company resulted in the quarrying being done on the property of the former and the processing at the plant of the latter Company. With the exception of a brief period of operation of the Shaw mine, production continued on this basis until 1933, when a new Company, *Canadian Refractories, Limited,* was formed to take over and develop the two properties as a unit.

The narrow-gauge railway was convered to standard gauge in 1929. Chrome-magnesite brick and other special products have been manufactured since 1933.

At the time of writing this report, only two companies, Canadian Refractories, Limited, and the International Magnesite Company, are operating. The latter Company is equipped to ship only crude or calcined ore.

It is very instructive to anyone interested in the utilization of non-metallic minerals to consider the history as recorded in the Reports of this Bureau from 1908 onward. Non-metallic minerals, and to a greater extent aggregates of non-metallic minerals, have wide variations in physical and chemical properties. A user accustomed to material from one locality may find his method of procedure entirely unsuitable for that from another. In 1908, the crystalline magnesite of the Veitsch type, from Austria, was in general use on this continent. The Austrian magnesite is higher in iron and lower in lime than that from Grenville, and, under the same treatment as accorded the Austrian product, the Canadian ore was unsatisfactory. Free lime was found in the burned product. Addition of iron ore improved the dead-burning of the product and made it clinker. In the reports of the Bureau of Mines, the disabilities of the Canadian magnesite are mentioned frequently. However, the supply from Austria was cut off in 1914 and Canadian consumers turned to the Grenville deposits. It was found that the addition of silica would convert all the lime to silicate, and the addition of iron would enable a clinker to be made. As a consequence, the Canadian material came into increasing use, and in 1919 it was able to compete successfully with the Austrian ore, when the latter again became available.

In 1925, the Magnesite Committee of the National Research Council began a study of magnesite. A varied series of clinker, brick, cements, and plastics have been studied. Not only have the disabilities attaching to the use of the high-lime Canadian ore been overcome, but the physical and chemical peculiarities have been utilized to give useful products.

Faced with a demand for ore low in lime, the Canadian producers were obliged to sort the material carefully and mine from parts of the ore-bodies low in lime. With research, it became possible to use ore higher in lime, but certain parts of the ore-bodies still must be discarded, either by sorting or in mining. It is obviously desirable to be able to utilize the material of lower grade. Investigations carried out in the laboratories of the Department of Mines, Ottawa, showed that some concentration of MgO could be effected by calcining at a temperature high enough to decompose the carbonates and then slaking with water to remove the lime. The workers in the National Research Council laboratories improved the method by calcining at sufficient temperature to decompose only the magnesite, following which the magnesia, which is in very pulverulent form, can be screened out of the dolomite after a light crushing. These investigations are still in progress. Oil flotation, and separation of the dolomite from the magnesite electrostatically, are lines of attack that may receive further attention.

Uses of Magnesite

Magnesite is a substance of varied use. In part it is used as the carbonate, but for most purposes it is burned to the oxide. In the early days of the Canadian industry, the ore was shipped in the crude state with no other processing than sorting and crushing. Later, the crude ore was calcined at sufficient temperature to drive off most of the carbon dioxide. Such crude calcined ore can be slaked with water, and for that reason it is termed 'caustic calcined'. This has industrial uses in the manufacture of Sorel cement and heat-resisting paint, and some of the output from the Grenville district is still shipped in this form. By the use of suitable dead-burning agents and by employing a much higher temperature in the klin, a clinker known as 'dead-burned magnesite' may be produced. This is relatively unaffected by water, in which respect it is in decided contrast to the pulverulent caustic-calcined product. The clinker is used as linings in metallurgical furnaces and equipment and in places where high heat-resisting qualities are essential. Other substances, designed to give special properties, may be added to the clinker for making bricks and furnace shapes. Bricks may be re-burned to give a ceramic bond, or they may be bonded chemically.

Calcined magnesite is used in the manufacture of Sorel or oxychloride cement. The principal use of this material is in making floors, tiles, stucco, and other structural materials.

For the manufacture of carbon dioxide, the lower dissociation temperature of magnesite as compared to calcite decreases the cost of fuel. Comparatively little carbon dioxide is now made from Quebec magnesite, however.

Magnesium bisulphite has been used for the treatment of wood-pulp in the paper industry. It is more stable and a stronger solvent of resins than the corresponding calcium compound.

Magnesite may be used as a source of metallic magnesium, and at one time the metal was produced from Quebec magnesite by the Shawinigan Electrometals Company. Magnesium is used principally in alloys with aluminium, such alloys having greater tensile strength and resistance to shock than pure aluminium. The metal itself has a number of minor uses, as for example for flash lights in photography, and in fireworks, these uses depending on the dazzling white light emitted when the metal is burned.

Magnesium salts may be prepared from magnesite and are used in pharmacy, and in making toilet preparations. Some magnesium salts are used as 'fillers' and in various preparations to prevent scale in boilers.

Most of the Canadian output has been used as heat- or slag-resisting material, but some has been used in plastics and special cements.

Production

Table I, compiled from reports of the Bureau of Mines, gives the production of magnesitic-dolomite from the Grenville district for each of the years 1907-36.

Table I.—Production of Magnesitic-Dolomite from Grenville District

Year	Total Shipped Tons	Value $	Clinkered or Dead-Burned Tons	Calcined Tons	Crude Shipped Tons
1907 1908 }	200*	$ 520*			
1909	330	2,508			
1910	....	2,160			
1911	885	6,416			
1912	1,712	9,645			
1913	515	3,335			
1914	620*a*	21,126			
1915	16,285	137,353			
1916	53,976	525,966			
1917	58,340*b*	729,025			
1918	28,564	1,016,764	21,349	1,318	5,897
1919	9,940	283,719	6,696	1,656	1,588
1920	17,941	512,755	10,491	3,154	4,296
1921	2,927	74,110	1,373	684	870
1922	2,853*c*	76,547			
	Total Crude Mined				
1923	9,455	126,781	3,639	864	
1924	7,950	101,122			
1925	9,967	122,325	3,076	993	1,507
1926	9,130	137,431	3,384	1,187	
1927	15,305	230,309	6,309	1,028	
1928	27,709	346,991	12,070	1,125	
1929	39,499	491,170	17,544	1,265	
1930	28,006	336,162	12,482	854	
1931	23,963	295,579			
1932	....	262,860			
1933	....	360,128			
1934	....	382,927			
1935	....	486,084			
1936	....	769,176			
		$7,850,994			

* Approximate. (*a*) Graphite and magnesite; (*b*) High proportion crude; (*c*) From 5,645 tons crude mined.

Method of Working

In the Grenville district, until 1935, all the ore was extracted from open pits, either by hauling of cars or skips up an incline or by raising buckets with a derrick. In only one or two places was it possible to use horse-drawn dump waggons. Naturally, with increasing distance from the surface, the operation of the open cuts presented several difficulties. Walls of weak or jointed rock became dangerous with depth. Furthermore, a great deal of waste rock had to be removed along with the ore. Open pits as much as 180 feet deep were made.

In 1935, a stope was opened above a drift in the ore-body at the south end of the main (*B*) pit of the Canadian Refractories property, and in 1936 a drift was run from the north end of the same pit and stopes opened from it. A shaft has now been sunk 425 feet from the surface to make the deeper ore accessible.

Although only a relatively small part of the output to date has come from the underground workings, the newly adopted mining method seems to be successful. It offers the advantages that only the useful parts of the ore-zone need be mined, and not the whole body of rock as in the open pits, and that there is no high face or wall towering above the worker. Open pits may be economically used where the depth of working is not great and the output small. This is especially true of the earlier stages of development. In general, the serpentines and serpentine-carbonate rocks associated with the magnesite do not form good vertical walls.

Determination of Magnesite

In practice, the only effective way of determining the grade of magnesite or dolomitic-magnesite ores is by laboratory test. The three carbonates, calcite, dolomite, and magnesite, are so similar in habit and appearance that one is uncertain of the composition of a given specimen with megascopic examination alone. Certain megascopic features are, however, characteristic of the best ore. The magnesite is more resistant to weathering than dolomite or calcite, so that it stands in relief above the other carbonates on the weathered surface. The magnesite is, of course, less resistant than the serpentine. Much of the high-grade material is medium grained, with a milky or glassy appearance, whereas the dolomite and calcite are white and coarse grained, with duller lustre than the magnesite. However, both granularity and appearance are unsafe guides to the grade of the ore. Magnesite has a greater density than dolomite, but the ore has associated serpentine which prevents a determination of the amount of magnesite from the density.

One feature of these carbonates that proves useful in examinations conducted underground is that, on being struck with a hammer, the rock near the point of impact glows momentarily. The glow is quite feeble, but may be observed if the light from the lamp is directed away from the spot being examined. The glow from magnesite is pale yellow and that from dolomite a pale red. By striking the face in enough places, the quantity and distribution of the carbonates may be roughly learned. Occasionally, if a piece of the carbonate rock is broken from the walls underground, a flash of light may be observed as the break opens.

This phenomenon is also to be observed in a dolomite from the Tetreault mine, at Notre-Dame-des-Anges. The luminescence has not yet been satisfactorily explained but is probably the result of inter-atomic or inter-molecular re-arrangement in the broken crystals. The luminescence is different from many types in that the emitted light has the colour of the dominant spectral lines. Dr. D. A. Keyes, of the Department of Physics, McGill University, has examined the material from the Tetreault mine and found that emission of the same colours is induced by cathode-ray excitation.

The utilization of some ray that would provide a rapid means of estimating the value of the ore would be helpful. Of the various rays, the cathode ray seems most effective, but unfortunately there are technical difficulties in applying it.

A chemical analysis affords the best test of the grade of the ore. For practical purposes, most of the ore may be considered a mixture of dolomite, magnesite, and serpentine. Magnesite has only a slightly greater content of MgO than serpentine, so that a certain mixture of dolomite and serpentine could give about the same amounts of CaO and MgO as a mixture of dolomite and magnesite; therefore, a determination of the loss on ignition or of silica is important. It has been found that when the carbonates with associated serpentine are treated with hot acid, not only are the carbonates dissolved but the serpentine also is decomposed. If the solution is taken to dryness, insoluble silica with a small amount of other oxides is thrown down. The precipitate is ignited in an electric furnace, weighed, and recorded as 'insoluble'. 'Loss on ignition' is determined in the usual manner by heating a sample of the ore in an electric furnace. The combined Al_2O_3 and Fe_2O_3 (recorded as R_2O_3), and the CaO, are determined by the standard gravimetric methods. The deficiency from 100 of the sum of Ign., Insol., R_2O_3, and CaO is recorded as MgO. The direct determination of MgO has been found to be only slightly more accurate than this procedure.

Various methods of distinguishing dolomite from magnesite have been evolved. One used by M. E. Wilson consisted in heating a polished slab in a reducing atmosphere. The magnesite turned buff whereas the dolomite remained white.

The writer experimented with various methods of etching the carbonates. Lemberg's reagent, aluminium chloride and logwood dye, will cause calcite to stain blue, but dolomite and magnesite are unaffected. Meigen's test, *i.e.*, boiling with a concentrated solution of cobalt nitrate, will cause aragonite to become mauve, whereas calcite, dolomite, and magnesite are stained only slightly, if at all.

Dolomite is apparently slightly more readily soluble in hydrochloric acid than magnesite. The difference in solubility is not great, so that it is difficult to bring out the contrast by etching with acid. Sulphuric acid (dilute) with potassium bichromate attacks dolomite more rapidly than magnesite. A fair contrast is developed if the specimen is left for twelve hours in the cold solution. The contrast may be increased by treating the etched specimen with silver nitrate, which causes an orange precipitate to form on the dolomite. Attempts to decrease the time of treatment by using stronger or hot acid were unsuccessful. At least some magnesite contains sufficient ferrous iron that, on treating a specimen with hydrochloric acid containing potassium ferricyanide, it becomes stained with Turnbull's blue. Dolomite does not give this test. Unfortunately, no easy method could be found to fix the colour once it formed.

Organic dyes seem to offer one method of staining. Titan (Clayton's) yellow in KOH solution turns some magnesite red on boiling. This test is due to Piotrowski. Unfortunately, it is inconclusive on the Grenville magnesite, probably because of its low tenor of iron. The associated serpentine takes on the fire-red colour described as characteristic of magnesite. The serpentine probably carries most of the iron present in the ore. Other organic dyes have been proposed for the purpose of distinguishing the carbonates. An easy method of distinguishing them would be useful, not only for the scientific study but also to indicate the extent to which the ore might be treated by ore-dressing methods.

CLASSIFICATION OF MAGNESITE DEPOSITS

Magnesium carbonate has several modes of occurrence. The following classification, modified from that of Redlich, is convenient:

(1) Crystalline magnesite:
- (*a*) Replacement of limestone and dolomite.
- (*b*) Injection. Sagvandite type.
- (*c*) Vein minerals. (Few examples).

(2) Cryptocrystalline (so-called amorphous) magnesite:
- (*a*) Alteration of serpentine (may be hydromagnesite).
- (*b*) Veins in serpentine.

(3) Hydromagnesite and nesquehonite deposits:
- (*a*) Saline deposits (one example with magnesite).
- (*b*) Weathering of magnesian minerals.

Examples of all three types, and of most of the sub-types, are known in Canada. In general, the deposits of different type have different characteristics and find different uses. All types are known from widely separated localities outside Canada. The literature of magnesite is voluminous: K. Niinomy has published a volume of 109 pages giving a bibliography of magnesite occurrences. Certain deposits are considered types. Thus the type of crystalline magnesite in limestone and phyllite is known as the Veitsch type. The injection type is related to sagvandite and type examples may be the deposits near Dipynydal, Norway, described by Schetilig. Magnesite occurs as gangue in veins, but only rarely.

Truly amorphous magnesite is probably rare, but the fine-grained or cryptocrystalline magnesite found in serpentine is commonly termed 'amorphous'. It occurs as an irregular replacement of serpentine or in distinct veins. This may be referred to as the Kraubath type. Earlier writers were almost unanimous in ascribing deposits of this type to weathering. Recently, the consensus of opinion has changed, and most of them are now considered of hydrothermal origin. One reason for this change of view is the realization that hydromagnesite, or nesquehonite, is the carbonate that would be formed on weathering. For example, magnesite in Nevada has been altered to hydromagnesite at the surface.

Hydromagnesite is found as a lake deposit in British Columbia and also in the deposits of springs in certain parts of Europe. In the Green River formation of Wyoming, magnesite is found with sepiolite (meerschaum) and analcite in lake deposits. If a deposit of hydromagnesite were metamorphosed, it might give rise to a magnesite bed in a sedimentary series. Although some of the crystalline magnesites have been considered metamorphosed magnesite beds, there are objections to this view, and well-substantiated occurrences of magnesite of this origin are not known to the writer.

Some uncertainty exists regarding the proper classification of the Grenville magnesite deposits, although it is certain they all fall in class 1. Wilson would consider them all to belong to class 1(*a*), but, as shown in a subsequent section of this report, they may be related in part to class 1(*b*).

A review of the literature dealing with the crystalline magnesite deposits shows that most occurrences of crystalline limestone are associated with sedimentary rocks older than Mesozoic. The sedimentary formations are the metamorphic equivalents of limestone, shale, and sandstone, and in a rather surprisingly large number of the deposits the magnesite is associated with the altered shale and sandstone rather than with the limestone. The Grenville deposits are higher in lime and lower in iron than many of the deposits being exploited elsewhere. In character of country rock and intrusive rock, they are very similar to deposits in Ceylon. In Nevada, magnesite appears to have formed during the magmatic period of the intrusive rock and this relationship is observed in Grenville township.

In view of the great extent of many of the magnesite deposits exploited elsewhere, it may reasonably be expected that intensive prospecting of the Grenville limestone areas in Canada will disclose that magnesite is more widespread than now appears. The occurrence of magnesite boulders in places where it is improbable that they could be borne by ice from any of the known deposits likewise encourages further search. Of course, it is probable that the boulders to attract attention are the exceptional types and that high-lime boulders may be numerous also; but it is generally said, by those who have prospected in the vicinity, that the boulders are better grade than the known deposits. Unfortunately, as shown in the first section of this report, overburden is heavy and prospecting laborious.

Wilson lists a number of occurrences of magnesite in Canada, but, in general, the geological data are inadequate to assign the deposits to their correct position in the scheme of classification outlined above. The most important information appearing since Wilson's report is in Geological Survey Memoir 98, by Reinecke, on the deposits of hydromagnesite in the interior of British Columbia, and in Summary Report, 1932, Part AII, also of the Geological Survey. In the latter report, an occurrence near Clinton, B.C., of magnesite associated with serpentinized

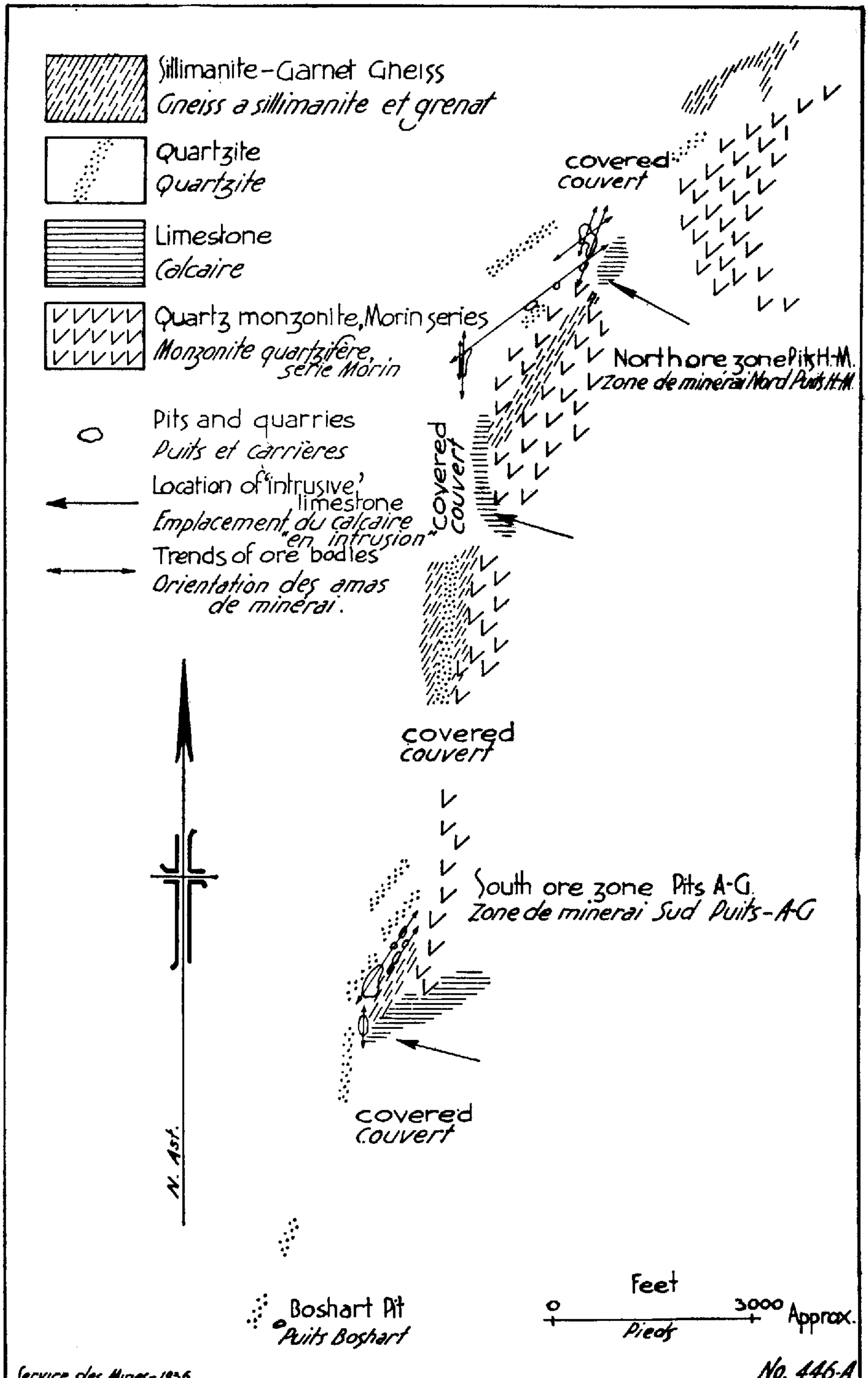


FIGURE 1.— Sketch of ore-zones of Canadian Refractories, Limited.

rocks is described by Cockfield and Walker, and an occurrence in the Cranbrook district, B.C., of crystalline magnesite by C. E. Cairnes. Preliminary work in the vicinity of Cranbrook shows the deposits to be large. They are associated with Precambrian schists and quartzites. Two analyses given by Cairnes (p. 103, Part AII) show only a low tenor of alumina; but according to other analyses, it is present in considerable amount. The writer has examined some specimens from the Cranbrook deposit. These show coarsely crystalline magnesite, associated with a considerable amount of an aluminous mineral.

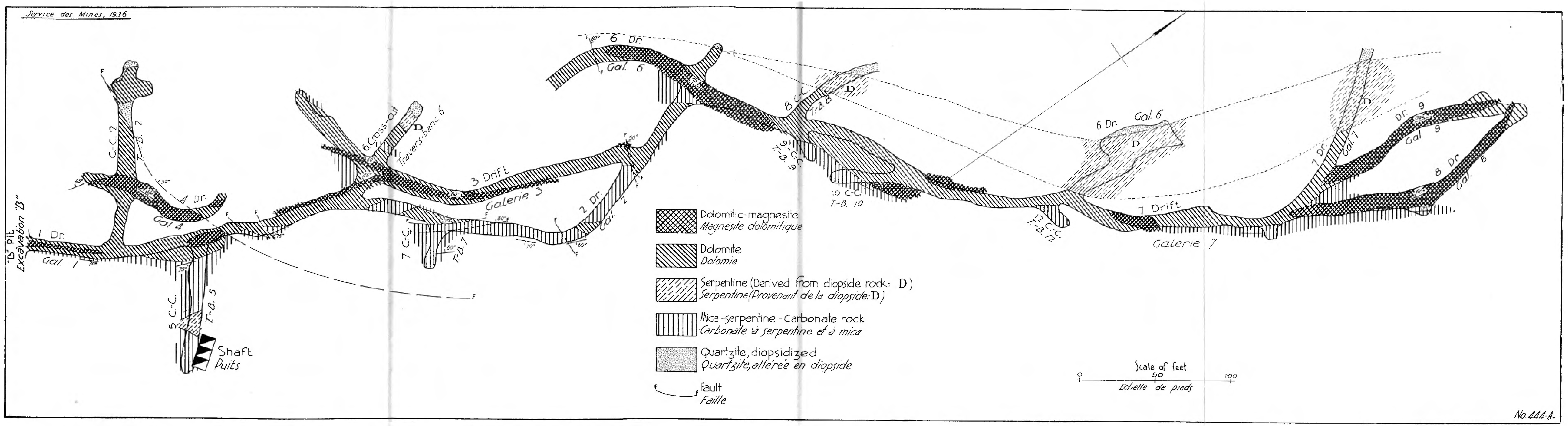
DESCRIPTION OF PROPERTIES

General Statement

It must be emphasized at the outset that the ore does *not* consist of magnesite alone, but contains considerable serpentine and dolomite. The best ore has about 25 per cent dolomite and is, therefore, appropriately termed a dolomitic-magnesite. The intimate mixture of the 'impurities' with the magnesite has been turned to good account by research, through the efforts both of companies that have mined the material and of the Magnesite Research Committee of the National Research Council of Canada.

For practical purposes, the ore may be considered as composed of the three minerals, dolomite, magnesite, and serpentine. Other minerals may be present, but if so they are in minor amount. An important point is that the ore contains two carbonates, magnesite and dolomite. It is generally recognized that calcite, dolomite, and magnesite may deviate only slightly from the formulae $CaCO_3$, $CaMg(CO_3)_2$, and $MgCO_3$, due to solid solution of lime or magnesia as the case may be. Calcite may occur as a separate mineral mixed with dolomite, but not with magnesite. Dolomite may occur with either calcite or magnesite.

All writers on the geology of areas with many outcrops of Grenville rocks have emphasized the fact that, with the exception of the beds of massive quartzite, the Grenville rocks are less resistant to erosion than the predominant granites and gneisses. Consequently, the Grenville rocks, and particularly the limestones, tend to underlie valleys. Dolomite and magnesite offer about the same resistance to abrasion as does limestone but magnesite is superior to dolomite, and dolomite to calcite, in resistance to solvents, *i.e.*, chemical weathering. The serpentine is quite stable toward these latter agents, and the toughness of the aggregate of serpentine makes it relatively resistant to abrasion as compared to other members of the Grenville series. The deposits of magnesite, therefore, are somewhat more resistant than the limestones to both abrasion and weathering. It is noteworthy that several of the magnesite deposits originally were exposed on ridges rising above the surrounding valleys. It should be stated that not all the valleys are underlain by Grenville rocks; some are carved in igneous rock. This is particularly true where cupolas of igneous rock penetrate the Grenville series.



Map No. 444-A.— Underground workings in the Southern ore-zone, Canadian Refractories, Limited.

Canadian Refractories, Limited

The Southern Ore-Zone

Most of the ore produced in the past fifteen years has come from the pits designated *A* to *G* in the southern ore-zone of the Canadian Refractories, Limited, property. The ore has been exploited by the very deep open-pit, *B*, and by underground workings extending from the north end of *B* beneath pits *C* to *G*. In addition, twelve drill-holes have been put down recently in this vicinity, so that more geological data are available regarding this section of the property than any other. Little is known concerning the distribution of ore in the parts mined out. No assay plans were made, and in the pits, of course, the whole of the ore-zone has been removed. Thus, much valuable information regarding the distribution of the magnesite within the ore-zone has been lost. Wilson, on the maps accompanying his memoir, gives the distribution of material in certain of the pits. Unavoidably, many of the determinations are based on inspection, and moreover, the elevations of the surfaces shown are not given.

It is necessary at the outset to make clear the distinction between *ore* and *ore-zone*. By 'ore' is meant the dolomitic magnesite with lime content low enough that the material may be used in the manufacture of refractories and plastics. The ore grades into high-lime carbonate with masses and stringers of serpentine. The carbonate is definitely not recrystallized Grenville limestone, but is in part a vein deposit with, in places, apatite, sphalerite, pyrite, and galena. The entire body of carbonates of this type, along with serpentine, is designated as 'ore-zone'. The ore occurs as more or less lenticular bodies lying in the ore-zone.

The zone within which ore may be encountered in the southern ore-zone is about 2,000 feet long. On the east side, a body of quartz monzonite trends at an acute angle to the quartzite which forms the west limit of the ore-zone. A short distance north of diamond-drill hole 14, the quartzite is cut by quartz monzonite. Near the southern end of the ore-zone, the intrusive rock is about 500 feet east of the quartzite. Here, the intrusive is interrupted by limestone which shows evidence of having been shoved ahead of the intrusive as far as the quartzite. No ore has been found south of this limestone. Where the ore-zone extends into the limestone, dolomite, but no magnesite, has been formed. Some limestone lies to the west of the intrusive in the southern part of the area delimited above but only comes into the ore-zone at the south end of pit *A*. A diabase dyke, 20 feet wide, intersects the ore-zone at the north end of this pit. Some serpentine has formed in cracks in the dyke and along its margin, but apart from this it is not affected by the adjacent magnesite nor has it affected the latter.

The west side of pit *A* is diopside rock with residuals of quartzite. The east side is serpentine and mica-serpentine-carbonate rock. According to the best information available, a narrow vein of grey ore was mined from the south end nearly to the dyke of diabase.

Most of the work has been in or near pit *B*. A drift and stope running south from the end of the pit show that the southern prolongation of the ore-zone is offset to the west with respect to that in pit *A*. The ore-zone pinches out near the end of the drift and its southern extension was not encountered in diamond-drill holes 10, 11, and 12. The ore-zone has the greatest width, 150 feet, near the main part of pit *B*, but narrows rapidly to north and south. Near the northern end of pit *B*, the ore-zone contains much serpentine and diopside rock. A vein of quartz in this part of the pit is bordered by diopside and this, in turn, by serpentine. Underground workings north of pit *B* show that ore-zone material forms irregular bodies with north-south trend that pass irregularly around blocks of the country rock. The pits *C* to *G* are inaccessible, but the underground workings have been driven beneath them. North of the pits, ore has been found in diamond-drill hole 3.

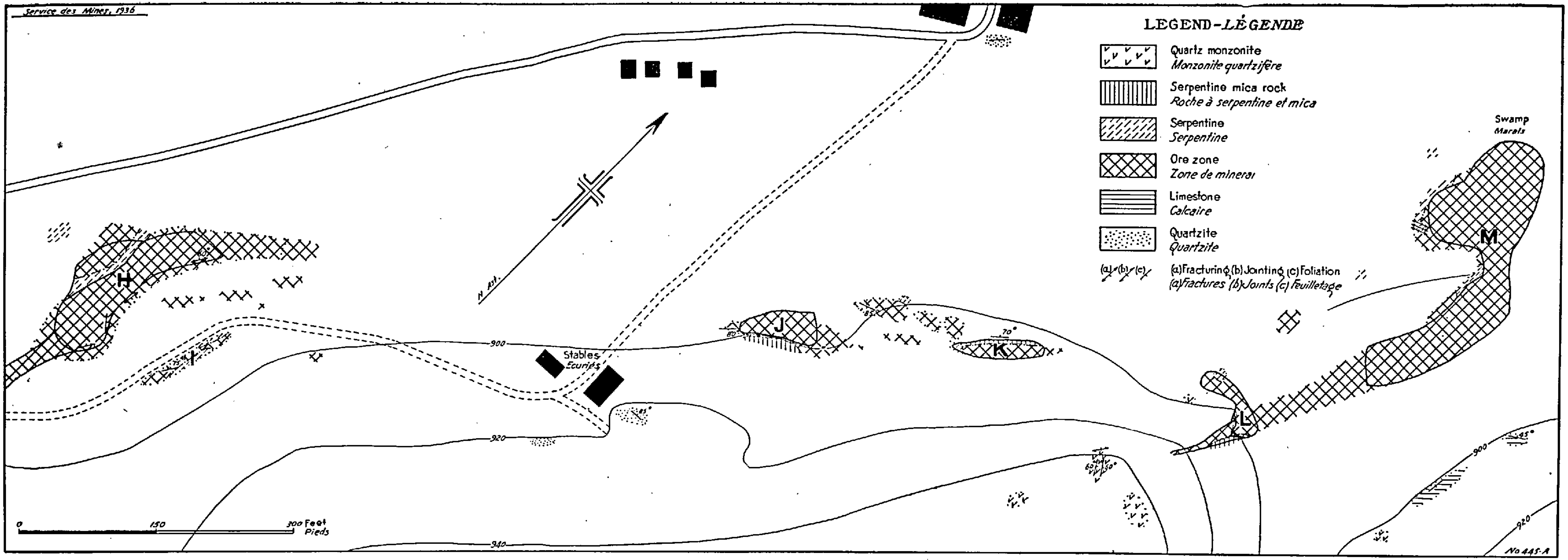
The status of the mica-serpentine-carbonate rock on the east side of the ore-zone is discussed elsewhere. The rock shows some irregularity in character and may be the result of alteration of gneisses of the Grenville. In any case, the amount of feldspar increases away from the ore-zone, and other characteristics suggest that it is metasomatized gneiss.

The width of the ore-zone varies considerably from place to place, as shown by workings and drill holes. The ore-bodies within the ore-zone are fairly large but of irregular occurrence. Unfortunately, not enough data are available to determine accurately their shapes. The results of the work to date would accord with the hypothesis that the ore is in pods, whose long axis plunges south, lying in the ore-zone. The only confirmatory evidence that may be offered is that there is a pronounced linear pitch in this direction in the quartzite adjacent to the ore-bodies. A more certain determination of the shapes of the ore-bodies must await further work.

The Northern Ore-Zone

North of the southern ore-zone there is a heavily drift-covered area with only one exposure, of diopsidized quartzite. Rising above the drift on the north side of the drift covered area is a hill composed of quartzite extensively altered to diopside rock flanked by bands of sillimanite-garnet gneiss. The eastern band is intruded by dykes of quartz monzonite. Near the kilns, Grenville limestone has been shoved into the sillimanite-garnet gneiss. Pit *H* is a short distance north of the kilns and is surrounded by drift. In this pit, a pronounced change in trend of the ore-zone from north-south to northeast-southwest is seen, so that it swings along the foot of a hill that rises east of the plant. Work done in 1936 suggests that a body of ore with a north-south trend may continue north of the 'bend'.

Near the stables, south of pit *J*, diopsidized quartzite is found, succeeded to the south by quartz monzonite with many residuals of sillimanite-garnet gneiss. Quartzite occurs to the north of the ore-zone, beyond the small stream and road. Furthermore, traces of diopside rock, possibly derived from quartzite, are found between pit *G* and pit *H* along the foot of the hill. Several small pits have been opened near the edge of the swamp northeast of pit *J*, and there the quartz monzonite comes closer to the ore-zone than at pit *J*. The easternmost pit of this zone is



MAP No. 445-A.— Northern ore-zone of Canadian Refractories, Limited.

only a short distance west of a body of limestone that is caught in the quartz monzonite. The most significant thing is that stripping of the southern prolongation of the ore mined from pit *M* has shown banded dolomite and magnesite. Unfortunately, the outside contacts of the extension are not visible, but an outcrop of quartz monzonite a short distance west suggests that the ore-zone has occupied a fracture extending into the intrusive rock. If the trends of the old pits are plotted, two directions, one parallel and one inclined to the strike of the Grenville, are found. This suggests that the ore is not a result of a simple replacement of Grenville but was controlled by fractures inclined to the structure of the Grenville beds. Unfortunately, no diamond drilling has been done recently on this zone, and the low ground does not afford sufficient exposures for detailed geological work. Considering reports on the old work and the disposition of the pits, this zone is worthy of detailed exploration. The complication introduced by ore-bodies with two directions of strike makes it possible that much valuable ore has been overlooked.

No work has been done east of pit *M*. However, the quartzite band with quartz monzonite on the south continues to the east. Diopsidized quartzite is found on a low mound rising above the drift east of the pit, and coarsely crystalline dolomite of the type characteristic of the vein-zone occurs there. This section deserves some exploration. The eastern end of the mound mentioned is near a small stream. Limestone is found to the east of the stream, with quartz monzonite to the south.

Diopsidized quartzite, which forms a highland to the east of the stream, is flanked on the south by quartz monzonite and on the north by a thick band of sillimanite-garnet gneiss. Unfortunately, the high ground is heavily covered with drift, and relatively few exposures may be seen, which perhaps accounts for the area being shown as 'Buckingham' series on Wilson's map. This zone extends as far as the peninsula lying east of Grenville lake. Serpentine and diopside, derived by replacement from quartzite, are abundant, but no magnesite was found. This is not, however, surprising in view of the sparse exposures. The heavy mantle of drift would make this section difficult to explore.

General Relationships of Ore-Bodies in the Northern and Southern Ore-Zones

A general view of the two ore-zones would be a series of beds with limestones on the east, and followed by quartzite and sillimanite-garnet gneiss to the west. The south end of the series trends almost north-south but changes near the plant to northeast. Quartz monzonite lies inside the bend and almost fills the area. Southward, small bodies of this intrusive almost parallel the trend of the other rocks, and, near the east, bands of sillimanite-garnet gneiss are common. In three or four places, Grenville limestones have been shoved by the quartz monzonite out of their stratigraphic position into the sillimanite-garnet gneiss. The limestones seem to mark the end of ore-zones. In the southern ore-zone, the magnesite occurs in and near the eastern side of the quartzite, whereas in the northern zone it appears to be within quartzite or beds intercalated in the latter. It is significant that in both ore-zones the ore is on the side near the intrusive rock.

The best ore has been found near places where there is a change in structure. At pit *B*, there is a 'bow' in the structure. The bow may be due to intersection of two structures of nearly the same trend. The ore in pit *A* does not seem to be a continuation of that in pit *B*. At pit *H* the trend of the ore changes. It is possible that two structures intersect in this pit and that, on the west side, ore may occur along a fracture to the north, although the main ore-body swings to the northeast. At pit *M*, a fracture inclined to the strike of the Grenville beds cuts the Grenville, and it seems probable that the intersections were responsible for the large ore-body here. Pits *B*, *J* and *M* were opened on the most important ore-bodies that have been found on the property, and it is significant that structural 'breaks' are found in these pits.

Shaw and Dobbie Mines

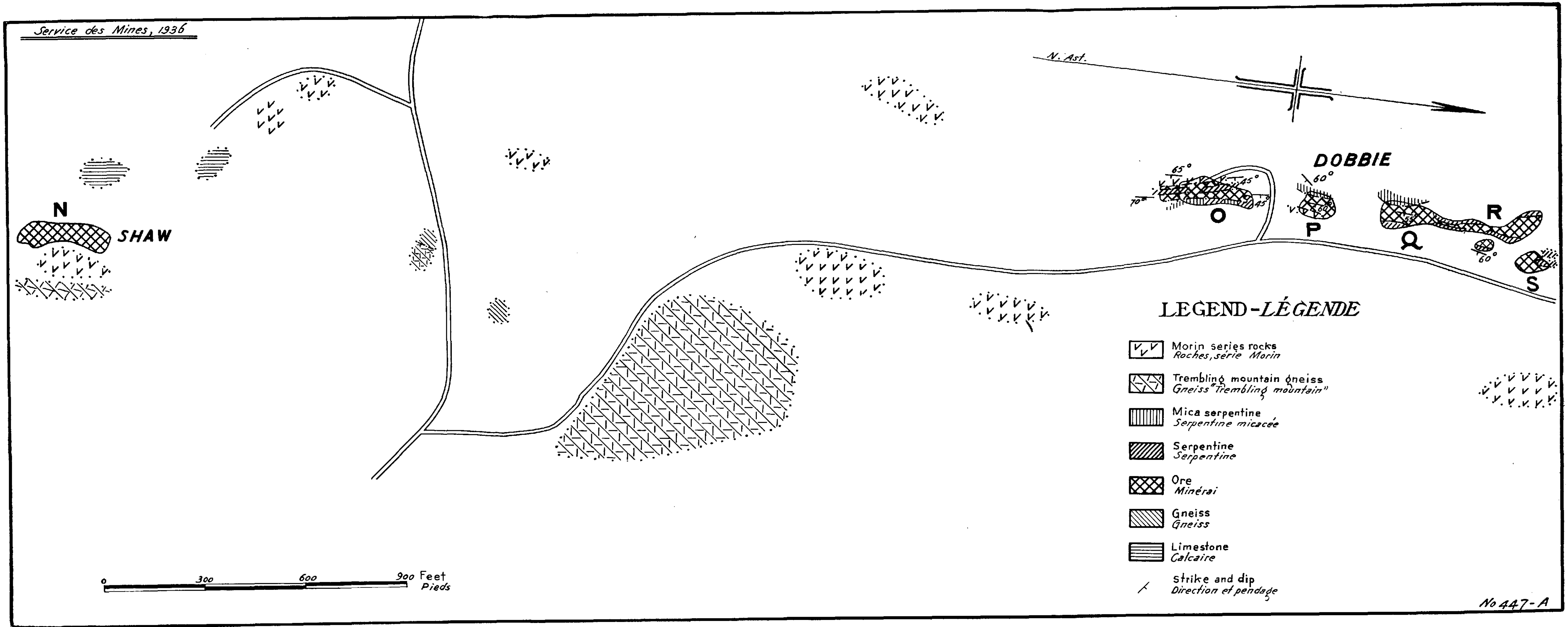
A high ridge of Trembling Mountain gneiss separates the Shaw mine (pit *N*) of Canadian Refractories, Limited, and the Dobbie mine (pits *O* to *S*) of the International Magnesite Company from the two main ore-zones (pits *A* to *M*) of Canadian Refractories. Both the Shaw and Dobbie mines are along the eastern foot of the ridge, and at first sight they appear to be on one band of magnesite; but examination of the terrane between the two properties shows that Morin and other rocks crop out in such a fashion that, if the two are a continuous ore-body, the connection between them must be extremely narrow and sinuous.

The Shaw mine has not been worked recently and the pit is inaccessible for examination, due to water. A number of small dykes of diabase porphyry may be observed in the pit. The writer could obtain no data on the grade or distribution of the ore.

At the Dobbie mine, the ore-zone has been exposed by stripping and pits for about 900 feet along a zone 1,200 feet long. In the 1,200 feet, the ore-zone is very irregular; pockets of ore have been exploited where the zone was sufficiently wide, but between pockets the ore may pinch to such an extent that it cannot be economically mined. At the north end, the ore seems to have spread over a greater width in the ore-zone, although the grade is not so good as at the south.

The present workings in the south (pit *O*) have given grey and white ore in fairly well defined bodies in good width. On the west side of pit *O*, a granite of the Morin series occurs and a knob of similar rock is exposed on the east side of pit *P*. Shearing along the contact has obscured the relationship, but the best evidence indicates that the granite is intrusive into the ore-zone. On the west side of pit *O*, the granite appears to dip beneath the ore-zone at about 45°. If this dip were projected, it would cut off the ore-zone at no great depth. But granite intrusions in carbonate rocks are commonly very irregular in form and it may be that the dip of the granite body changes before it intersects all the ore-zone The bulk of the Morin intrusive lying east of the ore-zone is more basic than the granite and probably antedates the ore.

The presence of the granite in the ore-zone introduces some uncertainty as to the amount of ore available at the Dobbie mine. If increased production is planned, the ore-zone should first be explored thoroughly.



Map No. 447-A.— Shaw mine and Dobbie mine.

Fortunately, the form of the ore-zone is such that diamond drilling would offer a feasible method of exploration.

An occurrence of magnesite of scientific interest at least was found during the summer of 1936 a short distance south of the farm-house on lot 14, range X, Grenville township. The occurrence is on the east side of a tightly folded and overturned syncline of sillimanite-garnet gneiss and quartzite, which pitches to the south. The magnesite is developed near the sillimanite-garnet gneiss and is associated with diopside rock and serpentine. Very little work has been done and there is no evidence that the ore is more than five feet wide. Its extension to the north is cut off by outcrops of massive and competently folded limestone. The extension to the south is covered. In the woods east of this occurrence, outcrops of altered quartzite are found in the fields on both sides of the railway track near the line between lots 15 and 14 of range X. These occurrences illustrate the wide distribution of serpentine and diopside. No ore is known to be associated with them, but they have not been explored.

Boshart Pit

A small pit has been opened by W. P. Boshart and C. Fitzsimmons on lot 16, range IX, Grenville township, just south of the limit of the property owned by Canadian Refractories. The general geological conditions are similar to those along the main ore-zones on that property. Quartzite, extensively altered to diopside and serpentine, crops out west of the workings and is followed to the west by Trembling Mountain gneiss. East of the pit, Grenville gneisses with injections of Morin rocks are found.

The main zone, which has been developed by a shallow pit, is on the east side of a mass of quartzite. It is uncertain whether any magnesite was produced from this pit. All the material on the dump is an aggregate of coarse calcite replacing dolomite with a little associated serpentine. Analyses of samples from the dump are:

Al_2O_3	0.07	0.58 (with Fe_2O_3)
Fe_2O_3	1.03	
CaO	47.64	48.72
MgO	7.72	5.87
Ign	41.60	43.20
Insol	1.94	0.60

ORIGIN OF THE DEPOSITS

Special Rôle of Limestone

The crystalline limestones near the intrusions of quartz monzonite have a special rôle. It is well known from experiment and from observation that limestone under pressure yields easily to deformation. In places, limestone has been observed to 'intrude' less plastic rocks as dyke-like bodies. Apparently, at the time of introduction of the magma of the quartz monzonites, the limestones had a plasticity similar to that of the magma, and in places the latter actually forced limestone into the originally clastic beds to the west. The behaviour of the limestone may be likened to the water of a bow-wave in front of a moving vessel, although the magma was, relatively to the limestone, much less rigid than the boat to the water. In a few places, the magma was actually able to send small dykes into the limestone, but in general it advanced through more fissile rocks, such as the sillimanite-garnet gneiss. Near the northern ore-zone of Canadian Refractories property, the sillimanite-garnet gneiss has been almost obliterated by the intrusive.

The behaviour of the limestone as described above has complicated the structural geology, because it has caused limestone to occur away from its stratigraphic position in the series. Fortunately, the limestones that have been squeezed into the other formations are rather distinctive; planar foliation with a pseudo-conglomeratic structure is more common in them than in the less squeezed limestones. Near pit *A* (Canadian Refractories), the limestone has been shoved to the west as far as the main band of quartzite and is intersected by ore-zone alteration. Inasmuch as the deformation of the limestone was contemporaneous with the introduction of the quartz monzonite, the period of magnesite formation post-dates it.

Serpentine

At some time after the formation of diopside, both in the Morin rocks near the deposits of magnesite and in the diopside rock itself, diopside became unstable and was converted to serpentine, probably the result of a change in the character of the pervading solutions. Diopside is $CaO.MgO.2SiO_2$, whereas serpentine is $2H_2O.3MgO.2SiO_2$; therefore, water has been added, and lime and silica abstracted or magnesia added. It seems probable that the CaO not required for serpentine went to form lime carbonate, which combined with the magnesia available in the ore-zone to form the coarse-grained dolomite fringe found around some of the magnesite ore-bodies. Analogous changes of diopside to serpentine with release of calcium carbonate have been described by Adams and Barlow. The formation of magnesite and serpentine at least overlapped, if the formation of serpentine did not continue longer than and begin earlier than, the formation of magnesite. Serpentine not only forms the walls of vein-like bodies of magnesite but also is contained within the magnesite as disseminated grains and as veins. Unlike magnesite, dolomite formed after serpentine. It occurs as veins replacing magnesite and as crystals lining cavities in serpentine. At Boshart's pit, dolomite is replaced by calcite, and, in the main magnesite zone calcite, and at one locality aragonite (on calcite), occurs coating fissures developed in magnesite and dolomite. Thus a carbonate sequence of magnesite, dolomite, calcite, and aragonite is clear.

Serpentine appears to have been stable for a long time and one variety may be replaced by another. In general, the dark varieties are veined and replaced by the lighter coloured ones. A black chloritic-appearing aggregate of serpentine occurs on the east side of the ore-body. It contains small 'eyes' of a light coloured aluminous mineral. Light yellow serpentine replaces the dark, the knots of aluminous material are removed or in some places enlarged. In some places, spinel structure and residual spinel may be seen in the cores of the large grains, associated with light coloured serpentine and dolomite. The chemical composition of the aggregate is shown in Table II.

TABLE II.—ANALYSES OF SERPENTINE AGGREGATE

	I	II	III	IV
Insol. (largely SiO_2)	48.12	22.00	28.00	6.64
Al_2O_3	14.26	1.59	4.86	16.98
Fe_2O_3 (total Fe)	14.30	2.57	2.40	1.88
MgO	7.30	30.40	36.90	34.80
CaO	8.79	12.00	0.18	0.39
CO_2	....	....	....	5.70
Ign.	....	25.24	21.60	

I, II and III.—Dark serpentine rock, pit *B*, Canadian Refractories, Limited.
IV.—White aluminous clot from yellow serpentine.

The aggregate derived from a spinel is not rare in the yellow serpentine, and in association with dolomite, in the rock exposed in the pits. The occurrence is significant in that at least a part of the ore-body appears to have occupied the position of aluminous rocks.

SERPENTINE CARBONATE ROCK

A body of serpentine carbonate rock occurs on the east side of the southern ore-zone of the Canadian Refractories property. Its origin offers several problems. In the first place, the body is rudely lenticular and extends along the regional strike through about the same interval as the main ore-body. The rock is obviously secondary, but its original character is uncertain. It is clearly not a metasomatized ultrabasic rock, because it is thin-bedded in places and on the side away from the ore-body contains cryptoperthite grading to microperthite. Quartz is found sparsely on its eastern side.

The writer interprets this rock as an altered phase of the sillimanite-garnet gneiss that is related to the quartz mangerite south of the northern ore-zone and occurs on the east side of the quartzite between the two ore-zones. Its extension to the south of the southern ore-zone of Canadian Refractories is interrupted by a transgressive body of limestone, but still farther south traces of the unaltered gneiss are found and it is noteworthy that no magnesite occurs there.

RELATIONSHIP OF MAGNESITE TO MORIN SERIES

The relation of magnesite to diopside is mentioned elsewhere. Diopside appears to be particularly prevalent near Morin rocks of intermediate calcicity, such as the quartz monzonite occurring a short distance from the magnesite deposits. The magnesite is observed in one place to penetrate this facies, thus indicating that it is younger than this facies of the intrusive. At the property of the International Magnesite Company, an acidic facies of the Morin series cuts the magnesite. The magnesite was thus formed during the magmatic period of the Morin series. It is noteworthy that, in Nevada, Kerr and Callahan dated a magnesite deposit as occurring in the magmatic period of the parent series.

GENESIS OF THE GRENVILLE MAGNESITE

As indicated in an earlier section of this report, the writer considers that the Quebec magnesite deposits have not originated by simple replacement of limestone of the Grenville series, as proposed by earlier writers (Wilson and Bain).

Sedimentary Origin

Daly has postulated that magnesium carbonate was more abundantly precipitated in earlier than in later geological time (1). He has pointed to the abundance of dolomite in the rocks of the early Palaeozoic. Some writers contend that magnesium carbonate could be precipitated from sea water alone in Precambrian time. In the writer's experience, this inference is untrue with respect to the limestones of the Grenville series.

Replacement of Limestone

Wilson has argued that the deposits of magnesite are the result of replacement of original beds of Grenville limestone by solutions from a basic magma. He is of the opinion that the replacement was practically a pseudomorphing, and that the irregularities and structures of the ore are inherited from the limestone. Bain has offered a similar explanation. He emphasizes the rôle of relatively impermeable barriers, such as quartzite or dykes, in restraining the upward migrating solutions, which he considers derived from acidic rather than basic rocks. Both these hypotheses have the merit of outward simplicity. Nevertheless, many features, particularly some that have been disclosed by diamond drilling or development work since Wilson and Bain examined the deposits, are not compatible with their hypotheses, although some ore may have replaced limestones and other rocks.

The writer believes that limestones had little direct influence on the position of the ore-bodies. The magnesite was introduced as a more or less independent body and was in part replaced by other minerals, of which dolomite and serpentine are the most important. In addition, serpentine was formed as a reaction product between silicate rocks and carbonate. The source of the carbonates was the Morin series, the local representative of which is the Buckingham quartz monzonite. The ensuing sections of this chapter detail the arguments in support of these contentions.

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(1) Daly, R. A., *Report of the Chief Astronomer*, 1910; Geol. Surv. Can., Memoir 38, Part II, pp. 643-675.

Diopside Rocks

On the west side of, and in, the southern ore-body of the Canadian Refractories property, and in many places in the vicinity of other magnesite deposits, diopside rock is common. It consists almost entirely of an aggregate of white crystalline diopside. In places, dyke-like bodies, two feet thick, of the diopside rock cut pure quartzite, but in most localities it is found replacing quartzite irregularly. All stages from a slight to complete diopsidization of the quartzite are found. The quartzite is thin banded (bedded), with a finely crenulated structure. Commonly, the limbs of the folds are replaced by diopside and the tops remain as quartzite. The dyke-like bodies and the replacing bodies had the same origin, and the conclusions on the mode of emplacement drawn from the two types complement each other. The diopside could not have been a magma because of the unequivocal evidence for replacement offered by the irregular masses; on the other hand, all the constituents to form diopside could not have been in the quartzite as might be concluded from the irregular replacement type, because of the development of the dyke-like types in pure quartzite. The only satisfactory conclusion that may be drawn is that the lime and magnesia were introduced into the quartzite by solutions. It may be that the quartzite was impure with aluminous silicates; if so, a large part of the alumina was removed by the solutions that diopsidized the rock.

Analyses of diopside rock, quartzite, and serpentine are given in Table III.

Table III.—Analyses of Diopside Rock, Quartzite and Serpentine

—	I	II	III	IV	V	VI	VII
SiO_2	52.48	48.92	84.10	74.16	37.64	36.72	53.22
Al_2O_3	1.32	0.90	0.91	0.74	0.97	1.28	4.03
Fe_2O_3 (total Fe)	2.14	2.74	3.09	2.74	2.91	2.40	4.37
MgO	14.20	15.23	1.55	9.40	39.70	37.80	22.90
CaO	22.26	23.34	0.99	4.62	0.21	2.64	4.53
Ign.	1.05*	1.86	2.12	3.00	13.44	16.32	0.13*

* Carbon dioxide.

I.—Diopside rock from limestone.
II.—Diopside rock from quartzite, Kilmar.
III and IV.—Impure quartzites near diopside rock, Kilmar.
V and VI.—Serpentine rocks derived from diopside rock, Kilmar.
VII.—Enstatite-bearing rock derived from quartzite, near Perdue river.

From the close association of the diopsidization with the formation of magnesite, there can be little doubt that the two processes are related; nevertheless, the problem of diopsidization is not confined to the magnesite locality. As shown in the writer's report on the general and economic geology of the Lachute map-area, in the section dealing with metamorphic pyroxenite (1), the Morin series has produced diopside or related pyroxene from quartzite, from limestone, and from sillimanite-garnet gneiss. This type of alteration is confined to rocks affected by proximity to the Morin

(1) This volume, p. 19.

series. The magnesite deposit appears, therefore, to be related to the Morin series, and the formation of diopside also appears to be a peculiarity of the same series.

Emplacement of Magnesite

The principal problem offered by the occurrences of magnesite is the mode of emplacement. The recent work on the ore-zone near Kilmar has shown that the magnesite bodies are branching. A branch may leave the main zone and either return to it or die out. Such relationships are characteristic of dykes or veins. The banded structure, explained by Wilson and Bain as inherited from old Grenville beds, is characteristically the banding of a vein or dyke. Divergence of strike and dip of Grenville and ore-body may be found, substantiating the transgressive nature of the ore-body.

The choice between dyke or vein injection is difficult, and arguments supporting either mode of origin may be advanced. Magnesite, dolomite, and calcite are found in a few localities as vein minerals, so their origin as vein minerals is clear. On the other hand, the suggestion that certain carbonates and carbonate-silicate bodies are the result of the injection of a magma has been received coldly, if not with derision, by many geologists, despite the fact that the hypothesis is supported by such leaders in petrology as Brogger, Goldschmidt, and Daly. The principal objection that has been raised to a carbonate magma is that the low (as compared to silicates) dissociation temperature would give rise to a high pressure if carbonate were melted — a pressure that would cause the magma to break through to the surface. Advocates of a carbonate magma have suggested that water, silicates, and carbonates were molten together, so lowering the vapour pressure of the system that the magma could be emplaced without disrupting the walls. With the data now available from physical chemistry, these arguments are hard to refute. Goranson has shown that, under sufficient pressure, even a granite with water may be broken up into a solution of silicates rich in water and of water rich in silicates. Certainly, carbonates would tend to go into the water-rich phase and, with sufficiently high concentration of the solution, the water fraction would have many properties of a magma. The water-rich extract would tend to be intermediate between a magma and a hydrothermal solution. At an early stage of its crystallization, it might resemble a magma closely and, with increasing precipitation of the minerals, it would pass into a hydrothermal solution. No sharp line of demarcation might be drawn between the magmatic and hydrothermal stages. Such an explanation would reconcile certain puzzling features of the magnesite deposits.

No narrow bodies of magnesite of vein habit have been formed. In fact, the narrowest body of good magnesite observed is about two feet wide. These observations suggest that the magnesite could not penetrate the containing rock in small masses. This is a property of a magma. Furthermore, the magnesite appears to have advanced across bands of rock of diverse composition, including in one place Buckingham quartz monzonite, without significant change in character, which also would be characteristic of a magma. After the formation of the magnesite, dolomite from paper-thin stringers to large masses cut through the ore, but, in general, this episode shows the characteristic of hydrothermal alteration. It seems difficult to escape the conclusion that the magnesite came in as a highly concentrated solution and cut across older structures. It had the characteristics of a magma in the early stages but passed to a hydrothermal stage, thus producing the associated rocks by reaction and replacement.

Where the emanations were not sufficiently concentrated to form a 'near' magma, replacement was possible. In fact, even in the concentrated condition, some replacement would be possible. E. Clar has shown that part of the magnesite of the Veitsch type is not the result of replacement but was introduced separately. It is certainly reasonable to relate all the magnesite in a deposit to one source. The replacement and independent types are probably one and the same. Evidence of replacement does not invalidate the suggestion that a part of the magma was introduced in a highly concentrated solution, although evidence of replacement in the Dipyndal deposits was cited by Redlich as refuting the hypothesis of magmatic injection offered by Schetelig. However, evidence for replacement is found in most pegmatites and in almost all granites.

Source of Magnesium in Morin Rocks

Although the data available indicate that the Morin rocks were the source of the magnesite, the reasons for the original presence of magnesium are not clear. There are two possibilities: either magnesium was an original constituent of the magma, or it was introduced into it. It is probably more than an accidental circumstance that the magnesite occurrences are near the axis of a syncline where the Morin rocks have traversed a considerable thickness of meta-sedimentary rocks. Limestone members might have contributed their carbonate to the magma, originally rich in magnesium. The magnesium carbonate would be concentrated into the rest-solution, to be injected to form the deposits. In the hydrothermal stage, the lime would probably be more soluble than the magnesium, and this relationship would explain the enrichment in lime in the late stages. It is possible, too, that incorporation of sillimanite gneiss may have played a part in the formation of the magnesite.

If the deposition of magnesite was due to replacement of calcite or dolomite, it is pertinent to enquire into the character of the solution that brought about the change. There has been a tendency to attribute the alteration to magnesium chloride, because the consensus of opinion is that magnesium chloride changes calcite to dolomite in sea water. If magnesium chloride formed the magnesite, it is surprising that no extensive occurrence of minerals containing chlorine is found near the deposits. Scapolite and apatite are the only two chlorine-bearing minerals observed, and even these are present in less than the amount usual in the region of metamorphic pyroxenites. In many localities in the Lachute map-area other than near the magnesite deposits, a rather strong case for the presence of abundant chlorine may be put forward. Chlorapatite and scapolite are abundant. However, one can advance few arguments to support the hypothesis that chlorides were responsible for the formation of the magnesite.

If the magnesium and calcium had been carried in solution as bicarbonate, no abnormal minerals would be found in the neighbourhood of the ore-zone. Unfortunately, the physical-chemical data bearing on the problem are very incomplete. Measurements have been made only near ordinary temperature, and extrapolation of these data into regions of higher pressure and temperature is exceedingly hazardous. It is not known whether, as at ordinary temperatures, magnesite can be precipitated from solution at high temperatures. The stable phase at ordinary temperature is a basic carbonate. Until such investigations are complete, it is useless to hazard a guess as to the conditions under the temperature and pressure obtaining where the magnesite was formed. It is certain that at one stage of the history of the deposit there was pneumatolysis, and, on the basis of alteration of the country rock, it is more probable that the active agents were water and carbon dioxide than that they were chlorine-bearing.

PROSPECTING FOR MAGNESITE

Inasmuch as the Grenville magnesite deposits are the only ones of their type yet known in eastern Canada, and since it is important to maintain a supply of the material for the manufacture of basic refractories and other products, the following data, summarized from the body of the report, are presented as a guide for prospectors.

Considerable prospecting for magnesite was done in the map-area prior to 1919, so that many of the exposures have already been examined. Therefore, the prospector today must examine obscure outcrops, and even trench the superficial material, in order to find new deposits. Diamond drilling might be necessary to test favourable localities. Boulder tracing may prove valuable in locating areas worth prospecting.

It has been shown that the magnesite was formed by material coming from Morin rocks. The rock most closely associated is a green, medium-grained, commonly gneissic, quartz monzonite of the Morin series. It outcrops in small masses that may represent the cupolas extending above large masses of magma. In limestone, small masses of the Morin rock are not rare. Although the limestones of the Grenville series may be indirectly related to the deposits of magnesite, country underlain entirely by limestone is not the most favourable for prospecting for magnesite. Apparently, when magnesium was introduced, it was diffused through a large volume of limestone, with resultant formation of dolomite. Near and in sillimanite-garnet gneiss and quartzite is a favourable place to search for magnesite, especially where the series is near limestone. A sequence of intrusive (Morin) limestone — sillimanite-garnet gneiss—quartzite appears to be a favourable one for prospecting. The writer is unable to decide whether the clastic rocks have provided a barrier for material coming from the magma or have actually precipitated it. In any case, the margins of the large limestone masses against Morin rocks, or the thin limestones in other meta-sedimentary members of the Grenville series, appear to be more favourable for prospecting than the large areas of limestone.

A syncline of limestone underlies the valley of Perdue river, but near its edges are quartzite and aluminous gneisses. A short distance south of Lost River village, small masses of Morin quartz monzonite cut the series, and enstatite, a mineral rich in magnesia, replaces quartzite. The introduction here of MgO is undoubtedly a manifestation of the same process that formed magnesite.

Metamorphic pyroxenite is widespread, so that the rock is not an index to the presence of magnesite. White diopside rock derived from quartzite is more restricted in its occurrence, but even this rock is found without magnesite. The presence of large masses of light coloured serpentine may indicate a locality worth prospecting, but even this is not an infallible guide to magnesite.

A.— Pit *B* Canadian Refractories Limited, showing narrowing of ore zone to north.

B.— South end of pit *B*, from entrance of No. 1 stope. Shows vein structure.

C.— Quartzite (in relief) replaced by diopside, west side of pit *B*.

A.— Pit *A*, looking south. Intrusive limestone near stairs at south end.

B.— Pit *A*, Diabase dyke cutting ore-zone.

C.—South pit International Magnesite Co. Looking toward Shaw Mine.

ALPHABETICAL INDEX