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ON THE IGNEOUS ORIGIN OF CERTAIN ORE DEPOSITS.

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Hill of Iron Ore, River Saguenay, Province of Quebec.

On the Igneous Origin of Certain Ore Deposits.

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The numerous and elaborate investigations into the nature and origin of ore deposits which have been carried out in recent years have led to the somewhat startling conclusion that certain of the deposits in question are of igneous origin. In stating that they are of igneous origin it is not meant merely that heat was in some way connected with their genesis, but that using the term as it is employed by geologists, that these deposits have cooled down and solidified from a molten condition like the other igneous rocks with which they are associated. The most important investigations into this class of ore deposits are those of Professor J. H. L. Vogt, of the University of Christiania, the results of these, however, having been published principally in the Sweedish language are not so well known as they deserve to be, and as a valuable resume of his investigations has just been given by Prof. Vogt in the Zeitschrift für praktische Geologie, (numbers 1, 4 and 7, 1893) it has been thought that a brief presentation of the facts known concerning these deposits might be appropriately brought before the Mining Association at this time, especially in view of the fact that although this is a comparatively small class of ore deposits, it seems to be one especially well represented in Canada.

In order to present this subject in as clear a manner as possible, it will be advisable first to say a few words on some recent investigations into the nature of igneous rocks in general, and the processes which are at work during the cooling of molten magmas, by the solidification of which igneous rocks are produced.

Recent researches have shown more and more clearly that a fused mass of rock is very similar to any ordinary solution of salt or sugar in water or any other solvent. As the fused mass slowly cools one mineral after another crystallizes out, a definite order being always observed.

The mineral containing the largest amount of base, such as iron, lime or magnesia first separates out, then a series of other minerals containing less base, until finally there remains only a comparatively acid portion of the magma which may be considered as the solvent of the others, corresponding to the water of the saline solution above mentioned, which solvent may eventually crystallize itself. Thus for example in the case of a granite, we find that the various ores, magnetite, titanic iron ore, pyrite, etc., first separate out, then the mica or hornblende, then the feldspars, and finally the quartz. The ores together with the mica and hornblende may thus be considered as having been originally held in solution in the molten feldspars and quartz. Now it is known as the result of elaborate experiments on various saline solutions, that if a solution of any salt be heated and allowed to cool gradually the salt tends to concentrate in the cooler portions of the solution. It is also found that in concentrated saline solutions there is a certain tendency for the lower part of the fluid to become richer in salt than the upper portion, that is for the salt to settle toward the bottom. In the case of certain alloys also, as is well known, it is often impossible to obtain a homogeneous mass on casting, owing to the persistent way in which certain constituents of the alloy will concentrate toward the top or bottom of the bar or casting during cooling. Even in pig iron it is found that the amount of sulphur and phosphorus will vary considerably in the different portions of the same pig for similar reasons. This phenomenon in the case of alloys has long been known as liquidation.

In molten rock also a similar tendency to separate into portions differing in composition is clearly shown to exist by our geological studies of erruptive magmas, this tendency resulting in the separation of certain more basic parts of the magma from others which are less basic—that is to say, the dissolved or basic material concentrates in certain places and this gives rise to a lack of uniformity in the mass—part of it being richer in certain minerals than other parts. In all probability differential cooling and the action of gravity are not the only factors which tend to bring about these remarkable phenomena in rocks, many other factors some of which we do not even suspect as yet, probably also working in the same direction. But whatever the causes may eventually prove to be which are most potent in bringing about these remarkable irregularities in molten rock masses, the fact remains that in cooling such masses do fall apart into portions differing in composition.

Now it stands to reason that since these changes are brought about by movements in the molten mass, the more fluid the mass is, the more favorable will be the conditions for such irregularities to develop themselves, and hence as basic magmas, both natural and artificial, are more fluid than acid magmas, it is in basic magmas that such irregularities will be most strikingly seen. As actual examples of this process we may take for instance the basic borders which we find in connection with so many granite masses, where during cooling the more basic part of the magma has concentrated itself toward the sides of the mass. The dark spots and patches which disfigure so many granites are in many cases at least, portions of such basic parts which have been separated by subsequent movements in the magma. As a granite, where this is excellently seen, the Garabal Hill granite of Scotch Highlands may be cited, or the celebrated Brocken massif of the Harz Mountains, in which a gradual passage from granite to gabbro can be clearly traced. Many similar examples nearer home may be cited, as for instance the igneous core of Mount Royal and many of its associated dykes in which remarkable variations of composition may be observed.

It is a universally recognized fact that ore deposits usually have some connection with igneous rocks, that is with rocks which have solidified from a molten condition. Of these ore deposits however, two classes have, as Prof. Vogt points out, a peculiarly intimate relation to such rocks, namely :

1st. Titanic iron ores.

2nd. Sulphide ores containing nickel.

These deposits not only occur in connection with the igneous rock but actually appear to form part of it, the ore occurring distributed through the rock and the heavy bodies of ore merging gradually into it in many places, so that it is impossible to tell where the rock begins and the ore body ends. The ore body in fact seems to be merely a portion of the igneous mass in which the ore, which is one constituent of the normal rock, is concentrated sufficiently to form workable deposits.

One of the most celebrated deposits of this class is that occurring at Taberg in Smaland, in Sweden, and which has long been recognized as merely a local variety of a great intrusive

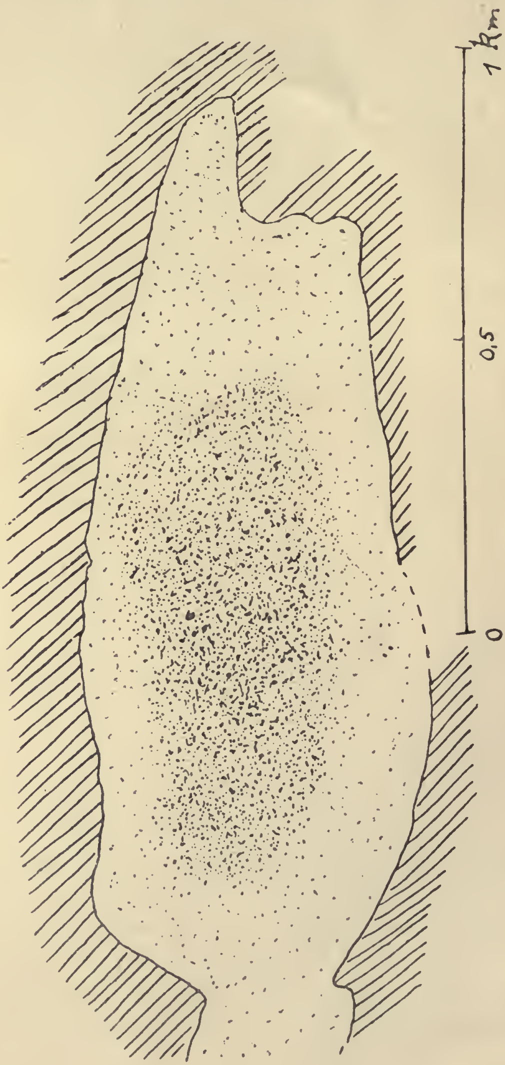

Fig. 1.

Sketch showing the mode of occurrence of the Iron Ore at Taberg in Sweden. The lighter portion is the gabbro mass with the iron ore concentrated toward the centre. (After Vogt.)

mass of rock belonging to the Gabbro family, and known in Sweden as Olivine Hyperite. This rock, which is poor in iron ore, can be observed step by step to pass over into the ore body, which has been extensively worked, and consists of a mixture of titaniferous iron ore and olivine, the ore forming about 50 per cent of the rock.

A sketch of this occurrence taken from Prof. Vogt's paper and showing the concentration of the iron ore in the central portion of the mass is given in Figure 1.

Another large deposit of iron ore at Cumberland, Rhode Island, occurs in a precisely similar manner as part of a gabbro mass and was for years extensively worked, but had to be finally abandoned on account of the large amount of titanic acid which it contained. In Brazil, Derby has also described the occurrence of large bodies of iron ore which gradually pass over into a mass of pyroxenite, of which they form part. Similar deposits of titaniferous iron ore of large extent have recently been recognized by Winchel in Minnesota, and by Kemp in the Adirondacks. In the latter case where the body of iron ore is about 20 feet in thickness, the great mass of gabbro of which it forms a part is closely related in petrographical character and probably in age, to the great areas of gabbro or anorthosite which in Canada occur in a number of places in our Laurentian country, occupying in some places hundreds, and in other places thousands of square miles.

These Canadian rocks also contain in many places large deposits of iron ore which are invariably rich in titanic acid, a fact which has made itself very patent in the failure which has followed all attempts to work them. Of these one of the best known is the great body of titanic iron ore near Baie St. Paul on the Lower St. Lawrence, where, in a great mass of gabbro or anorthosite, solid bodies of the iron ore 90 feet in thickness occur, which have been traced for a mile or more. An attempt to work these made years ago, resulted in the loss of about £80,000 sterling. Other deposits of considerable size are known in the district north of Montreal, near St. Hypolite and St. Julienne, as well as at several other points in the so-called Morin gabbro area. In these as before, the iron ore occurs as a constituent of the gabbro but is locally concentrated so as to be very abundant at these points.

Another extensive deposit, although less widely known occurs on the River Saguenay, between Chicoutimi and Lake St. John. Here on the north shore of the river there is a group of hills composed of the titanic iron ore which occurs in another great gabbro mass having an area of not less than 5,800 square miles. This iron ore occurs principally in three bands, the most easterly of which is about 75 yards wide. The accompanying view has been reproduced from a photograph of this hill taken from near the shore of the Saguenay.

It is thus evident that we have in these great deposits of titaniferous iron ore, true eruptive or igneous masses which are merely local and extremely basic varieties of the gabbro in which they occur, due to the concentration in certain parts of the mass, from some of the cases before mentioned, of the most basic constituents of the rock. It will also be seen that these peculiar deposits are not confined to one locality, but are found under similar conditions in widely separated parts of the world.

When it is once recognized that these deposits have the origin here described, a solution is afforded to what has hitherto been a puzzling fact, namely, that all the iron ores occurring in the so-called Norian series in the Laurentian, which series is composed exclusively of eruptive anorthosite or gabbro, are rich in titanic acid, while in the same district deposits of magnetite free from titanic acid will be found in the associated gneisses.

Vogt notices that in the cases which he mentions, these iron ores occur toward the central portions of the igneous masses rather than toward their margins, while in the case of the sulphide ores forming the other class of these deposits the reverse is the case. This does not however, appear to be by any means invariably the case in the similar deposits of titanic iron ore in Canada.

The igneous origin of many of these deposits of titaniferous iron ore has long been recognized, but Prof. Vogt proceeds to show that certain great deposits of sulphide ores have in all probability a similar origin.

SULPHIDE ORES CONTAINING NICKEL.

He first shows that the nickel ores of the world fall into three principal classes.

1.—Ores containing arsenic and antimony, with or without bismuth.

2.—Sulphuretted ores without arsenic, that is to say, nickeliferous pyrrhotite or pyrite, millerite, polydymite, etc.

3.—Silicated nickel ores.

Of these, No. 1 occur principally in veins, as for instance in various places in Saxony also, at Mine la Motte and Bonne Terre in Missouri.

No. 2, which is the class of which this paper treats, occur in basic intrusive rocks being apparently formed by a differentation of the magmas and local concentration of the ore. Of these the celebrated Norwegian deposits as well as those of Varallo in Italy, and of Sudbury in Canada are examples.

No. 3, occur as veins in serpentine, which results from the alteration of basic eruptive rocks, the ore being leached out during the process of decomposition and accumulated in the veins by lateral secretion as in the case of the great nickel deposits of New Caledonia, which are now the principal competitors of our Canadian nickel deposits.

Dismissing the first and third classes of deposits as having quite a different origin and confining our attention to the second class, the first striking fact to be noticed concerning them is, that they are so simple and uniform in character in all parts of the world, that a mineralogical description of one set of deposits would serve for all. The principal minerals which they contain are pyrrhotite or magnetic iron pyrites, a sulphide of iron which almost invariably holds a little nickel and cobalt, but which in these deposits usually contains 2 to 5 per cent. of these metals. Pyrite containing nickel and cobalt is also present, usually in smaller amount than the pyrrhotite, and having a better crystalline form owing to the fact that it is crystallized sooner. This mineral usually contains proportionately more cobalt and less nickel than the pyrrhotite. With these in a few deposits, minerals richer in nickel have been observed, three of these have been certainly recognized and possibly others may yet be discovered. Of these pentlandite (Fe, Ni) S has been recognized at two Norwegian localities, and in considerable quantities by Mr. D. H. Browne at the Copper Cliff and Evans mines and at the Worthington mine in the Sudbury district. (*Eng. and Min. Jour.*, Dec. 2nd, 1893). Polydymite (Ni_3 Fe S_5) occurs at the Vermillion mine in the Sudbury district, while Millerite also occurs in certain of the Sudbury deposits, as well as at the Lancaster Gap mine in Pennsylvania. Copper pyrite, usually present in considerable amount, and titanic iron ore, complete the short list of minerals found in these deposits. Other metallic minerals are present only as the rarest exceptions and in very small amount, among these the most noteworthy being sperrylite, an arsenide of platinum (Pt As_2), discovered in the ore of the Vermillion mine above mentioned, and not known to occur anywhere else in the world.

This remarkable group of ores therefore contain nickel, cobalt, copper and iron, united with sulphur and some titanic acid, while lead, zinc, silver, arsenic, antimony, bismuth and tin are absent or occur only in traces. Moreover, a remarkable fact in connection with this class of deposits is that—as Prof. Vogt shows—if the average of large quantities of ore such as the output of a mine be taken, there is a certain ratio between the richness of the pyrrhotite in nickel, and the percentage of copper contained in the deposit. Thus in the Norwegian deposits he states that in those workings which produce an ore containing from 75 to 80 parts of copper to 100 parts of nickel and cobalt, the pure pyrrhotite holds about 2.5 per cent. of nickel and cobalt, while as the copper sinks the per cent. of nickel and cobalt in the pyrrhotite rises until when but 20 to 25 parts of copper to 100 parts of nickel and cobalt are present in the ore, the pyrrhotites holds over 7 per cent. of the latter metals.

In this connection a recent statement by Mr. D. H. Brown *(loc. cit.)* is of interest, namely that in the case of the Copper Cliff Mine, which, as the name indicates, was opened up and worked for copper before the ore was known to contain any nickel, on sinking, a decrease in the amount of copper has been followed by an increase in the richness of the pyrrhotite in nickel, the very large body of ore struck on the 7th level and which is almost entirely free from copper pyrites, consisting of a pyrrhotite averaging about 10 per cent. of nickel.

The following table will show this relation in the case of a number of the Scandinavian deposits and it would be a matter of great interest if it could be ascertained that a similar relation exists in the case of our Canadian deposits. As Prof. Vogt points out, in order to obtain averages for large deposits, it is best to draw the results from the analysis of the mattes obtained by smelting the ores of the several deposits, copper and nickel being concentrated in almost exactly the same proportion. It has been found in the case of the Scandinavian deposits that although the proportion between pyrrhotite and copper pyrite may vary considerably from day to day, the average for a considerable run is pretty constant.

RATIO OF NICKEL TO COPPER IN SOME OF THE MOST IMPORTANT NORWEGIAN AND SWEDISH MINES.

Name of mine.	Content of copper corresponding to 100 parts of nickel.	Percentage of nickel and cobalt in the pure pyrrhotite.
Graagalten mine......	75–80	About 2·5
Klefra mine.........	55	" 2·75–3·0
Erteli mine..........	45–50	" 3·0
Bamle district........	35–40	" 3·5 –4·0
Flaad mine..........	37	" 4·5
Senjen mine....	35–40 (about)	" 3·5 –4·0
Dyrhaug mine........	30–35	" 3·8 –4·2
Beiern mine.........	20–25 (about)	" 7·0

Prof. Vogt also draws attention to the fact that the average proportion of nickel to copper in the Norwegian ores is about 100 to 40 or 50, and that in the Piedmontese occurrences about the same proportion holds good, while in Canada where the associated igneous rocks are of a somewhat different character, there is often relatively more copper, 100 parts nickel to 100 or even 150 of copper being found in some deposits, while in others the ordinary Norwegian proportion still holds good.

In Norway there are some 40 gabbro masses with which deposits of nickeliferous pyrrhotite are associated, these being the largest nickel deposits in Europe. The gabbro, which is undoubtedly an igneous rock is composed of plagioclase feldspar and a rhombic pyroxene, thus belonging to the variety of gabbro known as Norite. These masses of gabbro occur in the Archean schists, generally intruded between the layers or beds but often cutting across them. The Norite of all the masses shows a remarkable tendency to differentiation so that one and the same mass, in different parts of its extent, will vary greatly in relative proportion of the constituent minerals.

The pyrrhotite, pyrite and copper pyrite are regular constituents of the Norite occurring in small quantities all through the various masses, but like the other constituents being found more abundantly in certain places, so that a gradual passage can often be observed from the normal Norite through a Pyrrhotite Norite to masses of pure ore. (Fig. 2). Sometimes on the other hand the ore occurs in masses sharply separated from the Norite. (Fig. 3). These segregations of ore are in the great majority of cases situated at or near the edge of the Norite masses, and Vogt regards them as strictly comparable to the basic borders or edges so often observed about granites and other igneous rocks as before mentioned, in which the basic portions are sometimes marked by similar gradual passages and in some cases by sharp transitions. These sharp transitions are easily explicable when one considers that any part of the magma having once separated itself from the rest, being possessed of a decidedly different specific gravity, and perhaps of a different degree of fluidity, would, if the whole mass were caused to move, keep itself separated by a comparatively sharp line from the rest of the molten mass. Figs. 2, 3, 4, 5 and 6, taken from Prof. Vogt's paper, will serve to illustrate the mode of occurrence of these ores. The scale is given in each case in meters.

Furthermore Vogt states—and this is a point which has a very practical bearing with those who are interested in our deposits—that in Norway, although it is of course impossible to establish a mathematical ratio between the area of the gabbro mass and the quantity of ore in the associated ore deposits, nevertheless experience has shown that the deposits associated with the small gabbro masses are always unimportant and that all the larger ore bodies are found in connection with the larger gabbro areas, as might be expected if his explanation of the origin of the ore is a correct one.

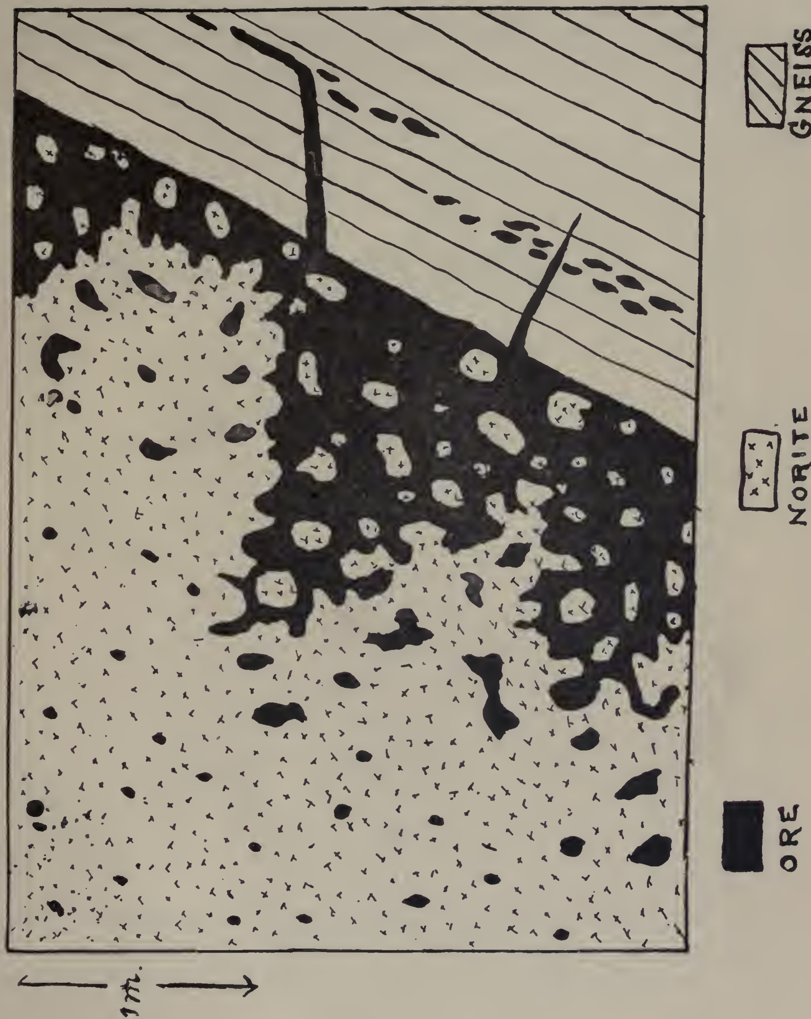

FIG. 2.

SECTION—MEINKJAR DEPOSIT, NORWAY. (After Vogt).

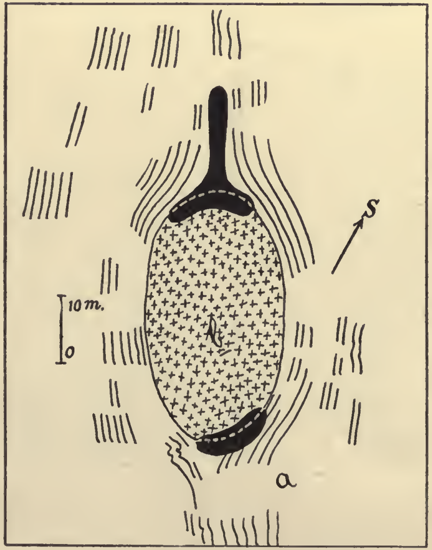

FIG. 4. THE SKAUG MINE. (After Vogt).

a. Gneiss, etc.

b. Gabbro.

The black portion shows portion of the nickel deposits.

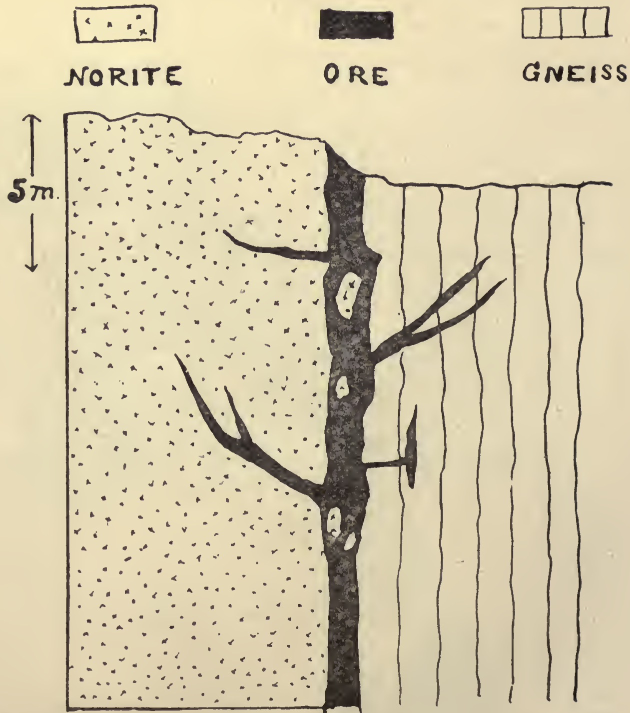

FIG. 3. SECTION—ERTELI MINES, NORWAY. (After Vogt).

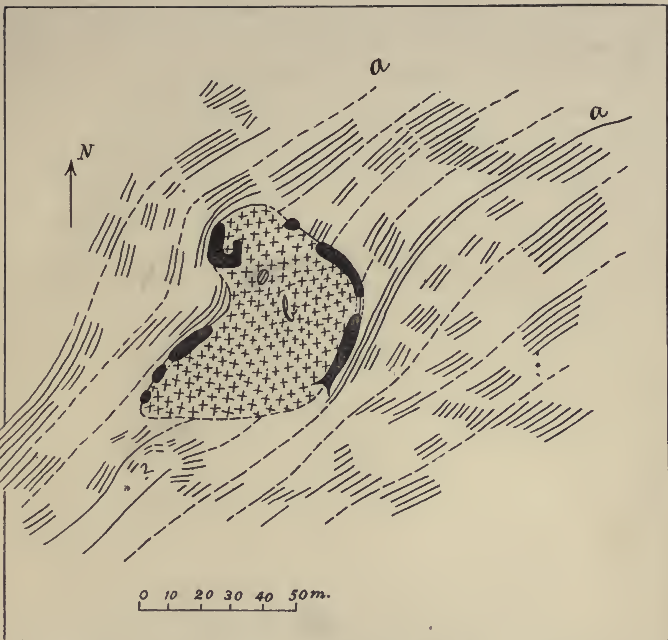

FIG. 5. PLAN OF MEINKJAR MINES, NORWAY. (After Vogt).

a. Gneiss and Hornblende Schist. *b.* Norite.

The black portions are openings in pyrrhotite with 4 p.c. of nickel.

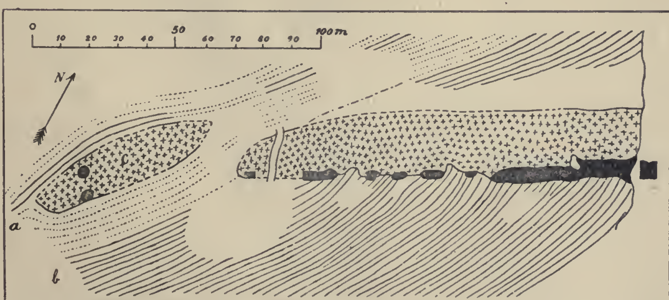

FIG. 6. PLAN OF THE NYSTEN AND BAMLE MINES. (After Vogt).

a. Red Gneiss. *b.* Black Gneiss and Mica Schist. *c.* Gabbro.

The black portions are openings in pyrrhotite holding 4 p.c. of nickel.

The nickel deposits of Varallo in Piedmont, Italy, which were worked from 1860 to 1870, are very similar in almost every respect to those just described from Norway, occurring like them in Norite near the contact with the country rocks. A similar association of nickeliferous pyrrhotite with a rock of the gabbro family also occurs at the Lancashire gap mine in Pennsylvania and at Schweiderich in Bohemia.

The great nickel bearing sulphide deposits of the Sudbury district —the largest and most important deposits or this kind known to exist— in mineralogical composition and mode of occurrences are remarkably similar to those just described in the several localities above mentioned.

The work of Mr. Barlow and Dr. Bell of the Geological Survey in the Sudbury district and the excellent geological map of the district which they have prepared present these remarkable resemblances in a striking manner. As in Norway, there are here a large number of igneous masses—some 60 in the 3,500 square miles embraced by the geological map above mentioned—composed of a rock, which, though it has been commonly called diorite, has proved in most of the cases where it has been carefully examined to be a gabbro more or less altered with the developement of secondary hornblende, that is to say substantially the same rock as in Norway and elsewhere. These diorites cut through the clastic rocks of Huronian age, to whose strike they in most cases conform in a general way, but like these latter are in places cut by granites of later age. The ore, as has been mentioned, is a nickeliferous pyrrhotite associated in some cases with polydymite, pentlandite or millerite and mixed with copper pyrite. It occurs disseminated through this gabbro or diorite, sometimes in sufficient abundance to form deposits which can be worked, the large workable deposits usually being formed by a concentration of these ores near the edges of the gabbro masses or at the contact of these with the Huronian rocks or with the granites, but never extending into these to any considerable distance from the gabbro.

Such deposits have no well defined wall but merge into the gabbro, the wall so far as the miner is concerned being the limit of profitable working due to the fading away of the ore body into the gabbro, so that in underground work an abundant sprinkling of ore through the gabbro serves as an indication of the proximity of heavy ore bodies.

Furthermore, as in Norway, there seems to be in these deposits a certain relation between the size of the deposit and the area of the gabbro mass in which it occurs, since all the extensive mining operations are carried on in deposits associated with large gabbro masses, while in connection with many of the smaller masses, smaller deposits as yet unworked and in many cases unworkable are known to exist. It is also as has been mentioned, not unlikely that a relation between the percentage of nickel in the pyrrhotite and the amount of copper present in the several deposits similar to that which has been noted in the Norwegian deposits may exist in these Canadian deposits as well. In fact these Canadian deposits resemble those of Norway, and all others of the class having similar geological relations wherever they occur throughout the world, in a most remarkable manner, the points of resemblance being so numerous and so striking as to preclude mere chance coincidence.

The facts in the case of these Sudbury deposits point to these also having originated in the elements of the pyrrhotite and copper pyrite, originally disseminated through the molten rocks, having during the process of cooling seggregated themselves together in certain parts of the magma, especially toward the sides, just as certain other constituents have a tendancy to do in igneous rocks of various kinds, especially in basic rocks such as these gabbros, and even in these very gabbro masses themselves.

This presented itself to Mr. Barlow, who has made the most careful study of these deposits, as the only tenable view concerning their origin, even before Prof. Vogt published the results of his elaborate studies in Norway. "The ores and associated rock" Mr. Barlow writes, "were in all probability simultaneously introduced in a molten condition, the patches of pyritous matter aggregating themselves together in obedience to the laws of mutual attraction." (Ann. Rep. Div. of Mineral Statistics, Geological Survey of Canada, 1889-90, p. 128.) One fact in the case of the Canadian deposits which might at first sight seem to oppose this view of their origin, is the frequent occurrence of the ore along or near the contact of the diorite with granite, which judging from contact phenomena, is more recent than the diorite and consequently would have been intruded after the ore deposits were formed and consequently cannot be considered as the wall rock of the molten diorite toward which the seggregation would take place. But it must be remembered that in such a district of hard and massive diorites and soft stratified rocks, any shattering which would precede the intrusion of the granite would probably tend to develope lines of fracture along the contact of these two rocks and thus afford a ready passage for the granite magma in these directions. The contact of the diorite and the granite would thus mark approximately, in many cases at least, the contact of the diorite with the Huronian rocks through which it was intruded.

Concerning these sulphide ores containing nickel therefore, Prof. Vogt sums up as follows :—

1. These deposits, which are numerous and occur in widely sep arated countries, are always found in connection with some basic igneous rock allied to gabbro and since this is invariably the case we must conclude that the deposits stand in some genetic relation to this igneous rock.

2. Since we can frequently trace a gradual passage from the workable deposits into the igneous rock by a progressive increase in the amount of ore in the rock, we must conclude that the ore masses were not in any way introduced into the rock subsequent to cooling, but were separated out of the molten magma during the solidification of the rock. This conclusion is also borne out by the remarkable simplicity and uniformity of chemical and mineralogical composition of these deposits throughout the world, by the relation between the size of the ore deposit and the area of the gabbro mass in which it occurs, as well as by the absence in these deposits of lead, zinc, arsenic, antimony, bismuth, etc., and of those minerals which are especially characteristic of the so called pneumatolitic action.

3. Owing to the fact that, as Fournet has shown, the metals copper, nickel, cobalt, iron, tin, zinc, lead, silver, antimony and arsenic have in

general a decreasing affinity for sulphur in the order named, the small percentage of copper, nickel, and cobalt present in the original magma unites with sulphur and thus becomes concentrated in any sulphide of iron which separates, while any tin, zinc, lead, silver, antimony or arsenic present in the magma is not so concentrated.

4. From what we know of the amount of copper, nickel and cobalt contained in these rocks themselves we are justified in concluding that these metals are always present in the original magma in amount quite sufficient to supply material for all the deposits in question, if only the concentration can be effected, and in this connection it would also follow that there must be a certain ratio between the size of the eruptive mass and the extent of the ore deposit.

5. The copper of the deposit always appears as copper pyrite. The nickel becomes concentrated in pyrrhotite or appears in the form of millerite, pentlandite, or polydymite, all minerals comparatively poor in sulphur, while the cobalt on the other hand is concentrated in the pyrite which is much richer in sulphur.

6. In the Canadian nickel bearing sulphide deposits, platinum in the form of sperrylite is sometimes found, which would seem to be analogous to the occurrence of native platinum and osmiridium metals in the more or less serpentized basic olivine bearing rocks in the Urals and elsewhere to be mentioned further on.

7. Titaniferous magnetite or Ilmenite almost always occurs in small amount in the nickel bearing sulphide deposits, indicating a genetic relation and to a certain extent a transition between these sulphide secretions and the deposits of titaniferous iron ore mentioned in the beginning of this paper as having a similar origin.

8. The nickel bearing sulphide deposits occur in almost all cases about the edges of their several igneous masses, a fact which, as has been mentioned, is susceptible of explanation in that the sulphides, following Soret's principle, become concentrated toward the cooling surfaces of the mass.

Another remarkable fact tending to the same conclusion and showing the importance of geological studies in connection with ore deposits is that although in the several widely separated countries the pyrrhotite deposits associated in the manner above described with the gabbros are so rich in nickel, the celebrated Fahlbands of Norway which are bedded or apparently bedded deposits consisting of heavy impregnations of pyrrhotite, pyrite, copper pyrites, etc., but occuring in gneisses or schists of various kinds contain hardly any nickel, hundreds of analyses showing the nickel and cobalt contents to range from .25 to .50 of one per cent., and what is still more remarkable the same is true of the similar Fahlbands so often associated with our Laurientian limestones in Canada, so far as these have been examined. In these the pyrrhotite and pyrite is present in large amount and is often associated with copper pyrite but only a very small quantity of nickel and cobalt, usually not amounting to more than a trace, is present. (Adams, Frank D., Preliminary Report on the Geology of a portion of Central Ontario, Geological Survey of Canada, 1894, Vol. VI, Part J, 1891-92-93.

METALLIC SEGGREGATIONS FROM IGNEOUS ROCKS.

Some few cases of the seggregation of metals in a free state are known to occur in igneous rocks. These deserve much more careful and extensive study than has yet been bestowed on them in view of the light which they promise to throw on the origin of ore deposits such as these which have just been considered.

These are of two classes :

1st. Iron-nickel alloys.

2nd. Platinum and osmiridium metals.

The celebrated occurrences of native iron holding about 2 per cent. of nickel, discovered by Nordenskjold in basalt at Uifak and Assuk in Greenland, are now believed to have resulted in the reducing action of the carbonaceous material in the rock through which the basalt was erupted, but these occurrences nevertheless afford an example of the concentration of nickel, which must originally have been disseminated in small amount throughout the molten basalt, in the iron which has been reduced in the way above described.

A more recently noted and even more remarkable occurrence is the Awaruite of New Zealand which is composed of 67·93 per cent. of nickel, ·70 per cent. of cobalt and 31·02 per cent. of iron and is found in a very basic igneous rock belonging to the Peridotites. (G. H. F. Ulrich, Quart. Jour. Geol. Soc., Nov., 1890.)

In the various parts of the world where platinum occurs in alluvial sands it has been found from time to time intimately associated with serpentine and chromic iron ore, thus indicating as its probable source some Peridotite or olivine rock, and Murchison long ago mentioned its occurrence in the serpentine rocks of the Urals. ("Russia in Europe," p. 484.) Some ten years ago, however, this probability became a certainty for on the western slope of the Ural mountains platinum was found in grains disseminated through an olivine gabbro, which there forms the bed rock on which the platinum bearing gravels rest. Recently, at a locality on the eastern slope of the same mountain chain platinum associated with chromic iron ore has been found so abundantly disseminated through an olivine rock that this latter can be actually worked with profit, as much as 93 to 110 grains of platinum to the ton of rock being found. (R. Helmhacker, Zeit. für prak. Geol. Feb., 1893, and Can. Record of Science, April, 1893. *See also* Eng. and Mining Journal, Dec. 22, 1893.)

It is thus evident that the platinum of commerce also occurs originally as a seggregation from basic igneous rocks.

The uniform character and constant association of chromic iron ore, wherever deposits of this mineral are found, with serpentine, which rock is a decomposition product of basic eruptive rocks rich in olivine, points very strongly to the probability of this mineral also being a product of the differentiation of basic igneous magmas during cooling, and before their solidification and alteration to serpentine. Our knowledge of these deposits, however, is not as yet sufficiently extensive, nor sufficiently exact to enable any definite conclusions to be reached on this most interesting question.

Although therefore these mineral deposits which present evidence of having originated in the differentiation of igneous masses during cooling, form a comparatively small class, they are full of interest especially for us in Canada where so many of these deposits occur, and this brief presentation of some of the principal facts concerning them has been given in the hope that the Mining Engineers of our Dominion, many of whom are engaged in working deposits of this class, having these facts in view may be induced to make a careful study of these deposits with a view of extending or perhaps correcting our knowledge concerning them.