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SOME PROBLEMS IN IRON ORE GEOLOGY IN SWEDEN AND IN AMERICA.

PER GEIJER.

During a long visit to the United States and Canada, in 1913, I had the opportunity to become acquainted with the geology of certain groups of iron ore deposits regarded by several observers as related to one or another of the principal iron-ore types of Sweden. The excursions that I made may have been brief in comparison to the complexity of the problems I intended to study, but the opportunities to discuss these problems—very often in the field—with the geologists engaged in solving them will go far to counterbalance this deficiency. The result is, in brief, that I have been able to contribute some new arguments to the discussion concerning the origin of the quartz-banded ores, just now a salient question in the study of ore deposits in Sweden and also in Norway, and that I have found that two metallogenetic provinces, one in the United States and one in Sweden, which have sometimes been compared to each other, show very remarkable analogies. These views have been presented to Swedish geologists in papers read before the Geological Society in Stockholm, and published in Swedish in its proceedings (*Geologiska Föreningens i Stockholm Förhandlingar*).¹ It is believed, however, that also the American geologists working with iron ores, will be interested to see what use can be made of their results for the solving of problems in another country.

¹ Vol. 35 (1913), pp. 439-483, and Vol. 36 (1914), pp. 157-173.

For my knowledge of American iron ores I am particularly indebted to Professor C. K. Leith, of the University of Wisconsin, Dr. D. H. Newland, of the New York Geological Survey, and Mr. G. W. Crane, late of the Missouri Bureau of Geology and Mines. The offer to take part in an "advanced students' excursion," under Professor Leith's guidance, gave the best possible opportunity to study the iron ore problem in the Lake Superior region; a visit in the company of Dr. Newland to some of the Adirondack mines gave me a good idea of the geology of that section, while the information previously given by Mr. Crane was of the greatest service to me during a brief visit to southeastern Missouri. The total number of the geologists whom I have to thank for kind reception and valuable help during my visit to the United States and Canada, is so great that I must abstain from enumerating them.

Apart from scattered deposits of titaniferous ores, bog and lake ores and some insignificant types, the iron ores of Sweden are divided into two geographically and geologically different groups. One district, generally known as central Sweden, comprises an immense number of deposits, mostly of small or moderate size, enclosed in highly metamorphosed Archean rocks.² The other district, in northern Lapland, north of the Arctic circle, contains fewer deposits, but among them some very large ones; the age is pre-Cambrian, but the metamorphism, though often strong, has not so largely veiled the primary characters of the ore-bearing rocks as is the case in central Sweden.

The ores of central Sweden are mostly low in sulphur and phosphorus, a fact from which the Swedish iron derives its old renown. The largest deposits, however, and all the more important ones in Lapland, contain a considerable quantity of apatite.

The two districts must be treated separately, as there are very important geological differences between them. It must also be pointed out that the present writer's position to the problems is

² While the American subdivision of the pre-Cambrian cannot be introduced for Sweden, it is certain that these rocks are at least as old as the Keewatin.

not the same in both cases: as regards central Sweden, the survey I am going to give will be a review of the results obtained by a great number of geologists, my own actual contributions having been very insignificant, while the discussion of the Lapland ores will be based mainly on personal experience.

A survey of the geology of the Scandinavian iron ores, intended for American readers, was given seven years ago by Professor Hj. Sjögren.³ In view of the rapid advance in our knowledge of some ore groups during the last few years, however, and of the fact that the writer holds another view than Professor Sjögren on several important questions, it is necessary to give at least a brief review of the views of the Swedish geologists, before starting any comparisons between American and Swedish problems.

Broadly speaking, the ore-bearing district of central Sweden lies between lat. 59° and 61° . Large parts of this belt, however, are made up of gneisses which are generally barren. This is, for instance, the case in the western half of the province Värmland, which belongs to the great gneiss territory of southwestern Sweden. Generally, however, the Archean in the country between the two given latitudes is composed of two groups, the supracrustal⁴ ore-bearing formation, and the granites. The latter are younger than the supracrustal formation, invading it as great masses that are generally classed as batholiths, although there is no possibility of definitely proving their batholithic nature. These granite areas are generally rounded, the rock being massive in the center, but more or less gneissic towards the margin of an area. Between them, the supracrustal formation forms narrow bands. On the whole, the relations between the two groups are essentially the same as is shown by the Laurentian and the Grenville in eastern Ontario, or the Laurentian and the Keewatin in the Lake of the Woods country.

It is now generally believed that the iron ores are older than the granites.

³ "The Geological Relations of the Scandinavian Iron Ores," *Trans. Am. I. M. E.*, Toronto meeting, July, 1907, Vol. 38, pp. 877-946.

⁴ The term *supracrustal* is used for rocks formed at the surface, as sediments, lava flows, and tuffs, while deep-seated rocks are called *infracrustal*.

The members of the supracrustal formation are hälleflintas, leptites, some gneisses, limestone and dolomite, mica schists (not common), and several types of iron ores. As the leptites are by far the most common rocks of the formation, it is generally called the leptite formation. The dip of the formation is generally very steep. As yet, no unconformities have been proved within it.

FIG. 43. Sketch map of the Archean in a part of the province Uppland. Scale 1:800,000. (After A. G. Högbom.)

The term hälleflinta has in Sweden long been used for quartz-feldspar rocks of a very fine grain (such as appear macroscopically dense) and conchoidal fracture. Many hälleflintas are acid volcanic tuffs (certainly in many cases silicified), consisting of fine ash or larger, once glassy fragments. Other forms consist of volcanic mud more or less mixed with normal sediments, and may grade into limestone. Some of these phases show a very regular stratification, best exemplified by the famous "banded hälleflinta" of Dannemora. In many cases, however, there is ample

evidence that the hälleflinta is a metamorphosed acid lava rock, with relic phenocrysts of quartz and feldspar.

In those pre-Cambrian districts in America that I have visited, real hälleflintas appear to be entirely absent. A dark green rock that occurs interstratified with the ironbearing formation at the old Mastodon Mine, near Crystal Falls, Mich., is the only hälleflinta-like rock I have seen. In part of the Piedmont region, however, hälleflintas must be important members of the volcanic series. Specimens collected by Messrs. Laney and Pogue, from the Gold Hill and Cid districts of North Carolina, that I saw in the Yale collections, indicate that the rocks of these parts show important analogies to those of central Sweden, even if they generally are less metamorphosed than the latter. The silicified tuff described by Pogue as "gunflint rock," is a most typical hälleflinta.

The leptites may be called coarse-grained hälleflintas or fine-grained gneisses, relations that suggested the once employed name hälleflint-gneiss.⁵ They are, in short, crystalline schists consisting of feldspar, quartz and a moderate quantity of dark minerals, and differing from gneisses only by their finer grain. In many districts, the leptites can be shown to have originated from hälleflintas through metamorphism, and their original nature must, on the whole, be the same as that of the latter—lavas, tuffs, and tuffites (mixture of tuff material and normal sediments). Remnants of a porphyritic structure are common. A regular banding is often seen. By a higher degree of metamorphism, the leptites may change into real gneisses.

While the greater part of the leptites are lava rocks or tuffs, there are also undoubtedly among them many intrusive bodies, representing the more deep-seated phase of the volcanic activity. Some gneisses that are intimately connected with the leptites probably have the same hypabyssal origin.

⁵ Leptite is an old term that was taken up again a few years ago. Previously, hälleflint-gneiss and *granulite* were used for these rocks. The former is rather unhandy, however, while granulite is used by French and German petrographers for various other kinds of rocks, which facts have caused the majority of Swedish geologists to return to the old term leptite.

The majority of the hälleflintas and leptites are acid rocks with a high percentage of quartz. The considerable part played by extremely sodic rocks is a remarkable feature. Very pronouncedly potassic types also occur, however, but are not so dominant. Amphibolitic rocks are common in certain districts, but their quantity is generally small in comparison to the acid rocks. Types of an andesitic or syenitic composition are rare.

Mica schists locally appear as members of the ore-bearing series, but are seldom conspicuous and do not, as a rule, contain any iron ore deposits. The most common rock of a distinctly sedimentary type is limestone (incl. dolomite). In some districts, there is a very regular alternation of beds of limestone and hälleflinta or leptite. In regions of stronger metamorphism, the limestone beds are often stretched and squeezed, the final result being a series of pitching lenses arranged *en échelon*. In petrographic characters, the limestone is similar to any crystalline limestone, such for instance as the Grenville limestones of eastern North America.

This very brief characteristic of the leptite formation gives the views embraced by the majority of the Swedish geologists. In recent years, however, attempts have been made to give another and radically different interpretation of these rocks. The author of this new theory is H. Johansson, who (for the first time in a paper published in 1906) explains the whole leptite formation, including limestones and the various types of iron ores, as deep-seated products of magmatic differentiation under mechanical influences. Johansson attacks the problem from several sides. Highly interesting are his contributions to our knowledge of the chemical characters of the ore-bearing rocks. Johansson finds the extreme differentiation in radically different chemical types, with a great scarcity of intermediate forms, to correspond better to the aspect of differentiation in deep-seated magma complexes than to that in series of surface extrusions, such as are known from younger geological systems. Another important argument is the close connection between the various types of iron ores, some of which are even by other authors regarded as magmatic, and the apparent relation between ore types and chemical character of the ore-bearing rocks. Recently, Prof. Sjögren has declared that he

shares Johansson's opinion of the leptites as a complex of deep-seated rocks.

When one thinks of the common occurrence of limestone in the leptite formation, sometimes in a regular, hundreds-of-times-repeated alternation with quartz-feldspar-rocks of an extremely fine grain never met with in a rock of a deep-seated origin, and many other features of this complex, it is difficult to understand how the same formation could be interpreted as a complex of abyssal intrusives. Though it is impossible to discuss the problem here in any detail, an important point may be emphasized. Those who regard the leptite formation as a supracrustal one, have started from districts where the metamorphism has been comparatively slight and it is possible to ascertain the original nature of the rocks. The existence of a series of intermediate stages allows the conclusion that other districts are built up of strongly metamorphosed equivalents of these rocks. Johansson and Sjögren, on the other hand, base their views on these latter districts.

It may well be that several of the facts pointed out by Johansson and Sjögren will cause some modifications of our views on the leptite formation, but in the judgment of the present writer, the conception of this formation as dominantly a supracrustal one is firmly founded on a wealth of evidence.

The iron ores of central Sweden occur almost exclusively in the leptite formation. There are several types, which in their typical development are very different from each other, but partly are connected through transitional forms. The main types are the following ones.

"Apatite Ores."—This ore type has a characteristic and sometimes considerable apatite content. It is represented by a number of deposits within a rather limited area. Grängesberg, the largest iron mine of central Sweden, belongs here. Most deposits of this type are high-grade magnetites or hematites⁶ with few gangue minerals except apatite. The ore bodies are more or less lenticular, and show clear contacts against their wall rocks, gener-

⁶ By "hematite" is here always understood specular iron oxide.

ally leptytes with some amphibolite. Some smaller deposits show an irregular, "schlieric" mixture of ore with a very high apatite content (up to 40 per cent.) and rock. On the whole, this group has many characteristics in common with the apatitic ores of northern Sweden (Lapland). It seems rather probable, that the apatitic ores of central Sweden are of an eruptive origin, but their present metamorphic state makes it almost impossible to trace the details of their geological history. It is worthy of note, however, that Johansson's views on the leptyte formation are largely based on the detailed study of the apatitic ore district.

"*Limestone Ores.*"—These ores are high-grade magnetite bodies, occurring in the limestones of the leptyte formation. Their characters in most cases strongly suggest a metasomatic origin. The magnetite is sometimes accompanied by a silicate gangue, whereby a transition is effected to the following type.

"*Skarn Ores.*"—The characteristic feature of these deposits is the association of magnetite with a gangue of dark silicates, pyroxenes, amphiboles, garnet, epidote, which is called "skarn." In many cases, the skarn ores occur in limestone, or in relations that make it probable that the ore and skarn mass has completely replaced a limestone. They are therefore by most authors regarded as metasomatic bodies, like the limestone ores, but the nature of the skarn further indicates that the replacement occurred under conditions of igneous metamorphism.

"*Quartz-Alumina Hematite Ores.*"—This ore type, which is not a very common one, comprises hematite ores with a moderate percentage of quartz and other rock-forming minerals, as feldspars or biotite. They are, on the whole, rather regularly bed-shaped, and are very intimately connected with their leptyte wall rock, containing thin beds of it and grading into it. Some of the deposits of this type are closely connected with the apatitic ores of Grängesberg, and show a characteristic, though low, apatite content.

"*Quartz-Banded Ores.*"—These ores are mostly hematites, with an iron percentage of about 50, much more rarely magnetites. The type gets its name from the very regular lamination

by alternating bands of iron ore and quartz. The quartz is mostly gray, but sometimes a red jasper. In at least one ore body (Utö) one finds red jasper in those parts where the iron occurs as hematite, and gray quartz where it is in the form of magnetite. A little amphibole is often present. Garnet and epidote are not uncommon, and can often be plainly seen to be of secondary origin.

The origin of the quartz-banded ores is just now one of the most debated points in the geology of the ore-bearing formation of central Sweden. It is further of particular interest to American geologists, as these ores have often been compared to the "banded ironstones" of the Lake Superior region, and the results of American workers have been more or less directly applied to our problem.

All those who regard the leptite formation as mainly a series of supracrustal rocks, have been wont to look upon the regular banding of the quartzeous ores as a relic of sedimentary stratification. For Johansson and Sjögren, who believe in a deep-seated origin of the whole complex, such a view is, of course, excluded. Johansson has not defined his views beyond the general application of magmatic differentiation, as already outlined. Sjögren, in 1907-1908, proposed a general theory for all the various iron ores of central Sweden, regarding them as formed through aqueo-igneous solutions ranging in temperature from magmatic downwards. The apatite ores are believed to represent the highest temperature. Concerning the skarn and limestone ores, the theory is not so formulated that it must materially differ from the views given above as representative of the present general opinion on the case. The quartz-banded ores are also regarded as aqueo-igneous injections. Professor Vogt's views on similar deposits in northern Norway have also had influence on the discussion of the Swedish ores. The deposits in question are quartz-banded magnetites of a rather low grade, and are regarded by Vogt as magmatic segregations in granitic rocks.

The main arguments for a sedimentary origin are the following:

The regular layer shape of the ore bodies, where not too strongly deformed, and the regularity of the banding.

The identity in composition and structure with banded ironstones of known sedimentary origin.

The locally appearing regular alternation of ore and wall rock.

The view is old, dating from a time when all crystalline schists were regarded as some kind of peculiar sediments. For most geologists, however, the change in opinion regarding several fundamental questions in Archean geology has not caused any change of view on this point. To the arguments derived from the characters of the ore-bearing formation and the ores themselves is added the use of analogous, but less metamorphic ironstones as keys to the problem. In this respect, no other district has been in importance comparable to the Lake Superior region. The remarkable analogies between the banded ironstones of this district and the Swedish ores in question have been emphasized by many geologists, the most detailed discussion being that given by Sjögren more than twenty years ago.

Notwithstanding the radical change of opinion that is expressed in Sjögren's more recent views on the same subject, most of our geologists still feel convinced of the truth of his older views.

It is true that we have no siderite or greenalite rock, nor any "ferruginous chert," in Sweden. When we remember that even in the least metamorphosed districts (like Utö) the dip is now vertical, and the ore-bearing series shows signs of a very great mechanical deformation, this absence of rock types that are unstable under anamorphic conditions is very natural. The two main types arising through deep metamorphism of these forms, however, the quartz-banded crystalline hematites (jaspilites) and the corresponding, often amphibole-bearing magnetite rocks, differ from the Swedish ores only by their lower *average* iron content (about 25 per cent. compared to 45 or 50).

This analogy, at least with regard to the hematitic phases, has formed the main basis for comparisons between the two metallogenetic provinces, but in spite of all descriptions I was surprised to find how complete it is.

Forms with gray quartz and finely granular hematite are represented for instance by the Striberg and Norberg mining districts in Sweden, and by phases of the Vermilion jaspilite. Hematite

with bands of red jasper is the main type of the ore at Utö and the typical development of the Marquette jaspilite. Ore with micaceous hematite is not uncommon in Sweden and closely resembles a certain type from the Marquette Range, and a phase of the Traders bed at Iron Mountain, Menominee. As to the iron content, it must be remembered that there are many ore bodies in Sweden that do not range higher than the richer parts of the Lake Superior iron-bearing formations.

The analogy between the magnetic phases has not received the same attention. In Sweden, ores of this type are not common, but northern Norway contains large deposits which, as already stated, have to be considered when discussing their Swedish counterparts.

Magnetite alternating with gray quartz is a subordinate phase of the Utö ore body, the bulk of which is a hematite with bands of red jasper. These relations suggest as a probable explanation that the magnetic ore represents the parts that were not oxidized before anamorphism, while this had been the case with most of the ore.

Concentrations of rich, not banded ore are sometimes, but only rarely, met with in the Swedish mines operating on quartz-banded hematites. It seems quite probable that the origin of these high-grade bodies is essentially the same as that of the workable ores of the Lake Superior country. This was also suggested by Sjögren in his first articles.

While thus the petrographic analogies between the Swedish and the American "banded ironstones" leave little more to be desired, the geological association is not the same in both cases. Sjögren and Johansson find this difference so important as to completely outweigh the common features of the two districts. These authors claim that even if the leptite formation were of supracrustal origin (which, in their opinion, it is not), its dominantly acidic-volcanic nature so strongly contrasts with the sedimentary Huronian series with their slates, quartzite and dolomite, that every comparison is absurd. If we leave the Huronian out of discussion, however, and compare the leptite formation to the Keewatin only, the difference is not so marked. Both series are mainly

volcanic, with little normal sediments save the iron-bearing formations. There is still a great difference, however, inasmuch as the Keewatin volcanics are femic rocks (metabasalts), but the leptites are salic rhyolites. Yet it is noteworthy that rhyolite rocks occur as members of the Keewatin volcanic series and sometimes show the same close relations to the iron-bearing sediments as do the metabasalts.

According to Johansson and Sjögren the champions of the sedimentary theory overrate the value of the banded structure as a proof of sedimentary origin. It is true that the old idea of the banding as due to annual climatic variations can hardly be upheld any more, but the train of thought nowadays is different, emphasizing the absolute similarity to structures of proved sedimentary origin and the absence of any really analogous phenomena in bodies of another origin.

The discovery of quartz-banded ores similar to those of central Sweden, and of magmatic origin was announced some years ago, and was brought forth as an extremely weighty argument against the sedimentary theory. These ores occur in northern Norway. Scattered deposits appear in the mountainous Lofoten Islands, but the largest ones are much further east, at Sydvaranger close by the Russian frontier line. Professor Vogt has described the Lofoten deposits as magmatic segregations in a schistose granite and believes them to have been formed in essentially the same way as the segregations of titaniferous iron ore in gabbro and anorthosite. Later, Vogt has applied the same views to the Sydvaranger district, regarded by him as one of the clearest cases of iron ores formed through magmatic segregation in acidic rocks. Professor Sjögren, who visited the Lofoten district only, arrived at a somewhat different conclusion. He found the immediate wall rock to be similar to the Swedish leptites, but to appear to grade into a real granite. Further, he describes intrusive contacts between ore (younger) and the wall rock. Sjögren concludes that the ore magma has been injected, in a state of aqueo-igneous fusion, the leptite rock being a granite altered through contact metamorphism. If the facts in the field did not allow any other interpretation, one would not have any right to

deny the existence of magmatic intrusive quartz-banded iron ores. Sjögren himself states, however, that his observations were made during hasty visits to the various mines, and no drawings or maps illustrating the contact relations are given. We may therefore be allowed to await more detailed data before taking any definite position. A skeptical attitude is also fully justified by the properties of the other Norwegian district of the same kind, Sydvaranger.

During a visit to this district, I was totally unable to find any proof of an eruptive origin of the deposits. Neither of the two hypotheses—Vogt's and Sjögren's—proved satisfactory. The ore-bearing rocks are leptitic, though partly more coarse-grained than the typical Swedish leptites. Among them are forms with a composition hardly ever found in igneous rocks, as types combining a high quartz content with a calcic plagioclase. There are no intrusion phenomena visible anywhere at the contacts of the ore bodies. The ore shows an exceedingly regular banding of magnetite and quartz. These facts caused me to express the opinion that the ores are highly metamorphosed chemical sediments.

While aware of a great resemblance between the Sydvaranger ore and some types of banded ironstones in other districts, including the Lake Superior region, I had no idea that the analogies to the latter are so complete as I have found afterwards.

The Sydvaranger ore has an average iron content of about 36 or 37 per cent. The mineral constituents are magnetite, quartz, and a light green amphibole. The amphibole is more common in the magnetite than in the quartz bands. Now and then there appear amphibole bands with only a little magnetite, and locally such bands take the place of those of magnetite throughout a small ore body. Garnet and diopside have been noted in one small ore body only. Within a limited area, a dark green hornblende takes the place of the quartz bands. The occurrence of an inclusion of quartz-banded ore makes it practically certain that this hornblende has been formed through the replacement of the quartz bands.

Among the iron-bearing formations in the Lake Superior region proper, the one most similar to Sydvaranger is the Negaunee of Marquette, when anamorphosed, as near Michigamme. In mineralogical composition—including iron content—and in regular-

FIG. 44. Quartz-banded magnetite, Sydvaranger, Norway. (Length of hammer shaft 60 cm.)

ity of banding, the analogy is complete. The only slight difference lies in the degree of metamorphism, the quartz bands of the Negaunee formation being frequently fractured during the folding, while the Sydvaranger ore shows the soft folding of the "rock flowage" depths. It is worth noticing, that the Negaunee formation locally shows the banding of amphibole and quartz also sometimes found at Sydvaranger.

The Keewatin iron-bearing formation of Moose Mountain, Ontario,⁷ shows even greater resemblance to that of Sydvaranger,

⁷ The writer visited this district as a member of the C 6 excursion of the 12th international geological congress, under the guidance of Dr. W. G. Miller.

the degree of metamorphism being also the same. The banding of magnetite and quartz, with more or less of a light green amphibole (chiefly in the magnetite bands), the iron content, the extremely strong folding, generally without fracturing, make the ore of Moose Mountain *identical* in the present conditions to that of Sydvaranger. Also at Moose Mountain there appears a phase with bands of dark green hornblende instead of quartz, and, by a curious coincidence, containing an inclusion of quartz-banded ore, which differs from the one described from Sydvaranger only through the fact that the replacement of quartz through hornblende is more evident.

The epidote, which accompanies part of the high-grade ore at Moose Mountain (Mine No. 1), at least partly replaces quartz (or secondary hornblende?). Unfortunately, the few hours at my disposal did not permit more than a very superficial study of this ore variety, which may have no counterpart in Sydvaranger, where epidote appears but, so far as I know, never in such quantities.

In view of all these analogies, I think there is very good reason for believing the geological history of the Sydvaranger ores to have been in all important points the same as that of the Moose Mountain iron-bearing formation, which is clearly of the Lake Superior type. As the Lofoten deposits probably are analogous to those of Sydvaranger, and are so described by Vogt, they cannot be accepted as proved cases of magmatic quartz-banded ores. As yet, therefore, no deposit of quartz-banded iron ore of undeniably magmatic origin has been found.

In the ore-bearing district of northern Lapland, as in Central Sweden, the pre-Cambrian consists of supracrustal rocks and large masses of deepseated intrusives. It is possible that the large intrusions partly are older than all the supracrustal rocks and partly intermediate in age between two subdivisions of them. The nature of the country, the deep and continuous drift mantle, and other causes have hampered stratigraphical and structural work, some of the main features in the geology of this region thus being still not definitely known. As in central Sweden, ore

deposits occur in the supracrustal rocks only. Volcanic rocks predominate in the form of lava flows, tuffs, and hypabyssal intrusions. The normal sediments, phyllite and quartzitic sandstone, are the youngest among the supracrustal rocks, and may possibly rest unconformably on the older, dominantly volcanic complex.

The bedded rocks generally have a very steep attitude, nearly vertical dips being common. From reasons already given, the structure has hitherto been only very incompletely deciphered. The degree of metamorphism is widely varying. At Kiruna, for instance, the volcanic rocks partly exhibit well preserved micro-textures. In other districts, the phenocrysts of the porphyries remain intact, but the groundmass is recrystallized (the rock thus resembles certain leptites) while at Gellivare, about 60 miles south of Kiruna, the metamorphism has proceeded so far as to render the volcanic rocks gneissoid.

The volcanic series has a chemical character rather different from that of the leptite formation of central Sweden. Rocks of a syenitic or quartz-syenitic composition are probably most abundant, but metabasalts appear in great quantities in certain districts. The metabasalts sometimes show ellipsoidal parting. Their plagioclase is a pure albite, a most remarkable feature that is ascribed to secondary processes. There are no ores in the metabasalts, all deposits occurring in porphyries of a syenitic or quartz-syenitic character. In by far the most cases, these rocks show a distinctly effusive texture, although lack of exposures may make it impossible to decide whether they really are surface flows, or intrusions at shallow depths. Sometimes, even when there is a practical certainty that the magma has actually been extruded at the surface, there is a gradual downward transition from phases with a volcanic texture to a fine-grained syenite. The best known case of this kind is that of the foot-wall rock of the Kiirunavaara ore body. It seems possible, that some eruptions have been subaquatic, which may account for this and some other puzzling geological and textural relations.

The ore-bearing rocks are classed as syenite-porphyr^{ies}⁸ and quartz-porphyr^{ies}.⁸

The syenite-porphyr^{ies} have a silica percentage of about 55 to 60. They are mostly sodic rocks. The most common dark silicate is a diopsidic augite, very often changed to amphibole (*i. e.*, uralitized). Magnetite is an important constituent and mostly surpasses the dark silicates in quantity. In some phases it forms 30 to 50 per cent. of the rock, the rest being a nearly pure albite feldspar. This type has been called magnetite-syenite-porphyr^y.

A very characteristic feature of the syenite-porphyr^{ies}, notably at Kiruna, is the common occurrence of rounded cavities more or less completely filled with hornblende, magnetite, apatite, titanite or feldspar. These aggregates, which apparently are not directly comparable to quartz or calcite amygd^{ules}, have been called nodules, in order to get a handy and neutral term. Professor Bäckström, the first geologist who undertook a systematic study of these nodules, found their minerals to be probably of a pneumatolytic origin. His explanation was, that the already solidified porphyr^{ies} were permeated by gaseous solutions coming from the same source as the rocks, and depositing their content of certain constituents as fillings in vesicles. The writer, while largely agreeing with Bäckström in considering the nodules as "pneumatolytic" bodies, has found what seems to be conclusive evidence that the material of the nodules was gathered through a sort of lateral secretion *during* the crystallization of the rock, the volatile constituents, which through their mechanical action caused the development of the blowholes, having contained the material for the nodule minerals. There is a close analogy to the miarolitic cavities of deep-seated igneous rocks, and to some types of litophys. The nature of the minerals, and the absence of any halogens (except the fluorine of the apatite) indicate that the compounds entering into the nodule minerals were in a state of solution in water. It is probable, that these solutions in most cases were above the critical temperature. Sometimes, however,

⁸ The names *keratophyre* and *quartz-keratophyre* have also been used. The writer's reason for dropping them is the present uncertainty among petrographers regarding the exact meaning of these terms.

the connection between the nodule minerals and the normal groundmass of the rock is so intimate that this explanation seems doubtful. These "embryonal nodules" may represent spots where the rock magma, although in a liquid state, was rich in the volatile, nodule-forming constituents, that is, in a condition of "aqueo-igneous fusion."⁹ The details in the evolution of the different kinds of nodules will not be understood until we have, by experimental work, obtained a better knowledge of the influence exercised by various gases in the magma under the conditions in question. Until then, we have to be content with some idea of the main features of the phenomenon.

The other rock type, the *quartz-porphyry*, is also sodic, but not so markedly as the syenite-porphyrries. There may be some discussion as to the use of the name quartz-porphyry for these rocks, which generally do not reach higher in silica than to about 70 per cent. They are rather well distinguished from the syenite-porphyrries, however, and the groundmass is that of a real quartz-porphyry, although the low silica content of the rock has not allowed any quartz phenocrysts to form. Dark minerals appear in small quantities only, magnetite generally predominating.

The Lapland *ores* are magnetites containing more or less apatite. Specular hematite of undoubtedly primary nature appears only in a very subordinate amount in the larger ore bodies; besides, it is the ore mineral of the inconsiderable Haukivaara deposits, which differ in many important respects from the other deposits.

The apatite content varies within wide limits, even within one single ore body. The phases richer in this mineral show many interesting textural features. Diopsidic augite is found as an important constituent in local phases of the Kiirunavaara ore body, and a light green hornblende is not uncommon. The latter is partly an alteration product of the augite (uralite) but probably in part primary. Titanite is rare and appears mostly in druses, or in the immediate wall rock of an ore body. The contacts of the ores are always sharply defined.

⁹ The often observed increase of grain when nearingmiarolitic cavities or other pockets exhibiting signs of the action of gaseous constituents may be cited as a probably analogous phenomenon.

Some of the larger deposits may be very briefly described as examples.¹⁰ The giant *Kiirunavaara* ore body, with a mass of at least 750 million tons, forms a steeply inclined bed with syenite-porphry, downward grading into syenite, for foot-wall, and quartz-porphry for hanging-wall. The much smaller *Luossavaara* deposit appears on the same geological boundary after an interval of less than a mile. In both cases the contacts are well defined, but in several places there extend numerous apophyses from the ore body into the wall rock. Where these dikes and veins of magnetite are numerous, the mixture of rock and ore is called "ore breccia." Locally the porphyry at the contact is, to a width of one meter or somewhat more, transformed to a matted amphibole mass. These phenomena are known from the foot-wall contact only, the hanging-wall showing only slight changes near the ore.

The ore is magnetite, with a varying quantity of apatite. While the content of this mineral partly is nearly *nil*, there are other parts of the ore bodies where it is very high, the apatite often being segregated in a pure state as irregular "schlieren" and streaks. Within limited areas, the ore contains a considerable quantity of diopsidic augite, or of uralite. Titanite is rare: tourmaline has been found in a few places near the contacts with the wall rock. Microscopical crystals of zircon are found in most thin sections of apatite segregations.

At *Tuolluvaara* the ore deposit occurs in a porphyry almost identical in composition to the *Kiirunavaara*-*Luossavaara* hanging-wall rock (quartz-porphry). The ore occurs in the form of dike-like, somewhat irregular bodies of workable size, and innumerable smaller dikes and veins down to almost microscopical stringers. The whole deposit may be described as an "ore breccia" analogous to that of *Kiirunavaara*, but of a much greater extension. The ore is magnetite with a lower average apatite content than the *Kiirunavaara* ore. Light green amphibole and white asbestos appear in some quantity. Small patches

¹⁰ A more detailed description of the deposits around Kiruna will be found in a paper by the writer, this journal, Vol. V., 1910, p. 699 (author's abstract of the Kiruna monograph).

of calcite or quartz, with biotite and a little chalcopyrite and titanite appear here and there in the ore breccia. While insignificant in amount, they are of interest as probably representing the last "juice" of the ore-forming solutions.

At *Mertainen* the country rock is a syenite-porphyry with magnetite nodules. The ore is magnetite with little apatite and some amphibole and titanite. It occurs in the same way as at Tuolluvaara, that is, as dikes forming an "ore breccia." The largest bodies, however, are not dike-shaped as at Tuolluvaara, but extremely irregular.

Painirova is a small deposit in many respects similar to *Mertainen*. The apatite content is higher, however, and the crystals are larger than generally in the Lapland ores, reaching a length of several centimeters. These conspicuous apatite crystals often grow out from the walls of an ore body, or radiate from enclosed fragments of wall rock.

The *Ekströmsberg* deposits, which are of a considerable size (containing at least 50 million tons), form a series of beds with only narrow bands of quartz-porphyry between. The largest bed is magnetite, the others are partly magnetite, partly crystalline hematite.

The *Gellivare* group of deposits, which ranks next to *Kiiruna-vaara* in size, and also the important *Svappavaara* ore body, both occur in highly metamorphic rocks. While it is apparent that they are very closely related to those already enumerated, it has not as yet been possible to reconstruct the details of their original characters.

For the last twenty years, at least, it has been clear to all observers that the iron ores of Lapland must be genetically connected with the porphyries. Regarding the nature of this relation, however, and the conditions at the actual deposition of the ore minerals, opinions have widely differed.

The first working hypothesis that can claim consideration was formulated by Bäckström in 1898: "The iron ores occurring in association with effusive rocks should accordingly have obtained their material from below, during the last stage of the volcanic activity, in the form of compounds of iron, phosphorus

and titanium (chiefly chlorides and fluorides), emanating as gas or as superheated solutions. In the surface regions these have been decomposed by the water and the silicates they have been in contact with."¹¹ This pneumatolytic hypothesis is supported by De Launay.

Other authors regard the ores as magmatic bodies. Högbom (1898), when discussing the magnetite deposits in syenitic rocks in the Urals, points out their close resemblance to the Lapland ores, and gives good reasons for putting them together as a well defined genetic group of iron ores (low in titanium) as magmatic segregations in syenite rocks. This magmatic hypothesis has been taken up by Stutzer, and partly further developed.

Bäckström bases his view on the results of his examinations of the "nodules" of the ore-bearing porphyries, which show that minerals, among them magnetite, which normally are among the first to crystallize in the magma, here are the last components to form.

The advocates of the magmatic hypothesis find their most weighty arguments in the mineral composition of the ore, and in the relations between different ore varieties in one and the same ore body. They also point out the insignificance of the pneumatolytic metamorphism recorded in the ore-bearing rocks, which allows the inference that practically no halogen compounds have permeated them.

The present writer has been able to add something more to the evidence already brought forth by Högbom and by Stutzer. At the same time, however, it was plain that while Bäckström's hypothesis cannot longer be upheld in its original form, the observations on which it was founded cannot be neglected. The work resulted in the formulating of a working hypothesis which may be called a compromise between the rival views:

Most of the ore bodies, and particularly Kiirunavaara-Luossavaara, are regarded as products of magmatic crystallization. (With this expression is then understood crystallization in a liquid solution or melt at some temperature higher than the lowest

¹¹ While this view is first expressed in a paper of 1898, the quoted passage is from a later work ("*Geol. Fören. Förh.*," 1904, p. 182).

crystallization temperature of a granite pegmatite—about 550°.) The belief that the solution was in a liquid and not a gaseous state is chiefly founded on the textures of the deposits, and the relations between various ore varieties. The evidence of the supposed high temperature is found in the mineral composition, magnetite, apatite and some diopsidic augite. Minor constituents are zircon and biotite. Specular hematite fills fissures. It is a characteristic feature that the titanite, which in the ore-bearing rocks belongs to the last phase of magmatic crystallization, or to the period of pneumatolytic destruction, when found in the ores appears in vugs or in the skarn-like amphibole mass sometimes resulting from metamorphism of the wall rock immediately at the contact. The rare tourmaline behaves in the same way. It is apparent that ores of this composition are not formed from watery solutions at moderate temperatures; they must belong to the magmatic temperature range.

Some other smaller deposits point at a somewhat different origin. While the chief constituents are the same as in the large ore bodies—magnetite and apatite—and the textural features also indicate a very close relation, there appear in subordinate quantities certain constituents which are of great importance as “key minerals.” Apatite dikes, which cut the quartz-porphyry of the Kiruna district, for instance, are very closely similar to phases of the Kiirunavaara ore body, but some of them contain considerable quantities of tourmaline, and a little albite and quartz. These minerals are often intergrown with the apatite. Zircon appears just as in the ores. Pyroxene is never found in these dikes.

These features seem to indicate that the relations of the apatite dikes to the porphyry are, in a way, analogous to those of a pegmatite to its mother rock—those of a “last juice of the magma.” At the same time, the obvious resemblance to the Kiirunavaara ore leads us to believe that the only difference between the two has been that the apatite dike magma contained more volatile constituents and therefore probably crystallized at a somewhat lower temperature than the big ore body. There is every reason to believe that the large ore bodies bear a similar

relation to their mother magma as do the apatite dikes according to this interpretation. This "last-juice nature" is also shown by the other forms of smaller magnetite segregations in the porphyries, as a swarm of titanite-bearing magnetite veins on Luosavaara which, like the apatite dikes, are intimately associated with quartz-specularite veins, and also by the "nodules." Further, the microscopic examination of the ore-bearing rocks has shown it to be the rule that the crystallization of the magnetite takes place *after* that of the feldspar. This phenomenon is especially apparent in the curious magnetite-syenite-porphyry, in which the magnetite is squeezed in between the albite laths.

It is thus a characteristic feature of the ore-bearing rocks that the magnetite forms "the last juice." It may crystallize as a constituent of the rock, regularly distributed through its mass, or it may be separated out in some way or other, along with certain other constituents, particularly apatite, to form bodies of their own—small nodules, dikes or huge masses. This last juice necessarily contains the volatile constituents of the magma, which may, indeed, have been the ultimate cause of this appearance of the magnetite. In some cases, indeed, as in that of the nodules, it is probable that the magnetite crystallized from gaseous solutions. Some emanations traveled far, and deposited their iron content at lower temperatures. Thus a hydrothermal after-action, after the eruption of the Kiruna quartz-porphyry, resulted in the lean quartzeous hematites of the Hauki complex. These ores are impregnations in silicified tuff rocks, and contain some tourmaline and orthite, but chiefly, besides the quartz, minerals characteristic of hydrothermal action near the surface: calcite, sericite, and a little barite.

While the proving of this nature of the magmatic differentiation which results in the Lapland ores, constitutes a step forward compared to the previously held views, the *cause* of this differentiation still remains to be found. There does not seem to be any possibility of explaining the phenomenon from the consideration of eutectic relations, in the way attempted by Vogt for magmatic differentiation in general.¹² The applicability of these views on

¹² J. H. L. Vogt, "Über anchi-monomineralische und anchi-eutektische Eruptivgesteine," *Vidensk. Selsk. Skr.*, Kristiania, 1908.

a case of ore differentiation in gabbro has recently been shown in a way that seems rather conclusive.¹³ In the ore-bearing igneous rocks of Lapland, however, other factors must have been at work. The possibility of a limited miscibility of the spinellids in silicate magmas cannot be denied, but we have, as yet, no field or laboratory observations that corroborate such a view.¹⁴ It is reasonable to suppose that the general chemical character of the magma has been a necessary condition for the kind of differentiation in question, but it has hardly been the only cause. Several features point to the existence of water in the ore magma, at least in some cases, and one is led to ascribe to this still somewhat mysterious agent some part in the differentiation process. The magmatic water is a deity that undoubtedly has been invoked more often than has been good for its credit, but we must not let the natural reaction carry us too far and lead to an under-estimation of its possible importance.

When the "pegmatitic" relations of the Lapland ores to their mother magma became clear, it was at the same time apparent that these magmatic iron ores are formed through a process radically different from the one that gives birth to the titaniferous ores. The latter are, as is well known, concentrations of the *first* crystallizing components, while the Lapland ores represent that part of the magma which is the last to crystallize.

The existence of several types of such late-magmatic ores, as one might call them, is proved, but they are not common. Late magmatic ores are included in Leith's "pegmatite type" of iron ores,¹⁵ and in Bergeat's "perimagmatic group."¹⁶ Both these terms which, so far as iron ores are concerned, may be regarded as synonyms, have a very wide scope.

Speaking of the ores as igneous rocks, we must call some deposits, for instance Tuolluvaara and Painirova, intrusive

¹³ S. Foslie, "The Ramsøy Deposits of Titaniferous Iron Ore," *Norges Geol. Unders. Aarsbok*, 1913, IV.

¹⁴ Compare, however, A. Harker, "The Natural History of Igneous Rocks," p. 200.

¹⁵ C. K. Leith, "Iron Ores of Canada," *ECON. GEOL.*, Vol. III., 1908, p. 276.

¹⁶ A. Bergeat, "Epigenetische Erzlagertstätten und Eruptivgesteine," *Fortschritte der Mineralogie*, etc., Vol. II., pp. 9-23.

bodies. The ore beds of Ekströmsberg, on the other hand, appear to belong to a series of surface flows. For Kiirunavaara-Luos-savaara, no decisive proofs in either direction have been found. Many geologists, including the writer, find the presence of ore fragments in the hanging-wall porphyry a very strong argument for the view that ore bodies have been formed at the surface. Others, among them Stutzer, believe them to be intrusives. For this view, a number of proofs are brought forth, among which none can be accepted as decisive, but which together compel consideration.

Several other iron ore deposits are often classed with those of Lapland as belonging to the same genetical group: Grängesberg in Central Sweden, Solberg and Lyngrot in Southern Norway, the Mineville group in the Adirondacks, Iron Mountain in Missouri, the Blagodat type of the eastern Ural Mountains, Cerro de Mercado at Durango in Mexico. Of these deposits, Grängesberg, Solberg-Lyngrot, and Mineville are apatite-bearing magnetites in more or less gneissic rocks, and resemble Gellivare, the most highly metamorphic representative of the Lapland ores. It is obvious that part of the present analogies may be due to similarity in metamorphism rather than in original nature.

The analogy between the "Old bed" at Mineville and the Gellivare ore bodies was pointed out by Sjögren in 1891. At that time, opinions differed widely with regard to the origin of these deposits. Since then, observers in both districts have independently arrived at the conclusion that the ore-bearing rocks are igneous, and the ores themselves magmatic segregations. Recently, Newland has emphasized the similarities that make the "21" mine at Mineville almost an exact counterpart of some of the Gellivare open cuts. From my own visit to Mineville, I have a strong impression of these analogies. There are, however, some important differences. The ore-bearing rocks of Mineville are undoubtedly deep-seated intrusives, but those of Gellivare probably intrusions at shallow depths.¹⁷ The chemical compo-

¹⁷ The exact mode of occurrence of the Gellivare rocks cannot be determined in their present recrystallized stage. They cannot be abyssal, however, and may even possibly be extrusives, like the Kiruna porphyries.

sition of the syenites seems to be very much the same in both districts, but the close association with anorthosites is without a parallel in Lapland, where the ore-bearing magma shows other chemical relations. Yet it seems very probable that the Mineville deposits represent a deeper—perhaps one could say earlier—stage of the same differentiation process that has given rise to the Lapland ores.

In the case of the Ural ores, or the deposits of Iron Mountain or Cerro de Mercado, it is clear that analogies with the least metamorphosed Lapland ores can be safely accepted as evidence of similarity in origin. Högbom, in 1898, concluded that there were no other ore deposits known which are more closely related to the Lapland ores than are those of Ural. Since then, prominent investigators have found reason to regard part of these Russian deposits in question as products of igneous metamorphism. Even if this should be right, however, it does not preclude the supposed relation to the Lapland ores. If the views of the differentiation process given here are right, one may expect to find, in close association with deposits of a magmatic nature, others formed at lower temperatures or through the action of gaseous compounds. In fact, as will be shown later on, one finds in America a somewhat similar example. It must also be remembered that several important analogies have become known since Högbom wrote his paper, for instance the existence of the curious magnetite-syenite-porphyrries also in Lapland.

To judge from available descriptions, the Cerro de Mercado, at the city of Durango, Mexico, certainly belongs to the ore type now under discussion. It seems, however, to be the only representative of the type described from Mexico.

Although Iron Mountain and related deposits in southeastern Missouri are among those sometimes classed with the Lapland ores, it has hardly been known that they share with eastern Ural the position of being the nearest relative to the metallo-genetic province of northern Lapland. Professor J. F. Kemp was the first to call my attention to this district. Later, I became acquainted with the important work recently carried out by Mr. G.

W. Crane, for the Missouri Bureau of Geology and Mines.¹⁸ I was able to pay a brief visit to the chief mines, Iron Mountain and Pilot Knob.

The ore-bearing porphyries are on the whole rather similar to those of Lapland. One detail that I have not seen mentioned in the literature at my disposal is the local occurrence of "nodules" of specular hematite, in every respect similar to the magnetite nodules of the syenite-porphyries of Kiirunavaara and Mer-tainen. The nodule-bearing rock is probably of very local occurrence. I observed it only as a few big blocks at the largest open cut on Iron Mountain.

The mode of occurrence of the primary or vein ore at Iron Mountain is almost precisely the same as at Tuolluvaara in Lapland: in both cases there appear some larger, dike-shaped masses, and a system of smaller dikes and veins, forming what is in Lapland known as an "ore breccia." No deposit in Lapland so closely approaches Tuolluvaara in these respects as does Iron Mountain. The composition of the ore differs from that of most Lapland ore bodies by the fact that the iron appears as specular hematite and not as magnetite. This difference, in itself of little importance, is further reduced by the possibility that the hematite may be martitic. The quartz, the last mineral to form in the Iron Mountain ore, does not appear in more than insignificant amounts at Tuolluvaara. Otherwise, the composition is the same, with apatite as the chief barren mineral, and some tremolite. The texture of the ore, however, is different. At Iron Mountain the apatite appears in prismatic crystals which grow out from the walls of the narrow ore veins, or radiate from inclusions of porphyry in the ore mass. While this texture is not observed at Tuolluvaara, it is, as already stated, very characteristic of another deposit in Lapland, Painirova.

The sub-Cambrian talus or "conglomerate ore" of Iron Mountain very much resembles the "conglomerate with hematite pebbles" which occurs in the sedimentary Hauki complex at Kiruna, somewhat higher up in the stratigraphical sequence than the ore-bearing porphyries.

¹⁸ G. W. Crane, "The Iron Ores of Missouri" (Missouri Bur. Geol. and Mines, 2d ser., Vol. X.).

While Iron Mountain thus combines features of Tuolluvaara and Painirova, Pilot Knob forms a striking analogy to Haukivaara. At both places there is a succession of rocks of probably agglomeratic and tuffogeneous nature, strongly altered through hydrothermal activity, silicified or changed to sericite schists, and impregnated with hematite. The "ferruginous breccia" of Pilot Knob is almost identical with a common form of the leaner ore at Haukivaara. The occurrence of some barite is also a characteristic feature at both places.

Crane summarizes his views regarding the origin of the ores as follows:¹⁹ "The ores, in general, are regarded as having been deposited from hot, iron-bearing solutions as an after effect of the porphyry extrusion, the solutions coming from the porphyry itself or from a source common to that of the porphyry. That at Shepherd Mountain is very largely a filling of stretch fissures due to the cooling and consolidation of the porphyry; that at Iron Mountain is in part fissure filling, but more largely a replacement of the porphyry, while that interstratified with porphyry breccia, as at Pilot Knob, Cedar Hill, and Russell Mountain, represents the more or less complete replacement and infiltration of stratified tufaceous beds by iron oxide."

Judging from my own hasty observations, I should believe that Mr. Crane has to some extent exaggerated the importance of the replacement process in the forming of the Iron Mountain ore. While proofs of replacement in small details are abundant, the dikes and veins, particularly the larger ones, have all appearance of being fissure fillings. In Lapland we have few examples of a replacement of wall rock by ore, but some cases where amphibole appears in this way. The same may possibly be the case at Iron Mountain. This unimportant detail excepted, Mr. Crane's results are absolutely the same as I have reached concerning the nearest Swedish relatives of these deposits. It is true that Mr. Crane speaks of the iron-bearing solutions only as *hot*, while I believe most of the Lapland ores to have been formed at magmatic temperatures, but this is of little consequence. For Iron Mountain, for instance, no direct proof of the temperature

¹⁹ *Op. cit.*, p. 139.

can be given, because of the absence of "key minerals"; all we can conclude is that the temperature has been higher than in most mineral veins, and at least approached the magmatic range. Whether it has actually been above the 550° limit, or a little below, does not constitute any important difference.

The recurrence of the types Tuolluvaara-Painirova and Hauki-vaara in Missouri, there represented by Iron Mountain, Shepherd Mountain, and Pilot Knob, respectively, strengthens the view that these two types of deposits represent different phases of one kind of differentiation, in a wide sense of the word. The data we can get out of the Missouri district thus uphold the working hypothesis proposed for the Lapland ores.

Certain other American iron ore deposits appear to be rather closely related to those of Missouri. The Barth deposit at Palisade, Nev., recently described by Mr. J. Claude Jones,²⁰ shows similar relations to the wall rock as does the ore of Iron Mountain. The ore is magnetite with a considerable percentage of apatite. The latter is often gathered spotwise, as is so often the case in the Lapland ores. It is remarkable that the ore occurs in a femic andesite, but one may ask whether, in this and similar cases, the actual wall rock always is also the one genetically most closely connected with the ore. At Palisade, rhyolitic rocks are also reported, but they are not ore-bearing.

The dikes and veins of magnetite at Iron Springs, Utah, are rich in apatite and show the same appearance of this mineral as the Iron Mountain ore.²¹ It may be pointed out as an interesting detail, that the Iron Springs ore sometimes (specimens in the Columbia University collections) shows "columnar jointing," with columns about one inch in diameter. Identically the same phenomenon is shown by the Kiirunavaara ore, but only within very small areas.²²

The appearance, at Iron Springs, of magnetite dikes and con-

²⁰ J. Claude Jones, "The Barth Iron Ore Deposit," *ECON. GEOL.*, Vol. VIII, 1913, p. 247.

²¹ Compare descriptions by C. K. Leith and E. C. Harder, *U. S. Geol. Survey, Bull.*, 338.

²² Per Geijer, "Igneous Rocks and Iron Ores of Kiirunavaara, etc," pp. 86-87.

tact deposits of the same mineral in the closest connection is a remarkable feature that gives us some hints at the probable explanation of the mysterious points in the geology of the Ural magnetites.

The nelsonite of Virginia is probably an analogue to the other titaniferous iron ores, and not to the group we have discussed here. It is a striking feature, however, that its apatite is of the fluorine-bearing variety, whereas apatite associated with gabbro generally contains more chlorine than fluorine.

A catalogue entitled "Maps and Memoirs on Swedish Geology" was published by the Geological Survey of Sweden in 1910. In the section "Ore Deposits" (compiled by Prof. H. Sjögren) will be found discussed all the papers relating to the Swedish deposits published before June, 1910. Some papers dealing mainly with other sides of pre-Cambrian geology, and in the catalogue listed under the heading "Pre-Cambrian Systems" are also of a great interest to the students of ore deposits. "Pre-Cambrian Geology of Sweden," by A. G. Högbom (Bull. Geol. Inst. Upsala, Vol. X., 1910, pp. 1-80), is a review intended to serve foreign geologists as an introduction to the problems of the Swedish pre-Cambrian. "Archæan Geology of the Coast-regions of Stockholm," by P. J. Holmquist,²³ contains a description of the ore-bearing formation of Utö, with large-scale maps.

The following list contains papers published after the catalogue, and some papers dealing with the quartz-banded ores of northern Norway.

PER GEIJER. Ein Vorkommen von turmalinführendem Eisenerz in Diabas (*Geol. Fören. Förh.*, Vol. 33, 1911, pp. 21-31).

Contributions to the Geology of the Sydvaranger Iron Ores (*Geol. Fören. Förh.*, Vol. 33, 1911, pp. 312-343).

Studies on the Geology of the Iron Ores of Lapland (*Geol. Fören. Förhandl.*, Vol. 34, 1912, pp. 727-789).

P. J. HOLMQUIST. Texture and Metamorphism of the Iron Ores (Swedish,

²³ *Geol. Fören. Förh.*, Vol. 32, 1910, pp. 789-913; also as guide No. 15, 11th Internat. Geol. Congress.

with a summary in German. *Geol. Fören. Förh.*, Vol. 35, 1913, pp. 233-272).

NILS SUNDIUS. Pebbles of Magnetite-Syenite-Porphyry in the Kurravaara Conglomerate (*Geol. Fören. Förh.*, Vol. 34, 1912, pp. 703-726).

J. H. L. VOGT. Über magmatische Ausscheidungen von Eisenerz in Granit (*Zeitschr. f. prakt. Geologie*, XV., 1907, pp. 86-89).

Norges jernmalmsforekomster (Iron Ores of Norway). *Norges Geol. Unders.*, No. 51. Kristiania, 1910.

J. H. L. VOGT, WITH F. BEYSLAG AND P. KRUSCH. Die Lagerstätten der nutzbaren Mineralien und Gesteine (Sydvaranger, etc., in Vol. I., 2, pp. 259-266).