

INTERNATIONAL GEOLOGICAL CONGRESS
XXI SESSION NORDEN 1960

IRON AND SULPHIDE ORES OF CENTRAL SWEDEN

GUIDE TO EXCURSIONS NOS A 26 AND C 21

By

N. H. MAGNUSSON



The Swedish geological guide-books

are edited by

THE GEOLOGICAL SURVEY OF SWEDEN

INTERNATIONAL GEOLOGICAL CONGRESS

XXI SESSION NORDEN 1960

**IRON AND SULPHIDE ORES OF
CENTRAL SWEDEN**

Guide to Excursions Nos A 26 and C 21

By

N. H. MAGNUSSON



The Swedish geological guide-books
are edited by

THE GEOLOGICAL SURVEY OF SWEDEN

CONTENTS

	Page
The geological history of central Sweden in Svecofennian (Svionian) time	3
The iron ores of central Sweden.....	7
The sulphide ores of the Falun type	31
The sulphide ores of the Ämmeberg type	39
The scheelite and molybdenite ores of central Sweden	44
Field guide	46

Key map: see inside of back cover

Excursion No A 26: Aug. 6th — Aug. 14th, 1960

Excursion No C 21: Aug. 26th — Sept, 3rd, 1960

Excursions leaders:

Professor N. H. Magnusson
Valhallavägen 46
Stockholm Va

Fil. lic. Åke Henriques
Geologiska Inst.
Tekniska Högskolan
Stockholm 70

The Geological History of Central Sweden in Svecofennian

(Svionian) time

The iron, manganese, and sulphide ores of Central Sweden all belong to the Svecofennian or Svionian cycle, which began with supracrustal rocks: volcanics and sediments. The volcanic rocks are in Sweden known as leptites and hällflintas, the difference between them consisting in the grade of their metamorphism, the hällflintas having dense ground masses, the leptites fine-grained, recrystallized ground masses. The leptites are, in effect, more or less metamorphosed hällflintas.

The volcanic rocks are best preserved in the westernmost part of the ore-bearing region. In the Grythytte area, for instance, N. Sundius has found extremely well preserved hällflint-lavas, with euhedral phenocrysts of quartz and feldspar, spherulites, micro-poikilitic quartz, and fluidal and granophyric structures. Even the more delicate vitroclastic structures are frequently well preserved. The tuffs are often bedded and sometimes show coarse agglomeratic layers with fragments of crystals and rocks.

The leptites have a more or less typical granoblastic structure, which has originated through recrystallization of the original dense ground mass. No original ground mass structures are preserved in the typical leptites. The phenocrysts, the banding, and the coarse agglomeratic structure can however, often be seen even in the leptites. All transitional types between leptites and hällflintas are present in the ore-bearing region. The grain-size of the groundmass of these transitional rocks varies from 0.03 to 0.05 mm.

The predominating acid leptites vary from potassic to extremely sodic types, intermediate rocks being subordinate. The leptites thus represent, from a chemical point of view, a very peculiar series of extrusives. In particular, the extremely sodic types, which have a widespread distribution in the leptite complex, are unknown in comparable quantities in other parts of the world. The lavas and tuffs also include dacites and andesites but in subordinate amount.

Limestone intercalations are common in the leptites. They appear as thin layers or larger lens-shaped bodies and vary from limestones poor in magnesia to dolomitic limestones and dolomites. Through thermal metamorphism the limestones and dolomites have been altered to crystalline rocks (marble). The impurities have given rise to new minerals — in the hällflinta region quartz, chlorite, biotite and muscovite, in the leptite region tremolite-actinolite, diopside, olivine, serpentine, and others. At the contacts of silicate rocks with limestones and dolomites reaction skarns appear.

The iron and manganese ores in Central Sweden always occur in the volcanic rocks, never in the true sediments, which form an upper division. After the volcanic period in which these volcanics, limestones, and dolomites as well as iron and manganese ores were formed there followed a period of more normal sedimentation, represented by greywackes and slates. The greywackes are clastic rocks with both mineral and rock fragments. The clastic structures of the greywackes are sometimes wonderfully well preserved. The greywacke layers, furthermore, are sometimes regularly bedded or laminated. In other cases the bedding



Fig. 1. Linear jointing in leptite, near Taberg, parish of Nordmark, Värmland. (After N. H. Magnusson.) The folding axes of the ore-bearing skarn-limestone body of Värmlands Taberg dip in the same direction as this linear jointing, which is the usual in the iron ore-bearing region. In such parts of this region where later tectonic movements have occurred, the linear jointings dip, however, often in other directions than the original folding axes.

is more irregular. In the laminated parts clayey layers are common, alternating with layers of fragments.

The slates, where they are best preserved, display their original clastic structures. The chief rock in such areas is of a light grey or greenish-grey colour, and in chemical composition similar to typical post-Archaean slates. In coarser-grained arenaceous layers the mineral fragments are well rounded. Argillaceous and arenaceous layers often alternate giving a banded appearance. Between the greywackes and the grey to greenish grey slates there sometimes appears a dark slate, rich in graphite and pyrite, and resembling the post-Archaean alum-shales.

Where the slates are best preserved, as in the Grythytte field, they are only slightly altered and consist of quartz, plagioclase, muscovite, and chlorite. Where the hällflintas are altered to leptites and leptite-gneisses, this low-temperature assemblage is replaced by an assemblage containing one or more high-temperature minerals such as biotite, cordierite, almandite, and andalusite. The original structure is altered to that of a hornfels, usually with no trace of the original clastic features. In regions of more marked schistosity these rocks can be designated as coarse-grained mica-schists with cordierite, almandite, or andalusite.

In the greywacke-slate division and sometimes also below it in the upper part of the leptite division, there occur effusive greenstones of a basaltic composition.

These rocks are developed as scoriaceous breccias, more seldom as lava flows rich in amygdules. The infilling of the vesicules, as well as the cement of the breccias, usually consist of calcite. Through later thermometamorphism the calcite has reacted with the greenstone and many new minerals, such as diopside, actinolite, and hornblende have resulted. These greenstones include true spilites and keratophyres, together with rocks with more calcic plagioclase which can be classified as saussurite-diabases.

The effusives are accompanied by intrusive greenstones in the form of sills or more irregular bodies. These are massive throughout and in the hällflinta regions have the structure and mineralogical composition of saussurite-diabases. In the leptite regions they are usually altered to amphibolites.

In the lower volcanic division (the hällflinta-leptite complex) dikes of hällflinta or leptite as well as dacite-, andesite- and greenstone-dikes have been found and in some mines greenstones appear flanking hällflintas or leptites in composite dikes.

The supracrustal complex must originally have been horizontal or nearly horizontal. It was later intensely folded and the strata usually have very steep dips. Except in a few well-preserved regions the rocks, and especially the sediments, have a more or less marked schistosity, which usually coincides with the stratification. In connection with the early folding and sharpening topography the sediments of the Larsbo series in southern Dalecarlia, and the Mälars series which has a large extension around lake Mälaren, seem to have been deposited. These sediments show more varying grain-size and composition than the previously mentioned sediments, that belong to the Grythytte series. In the Larsbo series quartzites are also common.

The intense folding, often isoclinal, together with later movements, caused deformation of the ores and the limestones. In regions with well-marked schistosity characteristic stock-like forms dip parallel to the linear structure of the surrounding rocks. The horizontal sections of the stocks having the form of more or less irregular lenses.

It is often uncertain whether the linear structure, characteristic of great parts of the ore-bearing region, is entirely due to the main folding. In some areas with steep dip it may have been formed by later movements along schistosity planes.

The intrusion of the oldest granites in central Sweden was synchronous with these strong orogenic movements which gave the granites their often strongly gneissose structure. These rocks are the Swedish urgranites. There is usually conformity between the contacts of these granites and the parallel structures of the supracrustal rocks, indicating that the granite magma intruded the leptites along schistosity- and bedding-planes. Here and there, however, the granites brecciate the ore-bearing formation and its limestones and ores. In the easternmost part of this formation the granites greatly predominate, the leptites appearing only as larger and smaller remnants. The granite series is differentiated into grey oligoclase-granites, intermediate granites and red microcline-granites. The intermediate types are usually augen-granites. As forerunners to these granites gabbros and diorites appeared.

The "urgranites" caused the thermal metamorphism and by merging of the contact zones this metamorphism became regional. It was through a combination

of folding, pressure and thermal metamorphism of varying intensity that the highly varying grain-size and structure of the volcanites and sediments in the ore-bearing region originated.

Solutions from the crystallizing granites have altered the volcanic rocks in smaller or larger areas to mica-schists and ore quartzites rich in such minerals as cordierite, almandite, andalusite, gedrite, anthophyllite, and cummingtonite. The solutions must have been rich especially in silica and magnesia and have been responsible for "magnesia metasomatism" first described by P. Eskola from Orijärvi and P. Geijer from Falun. The solutions have been driven before the granite front and are not to be considered as rest solutions.

In the intraorogenic period, that followed, the folded supracrustal rocks and the "urgranites" became intersected by numerous greenstone dikes. From a mineralogical point of view they can be characterized as amphibolites but here and there ophitic development of the plagioclases shows that these greenstones have been diabases from the beginning.

There followed a regional sinking, whether orogenic or epirogenic is not known, whereby the rocks of central Sweden descended to great depths, where palingenic processes predominate. With palingenesis, a more or less complete fusion took place and the rocks above the fusion zone became altered to coarse-grained, pegmatitic gneisses. These gneisses are usually very inhomogeneous, with coarser, pegmatitic veins. Here and there and especially in the peripheral parts of the gneiss area small, homogeneous fragments of the original rocks are preserved, including sediments, leptites, iron ores, "urgranites" and greenstone dikes. The alteration must have been progressive, for all transitions are shown between the old leptite—greywacke—slate—granite complex and the veined, pegmatitic gneisses.

In addition to the vein pegmatites there are intrusive pegmatites, closely connected on the one side with the vein pegmatites and on the other with so-called younger granites of the Fellingsbro—Stockholm series. The author regards these granites as palingenic products formed by a selective fusion of the old rocks with or without the help of squeezing. They are rich in silica and potash and are not accompanied by more basic rocks, whereas the "urgranites" are differentiated and accompanied by gabbros and diorites. The intrusive pegmatites are usually rich in silica and potash but the composition of the vein pegmatites varies with that of the surrounding rocks. There is, however, no clear distinction between the vein pegmatites, which are metamorphic differentiates *in situ*, and the intrusive pegmatites of which at least the larger ones and the connected granites must have come from deeper zones, where more complete fusion occurred.

I have, besides, come to the conclusion that intense pneumatolytic and hydrothermal alteration preceded the intrusion of the pegmatites and granites. The alteration involved solution of the most soluble substances and enrichment in the stablest constituents. In this case there was a reduction in silica, alkalis, and lime and an increase in alumina, iron, and magnesium giving birth to such minerals as cordierite, andalusite, sillimanite and almandite. The same alteration occurred even in the slates giving them a higher percent of the minerals just mentioned than normal. The slates, therefore, cannot have been the only source of the substances enriched in the gneiss complex, which has acted as a filter.

It is possible that the author with his theory has exaggerated the role played by the metasomatic alteration and underestimated the quality of original slates and greywackes, but it cannot be denied that the alteration took place and gave rise to rocks rich in alumina, magnesia and ferric oxide even where no such sediments existed.

That large amounts of pneumatolytic and hydrothermal solutions have been going through the gneiss-complex as indicated above is shown by the iron ores and the limestones. In the latter, large masses of skarn minerals originated by exchange with the surrounding silicate rocks and by addition from pegmatites and wandering solutions. In these limestones the skarn minerals occur in irregular spots and strings. Serpentine, olivine, chondrodite, pyroxene, spinel, scapolite, and mica are among the minerals present.

The alterations in the iron ores will be described later.

The granite material going through the gneisses in these filter processes gathered together in the roof of the gneiss-complex to give rise to independent granite massifs and associated pegmatites. According to my opinion these granites and pegmatites therefore must have a zone of veined gneisses at depth.

The above-named granites are usually surrounded by broad zones of fusion and pegmatitization and are rich in more or less assimilated fragments of the older rocks. In my opinion these granites are dome-shaped fusion cupola on the palingenic zones. In the pegmatites we find minerals rich in B, Be, Ce, P, and F and even uranium-minerals, and from the pegmatites they have gone into the iron ores in districts rich in such pegmatites. Here and there also micaceous alterations are connected with the pegmatites. These alterations are characterized above all by tourmaline, apatite, orthite, and beryl. Through such alterations iron-ores poor in phosphorus have sometimes got very high contents of this element.

The Iron Ores of Central Sweden

The iron ores of central Sweden are usually divided into three main groups: quartz iron ores, skarn- and limestone iron ores, and apatite iron ores.

The *quartz iron ores* are often very regularly bedded with thin alternating layers of quartz and crystalline hematite, the latter usually more or less replaced by magnetite. In the best preserved quartz-banded iron ores the quartz is a red ferruginous variety. Such ores show great resemblances to the Lake Superior jaspilites and thus belong to a world-wide Precambrian type, *i.e.* the "banded iron-stones". These regularly bedded iron ores are generally regarded as precipitates at the earth's surface, that is sedimentary in the wide sense of the word, the iron-bearing solutions being of volcanic origin.

P. Geijer and the author have, in a paper to the International Geological Congress in London 1948, expressed their common opinion about the origin of the quartz-banded iron ores in central Sweden in the following words:

"With regard to the quartz-banded ores, we agree with most previous workers in ascribing the origin of this type to a process of chemical sedimentation. As to the nature of the characteristic banding, we think one must not regard it so much as an alternation of layers of different character (ore and silica) as a



Fig. 2. In the Stripa mines, parish of Guldsmedshyttan, two different types of quartz-banded iron ores appear in the main ore body. One of them may be characterized as doubly-banded, with comparatively thick bands, the other as simply-banded, with thinner bands. The doubly-banded ore has hematite bands with thin layers of skarn and often also thin layers of quartz. These compound bands alternate with bands of quartz in which, beside a small amount of finely distributed hematite, there are thin layers of hematite. The photograph above is of a doubly-banded iron ore from Stripa.
(After P. Geijer.)

series of double layers composed of two components that were precipitated at the same time but settled at different rates. Our views, therefore, are the same as previously expressed by Moore and Maynard. There can hardly be any doubt that the silica was originally precipitated in a colloidal form. The character of the original iron mineral is not established with certainty. Siderite seems im-

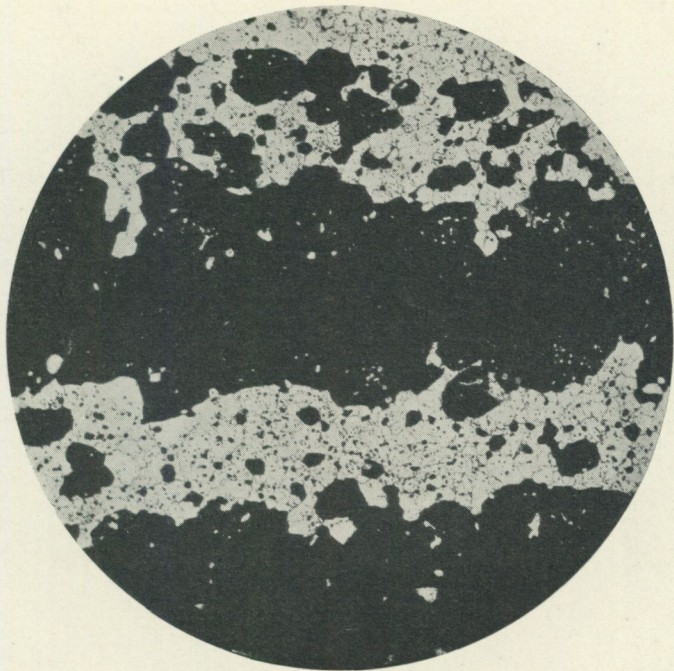


Fig. 3. Quartz-banded hematite iron ore. Thin section, $\times 22$. Hematite black, quartz white. Stripa mine, parish of Guldsmedshyttan. (After P. Geijer.) The quartz grains have dimensions between 0.06 and 0.20 mm. The amount of hematite in the quartz layers is, as the figure shows, not small. The dimensions of the hematite grains vary from 0.0005 mm to 0.3 mm. It is the smallest hematite grains that give the quartz the reddish colour.

probable, because its oxidation to hematite could hardly have left the fine stratification so undisturbed as is now the case. Greenalite is more definitely ruled out, as the ore bands are invariably too pure to have been derived from an original silicate. It therefore seems most probable that a trivalent oxide or hydroxide formed the original iron compound; however, siderite is not entirely excluded.

The source of the iron and silica must be sought in magmatic emanations, such as fumarole gases or thermal springs. All the rocks known to be older than the ores or directly associated with them are very low in iron, and sediments that resulted from weathering are unknown within the leptite series except its uppermost, ore-free parts. Therefore, the possibility that the quartz-banded ores are products of ordinary processes of weathering and sedimentation, as a number of workers have claimed in the case of similar deposits elsewhere, appears to be excluded in the case of the Swedish occurrences.”

Sometimes the intercalated layers consist of leptite or limestone or dolomite, and transitions exist to leptite-bedded and limestone-dolomite-bedded iron ores. Where carbonates of lime and magnesia had been precipitated together with



Fig. 4. The ores in the Nygruvan mine, the Norrberg field in the Norberg region, are typical quartz-banded iron ores with thin layers of hematite and thin layers of quartz alternating (the photograph above). The quartz has often a reddish colour from small scales of hematite. As skarn minerals appear here and there garnet and epidote. Locally and above all against the ore boundaries the hematite has been altered to magnetite. The quartz has locally been collected in irregular bodies of coarse-grained white masses with isolated larger flakes of hematite.

iron and silica, skarn minerals such as garnet, epidote, pyroxene, and amphibole have originated through reactions between already existing material. Such skarn has been called *reaction skarn*.

“Skarn” is a term which originally signified the gangue accompanying the ore mineral of the Persberg mines. At present it is used for silicates and silicate associations in iron, manganese and sulphide ores.

More intensive skarn-forming processes have taken place in connection with the magnesia-metasomatic alterations. The solutions followed shearing zones, fracture zones, and fissures attacking the surrounding leptites, carbonate rocks,



Fig. 5. The ore in the Bondgruvan mine, the Risberg field in the Norberg region, are in the main of the same quartz-banded type as in the Nygruvan mine. Locally these ores have, through magnesia-metasomatic alterations, gone over to skarn iron ores consisting of magnetite and a skarn rich in talc. Often the banding has been preserved and remnants of the original quartz-banded ores have also been found in the skarn ore. The adjoining leptite has been altered to mica schists and quartzites with such minerals as cordierite, gedrite and almandite. The photograph above shows a sample of a quartz-banded iron ore from Bondgruvan, where the quartz layers have been replaced by talc.

and iron ores. The skarn minerals originating through magnesia-metasomatism are richer in magnesia than the reaction skarns.

Together with the magnesia-metasomatic alterations the widespread sulphide ores of the Falun type originated, and the quartz iron-ores are, therefore, where the magnesia-metasomatism has reached them, often impregnated with sulphides sometimes in such amounts that they have been mined for copper and cobalt for instance.

In several districts quartz-iron ores rich in feldspar and mica occur. Some of these, which appear in close proximity to quartz-banded iron ores, are undoubtedly precipitates primarily mixed with tuff material. In the regions of the veined gneisses the quartz-banded iron ores have been impregnated with feldspar and mica, and quartz has been driven out and enriched in other parts of the ore masses. In these parts even magnesia has been enriched. Such ores are the pegmatite-iron ores and the quartz-anthophyllite ores in Kantorp. Where limestones, dolomites, and larger skarn masses were present, new skarn minerals have been formed through reactions between this material and the pegmatite solutions. These ores show a chaotic mixture of older minerals and new ones

and are called skarn-pegmatite ores. In the roof of the veined gneisses pegmatite dikes in larger or smaller masses have intruded the quartz-banded iron ores.

In connection with the folding and later pressure during movements in the earth's crust the original banded quartz-iron ores often lost their bedding and massive ores resulted with quartz more or less evenly distributed in the ore masses. There are hence all transitions between bedded and massive ores and between hematite ores and magnetite ores and from these ores to skarn-bearing types.

The original layers of quartz-banded iron ores have, as has been mentioned before, been strongly folded and deformed. As the quartz-iron ores have been more plastic than the surrounding leptites a thickening has often resulted along the fold axes. Where movements along shearing planes occurred, the ore-bodies on the contrary became divided in longish lens-shaped bodies dislocated along the shearing planes in relation to each other.

The author has newly made a new estimation of the resources of iron ores in central Sweden. According to this there should be at least 312 million metric tons of quartz-iron ores with an iron content of 104 million metric tons iron. The average iron thus should be about 33 %. The amount of iron varies, however, from 30 % up to a little more than 50 %. The amount of phosphorus is low, normally between 0.010 and 0.030 % but can go down to 0.007 % and up to about 0.085 % and more. The highest percentages are not the primary ones but caused by later alteration processes.

The *skarn and limestone ores poor in manganese* form a much more inhomogeneous group. They are divisible into several classes: quartziferrous skarn iron ores, metasilicate skarn iron ores, basic skarn iron ores, and limestone iron ores. To these ores are to be added basic skarn iron ores rich in manganese to which the ores of the Långban type are nearly related.

The *quartziferrous skarn iron ores* consist of magnetite together with amphibole, garnet, epidote, and an essential content of quartz. Sometimes, also, crystalline hematite, which has escaped the metamorphic processes, is present in subordinate amounts. The quartziferrous skarn iron ores must originally have been hematite ores, and as transitions are shown between them and the quartz-banded iron ores they are certainly sedimentary in the same way as the latter.

The *metasilicate iron ores* are magnetite ores throughout but here and there magnetite with the crystal forms of hematite has been found. The magnetite is accompanied by garnet, pyroxene, and amphiboles of varying composition. These ores fall within two groups: those rich in calcium and those rich in magnesium. The ores rich in calcium are characterized by andradite, pyroxene of the diopside-hedenbergite series, and actinolite. These metasilicatic skarn iron ores always appear in or together with limestones and dolomites in such way that it must be concluded that the presence of carbonate rocks has been necessary for the genesis of such large skarn masses. The ore-bearing skarn usually shows very irregular boundaries against the carbonate rocks, and remnants of the latter often appear in the skarn masses. The ore mineral, the magnetite, in its turn in most cases has an irregular distribution in the skarn. From such skarn iron ores there are, however, all transitions to ores with a uniform distribution of magnetite in skarn masses with homogeneous mineralogical composition. Here and there these skarn ores also show a more or less pronounced bedding.

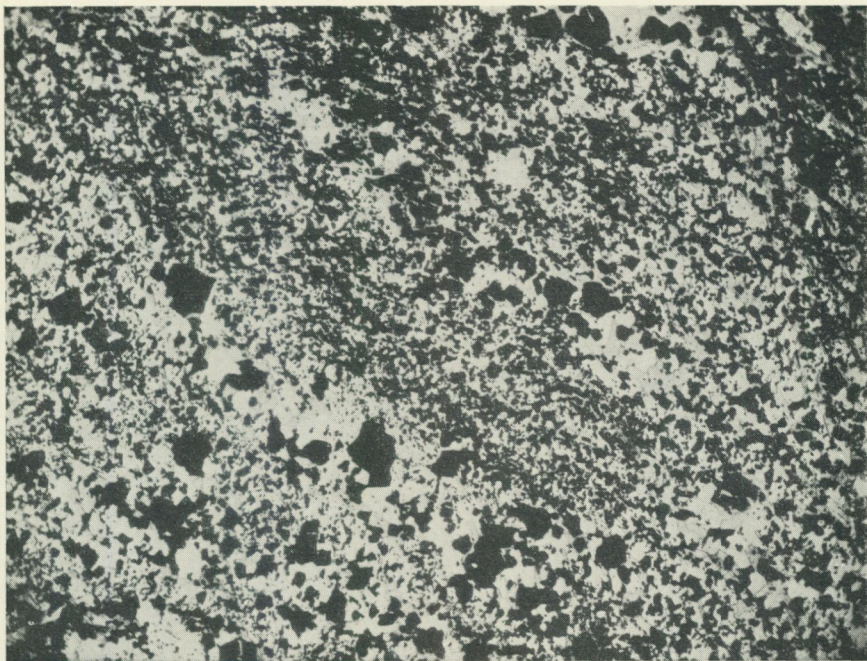


Fig. 6. Quartz-skarn-iron ore. Thin section, ord. light $\times 15$. Klacka-Lerberg mine, parish of Nora. (After N. H. Magnusson.) The ore mineral is magnetite together with subordinate hematite. The larger grains are later concentration products during the recrystallization. The ores were surely precipitated in a colloidal form. In this precipitation first hematite in the form of very small grains were formed. Hematite was later altered to magnetite and larger and larger grains were formed when the temperature rised.

The magnesium-rich ores are characterized by anthophyllite, gedrite, cummingtonite, and talc, and some occurrences show also small quantities of quartz. In the transitional types tremolite occurs. Where skarn ores rich in calcium and such ores rich in magnesium appear together, the skarn rich in magnesium is always the younger and in several mines it has been possible to show that the iron ores rich in magnesium are alteration products of the ores rich in calcium. It has also been possible to show that this alteration has taken place through magnesia-metasomatism, the surrounding leptites having been altered more or less to mica-schists and quartzites and along the contact between the ores and the leptites so-called mica "sköls" have originated. These sköls are thin zones consisting only of mica minerals with here and there small amounts of talc, gedrite, cordierite, almandite, andalusite, and so on.

Between the skarn iron ores with garnet, pyroxene, and actinolite and the talc-anthophyllite ores which are the richest in magnesia there exist relative magnesia-rich transition types with diopside and tremolite as characteristic skarn minerals.

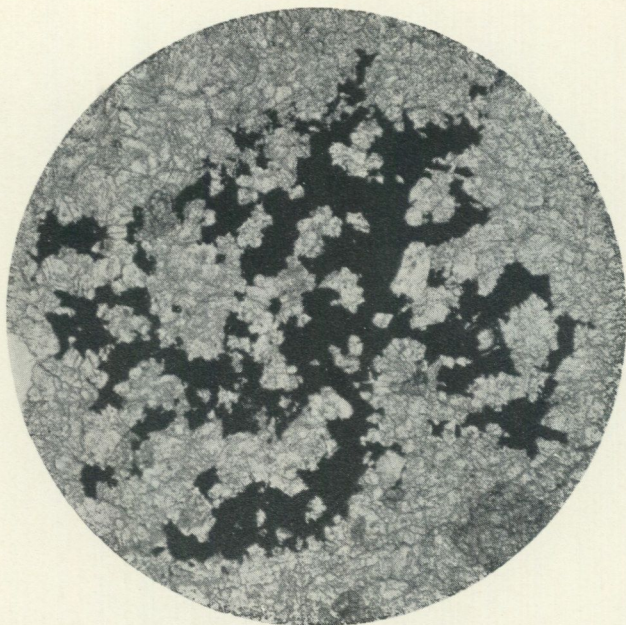


Fig. 7. Skarn-magnetite iron ore. Thin section, ord. light $\times 20$. Magnetite (black) in pyroxene skarn. Persberg mines, Filipstad region. (After N. H. Magnusson.) In this so-called Storgruve type actinolite and andradite-garnet often appear together with the pyroxene, which is a diopside with subordinate hedenbergite. Towards the leptite boundaries the garnet is often replaced by epidote. Pyroxene and actinolite are there replaced by hornblende.

It is quite clear that both the skarns rich in calcium and the skarns rich in magnesium have originated in connection with the intrusion of the 'urgranites'. The problem is whether the iron content has been taken from the already existing sedimentary iron ores or has come from the granites. The possibility must also be taken into consideration that both ways have been used by Nature.

Of greatest importance for the geologists in trying to solve this problem are the transitions between quartz-banded iron ores and skarn iron ores. It has already been pointed out that the former nearly always contain small amounts of skarn minerals and that these in most cases imply the presence of small amounts of limestone or dolomite material in the original precipitates. Where more such material had been precipitated, more skarn could originate through regional thermometamorphism in connection with the first granite intrusions. In the beginning the bedding was preserved but gradually it disappeared and the quartz was consumed and appears now only in remnants. These remnants can be quartz-banded and often contain preserved hematite. Usually hematite disappears in connection with this alteration and is replaced by magnetite. In the skarn masses hematite locally can be preserved even if quartz is totally consumed. Magnetite with the crystal forms of hematite has also been found.

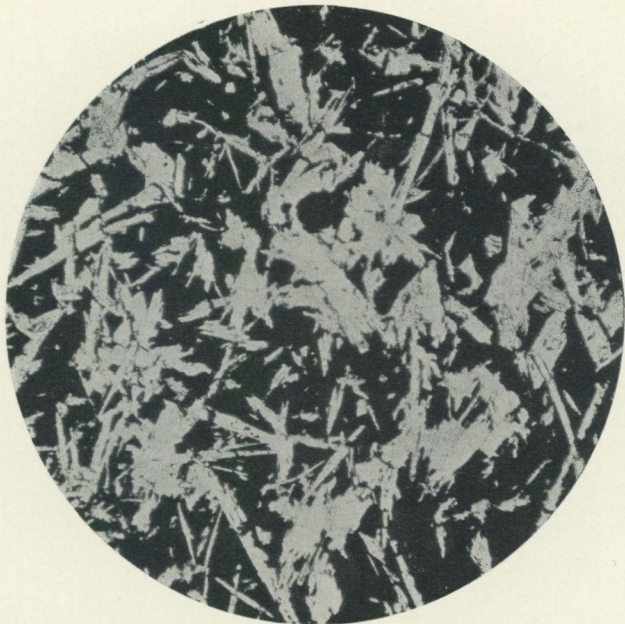


Fig. 8. Skarn-magnetite iron ore. Thin section, ord. light $\times 20$. Magnetite (black) in anthophyllite skarn. Persberg mines, Filipstad region. (After N. H. Magnusson.) In this Alabama type the anthophyllite is often altered to talc. Between this type and the Storgruve type there appear a zone characterized by tremolite and diopside. In the Alabama type there have also been found remnants of the Storgruve type indicating that the anthophyllite ores are alteration products of the pyroxene ores.

In these cases there can be no doubt at all that the ores from the beginning are chemical precipitates and that the present irregular distribution of the ore-material has resulted through later rearranging, and that the present mineralogical composition is the work of thermal metamorphism in connection with the appearance of the granites. The rearranging was facilitated by the tectonic forces, that caused the folding of the volcanic complex. We therefore often find a more or less rigorous orientation of the ores worth mining to contacts and folds. We find them also drawn out in the direction of the pitch. The tectonic forces have also facilitated the formation of skarn through breaking up of the quartz- and ore-layers, producing more points of attack.

The limestone ores proper always show a pronounced bedding provided that no stronger tectonic working up has occurred.

Remnants of quartz-banded iron ores and limestone-dolomite-banded iron ores and of skarn-banded iron ores with or without quartz have, during later years, been found in so many iron ore occurrences that the author now can dare to put forward the statement that nearly all of our skarn iron ores in central Sweden from the beginning have been sediments.

Where the skarn iron ores correspond to the ores mentioned above with the difference that no remnants of quartz-banded and limestone-dolomite-banded



Fig. 9. The skarn iron ores in the Högborn mines, parish of Grythyttan, are often banded (the photograph above) and all transitions exist between banded ores and massive ores with irregular distribution of magnetite in the skarn masses, which consist of actinolite, tremolite, hornblende, garnet, epidote, biotite, chlorite and talc. Together with the skarn-banded types there also occur limestone-banded and quartz-banded ores as remnants in the skarn masses. (After N. H. Magnusson.)

ores have been found it is naturally probable that they nevertheless have originated in the same way, that is, they are sediments altered through rearrangement, recrystallization and formation of skarn.

The skarn associations formed through reaction between already existing material have, as has been mentioned before, been called reaction skarns. The minerals that have originated in this way are mainly andradite, a pyroxene belonging to the diopside-hedenbergite series with more diopside than heden-

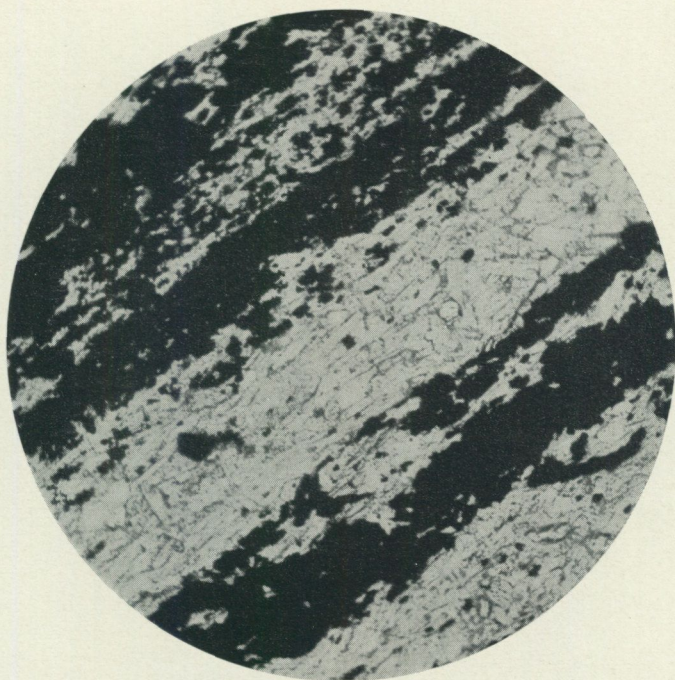


Fig. 10. Skarn-banded magnetite iron ore. Thin section, $\times 20$. Magnetite (black) and actinolite skarn (white). Långgruvan mine, Norberg region. (After P. Geijer.) There were in this mine all transitions between such banded skarn ores and massive types. Here and there also quartz-banded ores were found, locally with hematite, and in the Springa mine in the vicinity a quartz-banded hematite ore of the usual type has been mined. The author has got the impression that the larger skarn iron ores in this mine have been formed through material taken from poorer sedimentary ores. There have been a rearrangement of the iron material.

bergite and actinolite. Where leptite material has been present these minerals often have been replaced by epidote and hornblende.

The magnesia-metasomatic alterations soon followed the thermal metamorphism that caused the formation of reaction skarns and often these two types of skarn appear in the same occurrences and then there are all transitions between them. Often the reaction skarns have been "worked over" by the solutions rich in magnesia. It is possible that these solutions have also added some iron to the iron already existing in the occurrence, but in such cases the additional contribution must be very subordinate.

The *basic skarn iron ores poor in manganese* are characterized by orthosilicates such as forsterite, humite minerals, and serpentine. These minerals also often appear even in the tremolite-diopside skarn but only in small quantities. Together with both ore types there appears opicalcite in the limestones and dolomites. Opicalcite is a limestone with spots of forsterite, humite minerals, or serpentine. Serpentine is in these types an alteration product from forsterite



Fig. 11. The irregular skarn iron ores in the Haggruvan mine at Grönhult, parish of Hjulsjö, often contain quartz as bands and irregular aggregates. The skarn consists of pyroxene, actinolite and hornblende. Locally there have been found types with alternating layers of magnetite ore, layers of skarn with magnetite, layers of quartz and layers of hälleflinta (the photograph above). Agglomeratic layers with pebbles of magnetite ore have also been found in the vicinity. In the parish of Hällefors, W. of Hjulsjö, agglomerates have been found containing pebbles of manganiferous iron ores.



Fig. 12. The ores in the Kallmorberg mines in the Norberg region vary from magnetite iron ores with magnetite irregularly distributed in dolomite or in skarn masses to banded types, which vary from quartz-banded hematite ores of the usual type to dolomite with layers of skarn, quartz and magnetite. Together with magnetite there often appear also hematite, and the quartz has sometimes a reddish colour. In the dominating magnetite-skarn-iron ores often small remnants of quartz-banded iron ores have been found. These mines give good evidences for the opinion that the iron content in the skarn ores have been taken from originally existing sedimentary ores. The photograph shows a sample of the banded dolomite-skarn-iron ore.

and humite minerals. Together with these minerals there often occur in larger or smaller quantities such minerals as biotite, phlogopite, chlorite, fluorite, and spinel. Characteristic above all are the fluor-minerals. In addition, boron-bearing minerals: ludwigite and fluoborite and cerium-minerals: orthite, cerite, and törnebohmite have been found in these ores.

At the contact against the leptites there usually appear great sköls consisting of micas and amphiboles. The leptites are altered to mica-schists and quartzites of the types characteristic for magnesia-metasomatism.

As P. Geijer has pointed out, this ore-type, in a way very clearly indicating replacement, provides, in central Sweden, the only unquestionable evidence of iron ores that can have resulted from contact metasomatism. For many other types, with skarn of diopside and tremolite etc. such an origin is according to Geijer probable or at least possible, but it is only the extremely magnesian variety that presents unequivocal evidence, in the occasional but very characteristic appearance of borates typical of contact deposits.

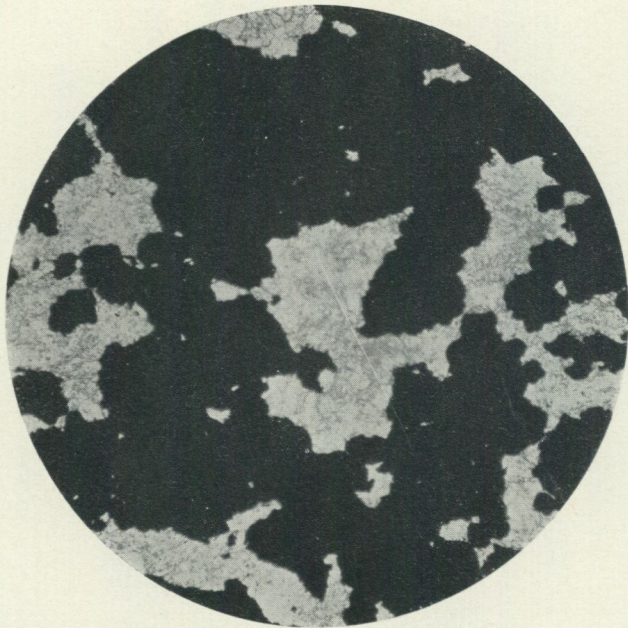


Fig. 13. Limestone-magnetite iron ore. Thin section, ord. light $\times 20$. Magnetite (black) in a mass consisting of calcite, serpentine, tremolite and diopside. Persberg mines, Filipstad region. (After N. H. Magnusson.) In this Skärstöten type the skarn minerals are subordinate in comparison with calcite and dolomite. The amount of silica in the original sediment was low, which explains the low amount of skarn in this ore type.

In this I could agree with Geijer, if these skarn ores were bounded to the contacts of the granites. Instead they usually appear together with reaction skarn and the magnesia-metasomatic skarn as the last product of the alterations caused by the granites, and they are locally enriched in fluorine, boron, cerium and so on.

Besides, the author has in two mines (now closed down) with such ores rich in magnesia in limestones, found that at least a part of the iron material has been taken from poor quartz-banded iron ores in the near vicinity of the limestones.

This opens an interesting perspective. Perhaps the small occurrences of skarn iron ores rich in magnesia and uncombined with other types can have got their iron content from iron sediments in the vicinity or deeper in the earth's crust.

As transitional types to the limestone ores proper the limestone ores with scattered spots of skarn-minerals can be considered. They are only local forms of the skarn iron ore types mentioned above.

The *limestone ores proper* usually consist only of magnetite and limestone or dolomite. Only in the best preserved region, the Grythytte area, there occur also limestone ore bodies with preserved hematite. The limestone iron ores, as has been mentioned before, often show a well preserved bedding. Together

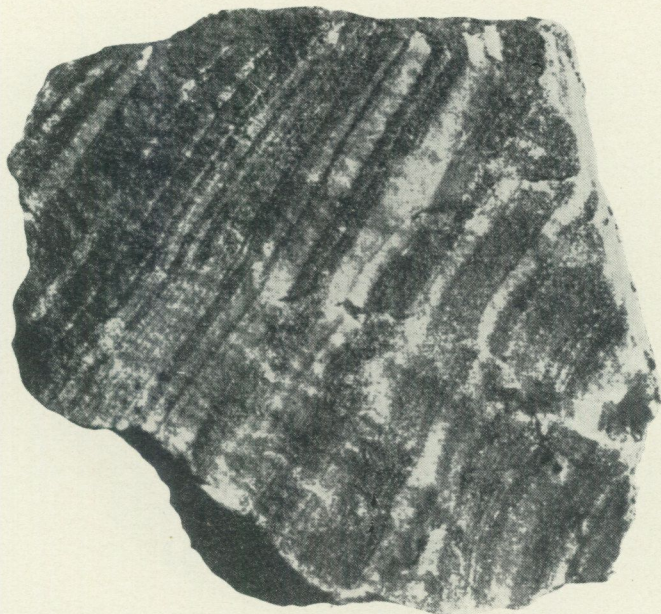


Fig. 14. Limestone-banded iron ore consisting of hematite, magnetite and calcite from the N. Klampåsgruvan mine in the Grythytte field. (After N. Sundius.) Only in this field the limestone-banded iron ores have been found to contain hematite. In all other regions the hematite in such ores has been altered to magnetite. The Grythytte field has the best preserved Svecofennian (Svionian) rocks in the whole iron-ore-bearing region of Central Sweden.

with the folding the bedding, however, often has been more or less destroyed. Observations in the Grythytte area especially have given good evidence of the sedimentary origin of the limestone iron ores.

The author's estimation of the resources of skarn and limestone iron ores poor in phosphorus has given 80 million metric tons with an iron content of 26 million metric tons. The average iron content should thus be about 33 %. It varies, however, from 25 % up to about 40 %. The phosphorus is low, usually about 0.010 % but can go down to 0.004 % and up to about 0.085 % and more. The highest percentages are not the primary ones but, as in the quartz-banded iron ores, they are caused by later alterations.

The *manganiferrous skarn and carbonate iron ores* can also be designated as basic orthosilicates and carbonates playing a dominating role in the gangue. The ore mineral is always magnetite. Usually the content of manganese in the magnetite is very low but can locally exceed 10 %. The dominant silicates are knebelite and dannemorite. The carbonate mass in these ores always contains more or less manganese. Often the content of manganese is high. Besides manganese carbonate the carbonate masses also contain iron, magnesium and calcium in varying proportions. The skarn iron ores rich in manganese always

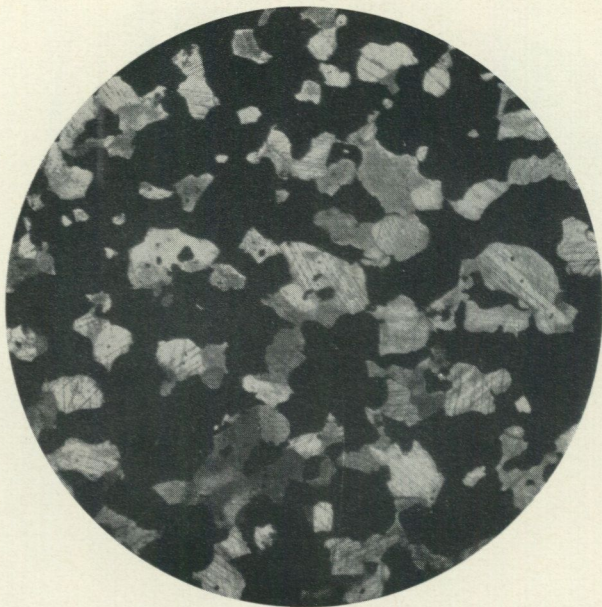


Fig. 15. Limestone-magnetite-iron ore. Thin section, ord. light $\times 13$. Magnetite (black) in a mass consisting of calcite. Sköttgruvan mine, parish of Ljusnarsberg. (After N. H. Magnusson.) This ore is limestone-banded. The figure shows the structure of an ore layer, the alternating limestone layers are nearly pure limestones. Skarn appears only at the leptite boundaries.

appear in limestones or dolomites, usually as layers. In the smaller and poorer occurrences, however, they occur as irregular concentrations.

The proportions between manganese carbonate and manganiferrous silicates vary from occurrence to occurrence. There are all transitions between ores rich in manganese carbonate to ores rich in manganese silicates. The content of silica varies from 2.5 % to 23 %.

At the contacts with the leptite, there usually appears skarn consisting of garnet, amphiboles (either hornblende or dannemorite), pyroxene, and biotite. The garnet consists of spessartite, grossularite, and almandite in varying proportions admixed with small amounts of andradite.

The formation of this skarn has often gone deep into both the leptites and the ores. Leptite layers in the ores have in this way often been replaced by skarn layers with remnants of leptite. That this skarn is a reaction skarn, younger than the ore itself, is clear from the fact that leptite dikes intrusive in the ores also have been altered to similar skarn at the contact with the ores.

A certain amount of graphite, 0.5—1.5 % C, is usual. It is still an open question if this graphite has originated through dissociation of manganese carbonate or is to be considered as an evidence that organic material has been precipitated together with these ores.

Characteristic for the iron ores, rich in manganese, is that the magnetite in

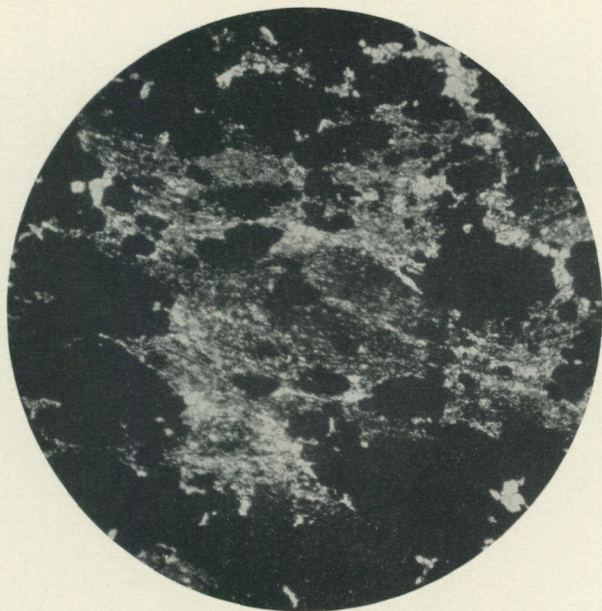


Fig. 16. Manganiferous iron ore rich in carbonate. Thin section, ord. light $\times 13$. Ställberg mines, parish of Ljusnarsberg. (After N. H. Magnusson.) The fine-grained banded parts are the more original ones. The larger magnetite grains have been formed through concentration of the material in connection with the recrystallisation. The carbonates contain manganese, iron, calcium and magnesium in varying proportions. The ores were surely precipitated in a colloidal form and later recrystallized.

the better preserved regions appears as a fine powder in both carbonates and silicates. This powdering disappears towards regions with higher metamorphism, in which the magnetite material is collected in larger and larger grains.

While others are more massive, several occurrences of iron ores rich in manganese are characterized by a pronounced bedding. Sometimes such ores occur together, with banded skarn iron ores or limestone ores poor in manganese, or with quartz-banded, or lepidite-banded iron ores poor in manganese. It is thus clear that even the ores rich in manganese must be sedimentary from the beginning and that the skarn must be a reaction skarn formed later than the ores themselves.

The author's estimation of the resources of skarn- and carbonate-iron ores rich in manganese ($> 1\%$ Mn) is 95 million metric tons with an iron content of 31 million tons. The average iron content should thus be 33% Fe. It varies, however, from about 20% up to about 50% . The percentage of manganese varies from 1% up to about 5% Mn. Locally it can, however, be even higher. Ores with up to 12% Mn have been mined. The phosphorus is very low, usually about 0.005% P and seldom higher than 0.020% P.

The so-called eulysites are skarn bodies with knebelite as the dominating

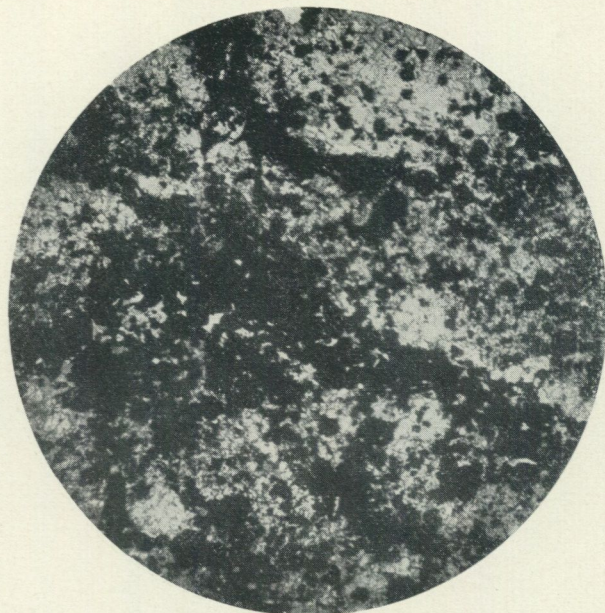


Fig. 17. Manganiferous iron ore rich in knebelite. Thin section, ord. light $\times 13$. Basttjärn mines, parish of Ljusnarsberg. (After N. H. Magnusson.) The more fine-grained parts are the more original ones, as in the manganiferous ores rich in carbonate. The knebelite grains often contain magnetite in the form of very small individuals. The larger magnetite grains are later concentration products. The ores were surely precipitated in a colloidal form and later recrystallized.

mineral. The eulysites hitherto mined have had manganese contents of 6 to 12 % Mn and iron contents of 24 to 33 % Fe.

To the basic skarn iron ores rich in manganese the *ores of the Långban type* are nearly related. In the Långban mines and some smaller mines in the Filipstad district iron and manganese ores occur in proximity with each other but not actually in contact. The iron ore minerals are hematite and magnetite; hematite and ferruginous quartz forming the main central masses of the iron ores. At the contact of the ore and the surrounding dolomite, hematite and quartz are replaced by magnetite and such skarn silicates as andradite, diopside, and tremolite. The manganese ores consist of braunite and hausmannite, braunite constituting the central part of the larger ore concentrations, hausmannite the outer parts of the larger bodies and the whole of the smaller bodies. Braunite and hausmannite are accompanied by a great many skarn minerals, such as rhodonite, manganophyllite, schefferite, richterite, tephroite, and yellow garnet (rich in spessartite). In addition there are several minerals containing Pb, As, and Sb, and also minerals containing Be, Ba, Ti, V, B, P, Cl, and F.

The most probable is, in my opinion, that the ores have been precipitated in the dolomites near the surface as thermal products. The precipitation must have occurred so near the surface that sufficient oxygen was present to produce



Fig. 18. At the boundaries of the manganiferous iron ores in the Kolningberg mines (the Norberg region) and the adjoining leptite, a peculiar skarn consisting of garnet, hornblende and black mica has been formed through reactions between the ores and the leptite. The photograph above shows a sample of such a skarn from Kolningberg. It is clear from the observations in the Ställberg mines that this skarn is younger than the ores. Where the ores have been intruded by leptite dikes, the same skarn has been formed at the contacts of these.

oxygen-rich minerals of Pb, As, and Sb. Abundant supply of oxygen was, surely, also necessary for the division of these ores into an iron ore and a manganese ore appearing side by side but never mixed. At the beginning of the thermal metamorphism that gave these ores the character of reaction skarn ores, the iron must have been present as Fe_2O_3 and the manganese as Mn_2O_3 and MnCO_3 . It is possible but not necessary that Fe_2O_3 and Mn_2O_3 were precipitated as $\text{Fe}(\text{OH})_3$ and $\text{Mn}(\text{OH})_3$.

That the Långban ores are unusually rich in different minerals depends primarily on the presence of the great number of elements precipitated in the original thermal deposit, but also on the complexity of the later mineral-forming processes. It is not, however, possible in a short review to describe and discuss in greater detail the interesting geological conditions and the many rare minerals which occur in the Långban mines. About 150 are described in the literature.

The Långban mines are now exhausted. Only dolomite is still mined.

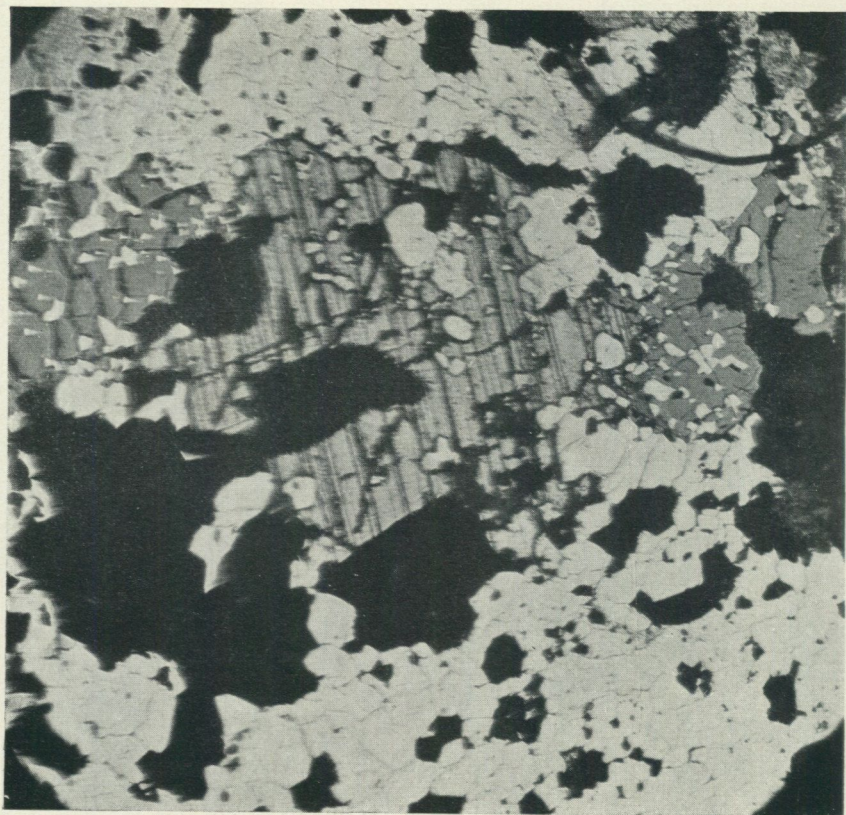


Fig. 19. Hausmannite porphyroblasts with polysynthetic twinning in a braunite ore. Microphoto, refl. light. The polished surface etched with conc. HCl during 1/2 min. (After N. H. Magnusson.) In the hematite iron ores porphyroblasts of magnetite have often been found in the hematite masses. In the same way hausmannite has been formed in the braunite ores of the Långban mines. In both cases the alteration has implied a reduction of Fe^{3+} to Fe^{2+} and of Mn^{3+} to Mn^{2+} .

The *apatite iron ores* appear in a relatively restricted area in southwestern Dalecarlia, with Grängesberg, Blötberget, and Idkerberget as the dominant occurrences, and the only ones worked at present. In spite of the limited number of mines and the restricted area, the ore quantities are considerable. Of the total quantities of iron in the iron ores of central Sweden, the apatite iron ores contain about 40 %.

The apatite iron ores usually constitute in horizontal sections lens-shaped bodies, orientated conformable to the bedding in the surrounding leptites. The ore-bodies terminate in apophyses. Small ore dikes here and there brecciate the surrounding rocks. In some occurrences strips of leptite have been found enclosed in the ores. In other places the compact ores go over to impregnations in leptites.



Fig. 20. Apatite iron ore. $\times 2/3$. N. Hammargruvan mine, Grängesberg. (After N. H. Magnusson.) N. Hammargruvan was a small mine, north of the Export field in the Grängesberg region. The ore mined had there an extremely high amount of apatite (the white in the figure). In the larger ores of the Grängesberg field the amount of apatite only locally reach the same height. In the Export field such concentrations are found in the main only along the hanging wall.

These observations indicate that the apatite iron ores are to be considered as intrusive bodies, which have intruded along bedding-planes in the leptites. These ores are thus magmatic ores of the same type as the Kiruna and Gällivare ores in northernmost Sweden. The ore magmas must have been rich in gases as they have often impregnated the surrounding leptites with skarn minerals, magnetite, and apatite. That these impregnations are nearly connected with the intrusion of the ore magmas is clear from the fact that leptite dikes intersect the ores without being impregnated by such skarn. Sometimes skarn impregnations are found all round the ores. In other cases, as in the large Export ore in Grängesberg, the impregnations are found only in the hanging wall. In this ore there has also been a concentration of apatite against this wall.

The apatite iron ores are mostly magnetite ores but hematite ores are often combined with them. Both types seem to be primary. Certain changes in the distribution of magnetite and hematite have, however, occurred through later processes. In Grängesberg, for instance, the hematite is altered to magnetite at the contacts of the late-Svecofennian pegmatites.

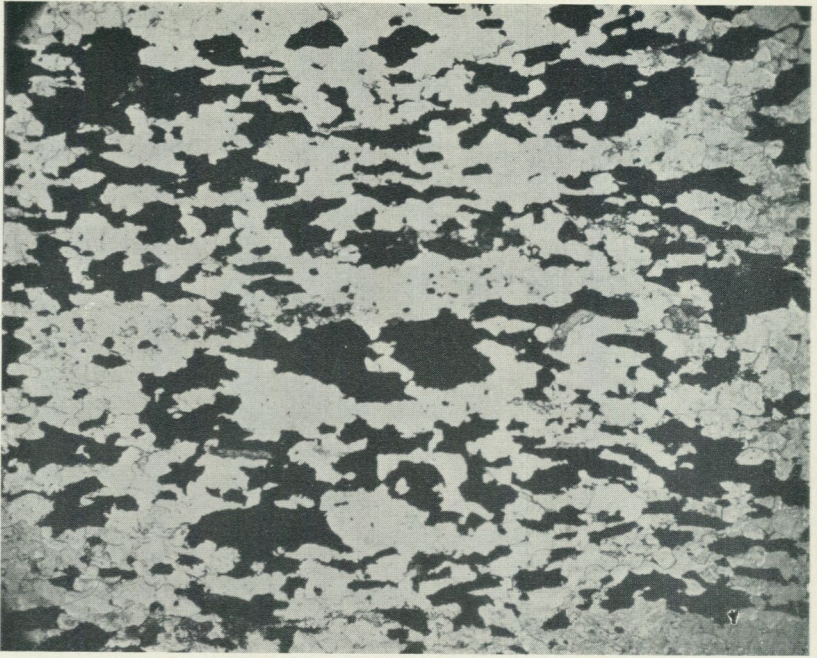


Fig. 21. Impregnation iron ores of the Lomberg type. Grängesberg field. Thin section, ord. light $\times 10$. (After N. H. Magnusson.) These ores appear as impregnations of hematite and magnetite in leptite. The minerals appearing together with the ore minerals are quartz, feldspar, muscovite and biotite, in subordinate amounts also garnet and epidote. Magnetite is considered as an alteration product of hematite. These ores are nearly connected with the apatite iron ores in the Export field of Grängesberg and contain between 0.20 and 0.06 % P. The amount of phosphorous is highest nearest the apatite-iron ores.

The ore minerals and apatite are in the ores accompanied by quartz and skarn minerals, among which actinolite is the dominating one. In more subordinate amounts the following minerals have been found: biotite, muscovite, chlorite, epidote, and garnet, and especially in Blötberget minerals rich in magnesia, such as tremolite, anthophyllite, cummingtonite, and cordierite, probably formed through later magnesia-metasomatism.

The skarn minerals are sometimes evenly distributed in the ore masses, especially in the richest parts, where the amount of skarn is low. In other parts they are collected in spots and "schlieren". Towards the apophyses they have often been collected in skarn masses poor in ore minerals. Where the ore material appears as impregnations in leptites, the ores have a certain, and often high amount of biotite and feldspar. The skarn impregnations in the leptites consist of amphiboles such as actinolite, hornblende, anthophyllite, and cummingtonite together with biotite, chlorite, and talc, and varying amounts of apatite and magnetite often collected in spots and "schlieren". Sometimes the skarn masses brecciate the leptites. The amount of quartz is usually low in the compact ores

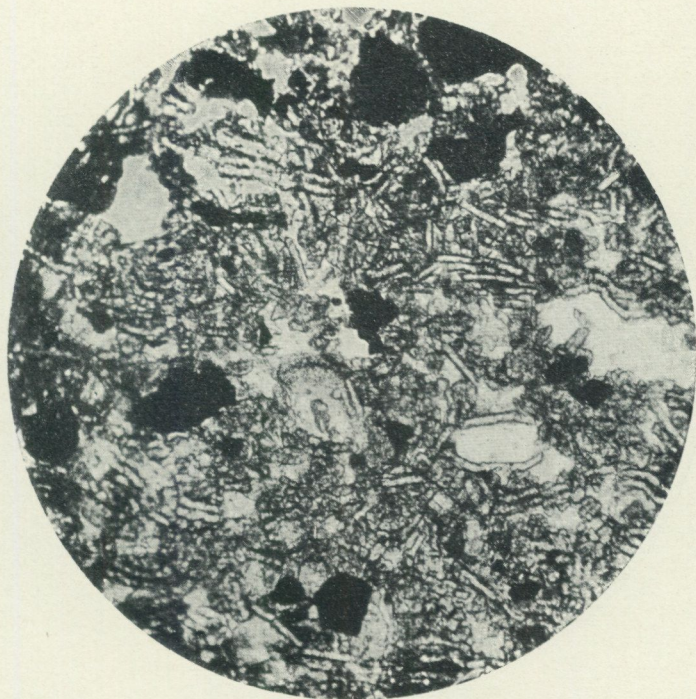


Fig. 22. Siderite ore, highly porous, with some magnetite grains. Thin section, ord. light $\times 36$. Mossgruvan mine, parish of Ljusnarsberg. (After N. H. Magnusson.) The magnetite grains are more or less altered to martite. Both martite and siderite have in some extension been altered to limonite (goethite). Among the weathered iron ores of Central Sweden only the ores of the Mossgruvan mine contain considerable quantities of siderite.

but increases in the same way as the skarn towards the termination of the ore shoots.

In Idkerberget the apatite iron ores are magnetite ores and appear as lens-shaped or more irregular bodies enclosed in a thick amphibolite which forms a continuous zone in this field.

In Grängesberg the apatite iron ores are nearly connected with impregnations of hematite and magnetite in the leptites. They are to be considered as impregnation breccias in which remnants of leptite appear. From such breccias there are all transitions to more concentrated ores. Owing to the genesis of these ores the ore minerals appear together with quartz, feldspar, muscovite, and biotite. The amount of quartz in relation to the amount of feldspar is usually higher in the ores than in the surrounding leptites and outwards from the apatite ores the amount of quartz rises more and more. Simultaneously the amount of skarn minerals such as garnet, epidote, and amphiboles increases, but the content of apatite on the other hand decreases outwards from the apatite iron ores from 0.20 % P to 0.06 % P.

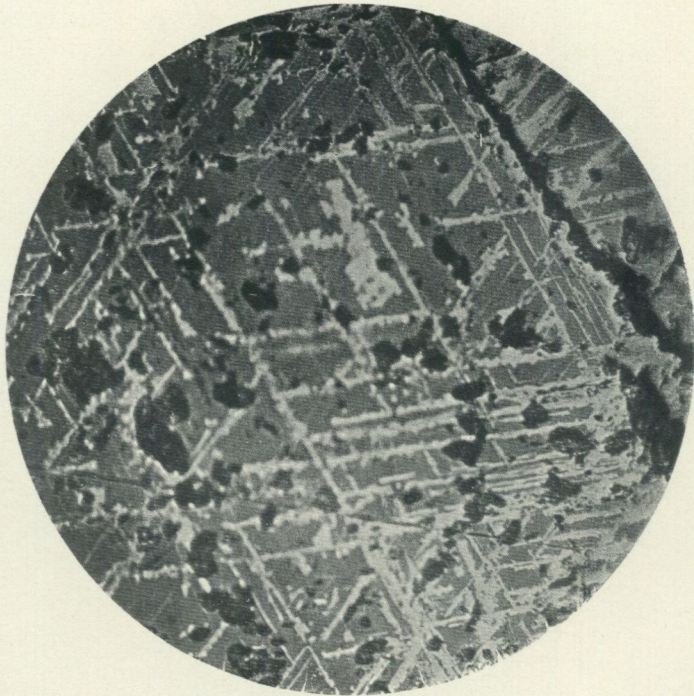


Fig. 23. Magnetite, partly martitized along the octaeder faces. Polished section, $\times 200$. Värmland-Taberg, parish of Nordmark. (After N. H. Magnusson.) One of the ores in the Taberg field has been weathered down to about 110 m depth. In the weathered ore magnetite grains more or less altered to martite occur in a mass of goethite and antigorite. Martite has been found near the surface in several iron ores in Central Sweden. Deep weathering has been found only in a few occurrences, however.

An impregnation zone with hematite and magnetite runs in the Idkerberget mines parallel to the amphibolite zone in which the apatite ores are enclosed.

The author's estimation of the resources of apatite iron ores in central Sweden is 164 million metric tons with an iron content of 94 million metric tons. The average iron content should thus be 57 % Fe. It varies, however, from about 45 % up to about 63 %. The Export field ores in Grängesberg have on average 60 % Fe. The phosphorus is high and varies from 0.52 % up to 1.30 % P. Apatite concentrations with about 9 % P are mined in the Export field.

Of the *post-Archaeon history of the ores* we know very little indeed. The very long continental history of the region, before the events of the Quaternary Ice Age, can now be traced only in those few deposits, where pre-Glacial weathering had gone down to unusual depths, so that its "roots" have been saved from erosion in Glacial and earlier times. The best cases are certain limestone- and skarn-ores, changed to a mixture of limonite and martite and passing downwards, through a zone of decreasing martitization, into unaltered magnetite ore.

It has been found that the limonite, or at least most of it, originated from the oxidation of secondary siderite. This siderite apparently indicates a downward transport of iron from the upper parts of the ore bodies, where weathering under reducing conditions had dissolved iron; later, surface waters percolating downwards more or less completely oxidized the siderite to limonite and parts of the remaining magnetite to martite.

Siderite appears as especially large masses in the Mossgruvan mines. In the other mines with soft ores siderite appears only as remnants in limonite ores. It is quite clear that siderite has metasomatically replaced calcite in the limestones and in the original limestone-magnetite ores. Contemporaneous with this alteration the alteration occurred of leptites, granites, and diabases to kaolin. In the granite dikes the quartz grains are often preserved. Silica has, however, on a relatively large scale been dissolved as colloids, transported downwards, and deposited as opal and chalcedony. In the Mossgruvan mines the deposition of these minerals has gone deeper downwards than the formation of siderite and appears even in the massive ore underneath the soft ore.

This first stage is the type of weathering that is known to take place under bogs and swamps. The oxidation weathering, on the other hand, points to other conditions, resulting in a better aeration of the sub-soil. There must have been a considerable precipitation, but this may have been very unevenly distributed through the seasons.

The martitization has followed the octahedral faces as well as the fissures and the surfaces of the magnetite grains. At the same time limonite replaced siderite and later on also martite and magnetite. In the Stollgruvan mines there appears a martite zone between the limonite ore and the unweathered ore, which here is a manganiferous magnetite ore. The formation of limonite must here be somewhat younger than the formation of martite.

Siderite and limonite formed in such cases, when manganese in significant amounts appears in the original ores, have taken up more manganese in comparison to the proportion between manganese and iron in the original ores. In the Mossgruvan mines the original ores had between 0.5 and 3.0 % Mn. In the soft ores amount is always about 3 % Mn. In the Stollberg mines the amount has risen from about 4 % Mn and can locally be more than 20 % Mn.

The Sulphide ores of the Falun type

The leptite complex is, as has been mentioned before, strongly folded. It was in connection with this folding that the intrusion of the older granites occurred. These granites constitute a differentiated series with grey oligoclase-granites, red-grey intermediate granites, and red microcline-granites. In the north-eastern part of Central Sweden, the older granites are the dominating rocks and the leptite formation with its limestones and iron ores only occurs as remnants in the granites. In iron ores and limestones in such remnants we often find impregnations of pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena, and the limestones are to a large extent altered to skarn. The remnants are usually situated in their original positions, and it is clear that the granites have come as solutions and have assimilated most of the leptite complex to get room.



Fig. 24. Mica schist with cordierite individuals (weathered and dark in the photograph). Nedre Skärsjön, Riddarhyttan. (After P. Geijer.) In this region the cordierite-bearing and locally also almandite-bearing mica schists appear over an extensive area, and the metasomatic alteration has gone over large parts of the already existing sedimentary iron ores forming new minerals and among them sulphide minerals, such as chalcopyrite and cobaltite.

Towards the west the granite runs out into lobes and smaller isolated granite-bodies, where the granite is purer in its consistence and has a more intrusive behaviour with sharper contacts. In this part of Central Sweden the zinc and lead deposits of the Falun type are situated.

As has been mentioned before, solutions from the crystallizing granites have altered the volcanic rocks in smaller or larger areas to mica schists and ore quartzites rich in such minerals as cordierite, almandine, andalusite, gedrite, anthophyllite, and cummingtonite. The solutions also carried iron, copper, zinc, and lead, and deposited them in the form of sulphides such as pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. Also small amounts of silver and gold followed the solutions. Silver has been deposited essentially in galena and gold as native gold.

The sulphides were deposited in places where the tectonic or other conditions were suitable, especially in limestones and in silicate rocks bordering the limestones. In some deposits, such as Sala and Kaveltorp, the sulphides occur only in the limestones, in other places they appear also in the ore quartzites and the mica schists or in fissures or along tectonic lines. Where the sulphides appear in limestones these rocks are altered more or less completely to dolomite and the dolomite is then more or less altered to opicalcite and to skarn, consisting

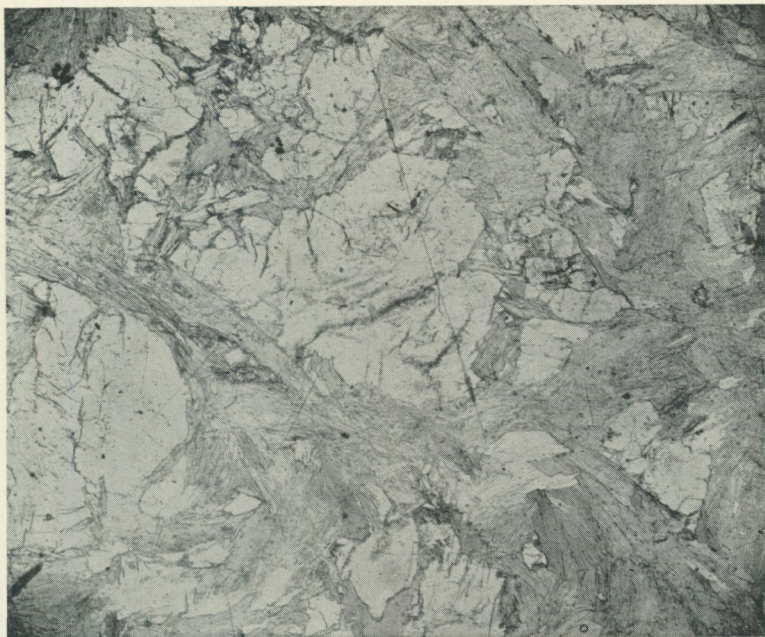


Fig. 25. Cordierite-gedrite-quartzite. Thin section $\times 10$, ord. light. Kaveltorp mines, parish of Ljusnarsberg. (After N. H. Magnusson.) The ores in these mines were zinc-lead ores of the Falun type. Such quartzites often also contain almandite, andalusite, sometimes staurolite, too. Between the ore quartzites and the unaltered lepite there usually appear mica schists with the same characteristic minerals.

of such minerals as tremolite, actinolite, diopside, anthophyllite, cummingtonite, humite minerals, forsterite, serpentine, and talc. Usually sphalerite and galena appear in skarn and dolomite. Only at Garpenberg the bulk of these minerals appears in the quartzites and the mica schists and at Saxberget, the richest ores appear in a straight fissure bordering the strongly folded dolomite—skarn body in the north. At Falun zinc and lead occur both in the limestones and in the ore quartzites.

The boundary between the skarn-dolomite ore bodies and the surrounding ore quartzites is often marked by rocks in Sweden called "sköls", consisting of biotite, chlorite, and talc in varying proportions together with amphiboles, such as anthophyllite, gedrite, cummingtonite, or hornblende as well as almandine or cordierite. From these bordering sköls other similar rocks go out along fissures in the surrounding quartzites. Where the bulk of the sulphides appears in the ore quartzites and the mica schists, as at Garpenberg, the ores often occur in such sköls and the whole ore-bearing area is here interwoven with thin zones of such rocks often branching or forming a network. Often the various ore bodies are connected by sköls. These sköl-zones were the highways for the ore-bearing solutions.

Along tectonic lines, where more material could be concentrated, compact and



Fig. 26. Ophicalcite. Serpentine pseudomorphs after humite minerals in dolomitic limestone. Nat. size. Stålklockan mine, Riddarhyttan. (After P. Geijer.) Ophicalcite is common in the limestone-dolomite remnants in the sulphide ores of the Falun type and also frequent where the same metasomatic alterations have gone over older iron ores appearing in limestones and dolomites.

richer ores appear, such as the fissure ore at Saxberget. In such ores there occur plenty of rounded pieces of the surrounding rocks indicating that the ores were deposited during intense movements in the rock masses. These compact "ball-ores" are also very fine grained and strongly "durchbewegt". Such ores also appear in other deposits, especially at Garpenberg. A structure resembling these ores often occurs in other deposits in places where the ores are compact and well concentrated. These observations clearly show that the sulphide ores have been precipitated during the folding processes and that the ores are concentrations in suitable places from solutions coming from the crystallizing granites.

In the Norberg region there are even in some places intimate connections between granite lobes and metasomatically formed quartzites.

In the *Falun mines*, there is a large rounded, central, compact ore body, essentially consisting of pyrite and smaller amounts of chalcopyrite, pyrrhotite, sphalerite, galena, and magnetite. In some parts of this compact ore there are remnants of dolomite often altered to ophicalcite and the dominating skarn mineral is tremolite. In other parts there are remnants of ore quartzite and the dominating skarn mineral is cummingtonite or anthophyllite. Towards south-east this ore body runs out in a narrowing lobe, which together with the rounded central ore body is surrounded by a sköl zone up to 30 m in width. To the south-west, nearly unaltered rocks (leptite and limestone) appear in the immediate vicinity of the sköls. In other directions they are surrounded by ore quartzites which pass outwards into mica schists. The ore quartzites are intersected by fissures along which there have occurred alterations to sköls, often containing concentrations of chalcopyrite. Even in the ore quartzites themselves there are here and there relatively large areas with chalcopyrite and some pyrite, forming spots and veins. In the ore quartzites there have been found small skarn-dolomite bodies with chalcopyrite, pyrite, sphalerite, and galena, but these are insignificant in comparison with the compact central ore body.

Amphibolite and quartz-porphry appear in composite dikes with amphibolite as border zones. Besides there are also independent amphibolite dikes. The sulphide-forming processes are younger even than these dikes, which here and there have been altered, the hornblende for example being replaced by grünerite. The dikes were also strongly deformed before the magnesia-metasomatism began its work.

The ores in the Falun mine contain on an average 30 % S, 4 % Zn, and 1.5 % Pb.

In the *Garpenberg mines* sphalerite and galena together with pyrite, pyrrhotite and chalcopyrite appear to a greater extent than usual in the ore quartzites and mica schists. Where the minerals have been more concentrated, there appear narrow strings (on an average 1 to 2 m wide) of compact ore with rounded pieces of the surrounding rocks. These strings, as all other ores are orientated in the direction of the pronounced schistosity. Also in the network of sköl rocks that intersect the field there are here and there smaller concentrations. This is also the case in the small dolomite-skarn bodies, where the dominating skarn is tremolite, more or less altered to talc.

In these mines large areas of "soft ores" have been found, that is, the original ores have been altered through weathering. Sphalerite, galena and chalcopyrite and other sulphides have been replaced by carbonates, sulphates, hydrates, and silicates. Limonite and kaolin have also been developed.

The weathered ores were separated from the others by a brecciated zone filled with water from the lake above, and it was only after having emptied the lake that the company could extend the investigations into the weathered region. The weathered ores contain 5.2 % Zn, 3.5 % Pb and 0.3 % Cu on an average.

The *Ryllshyttan mines*, are situated in the vicinity of Garpenberg. In these deposits a central rich zinc ore with subordinate amounts of galena and chalcopyrite was surrounded by diopside-garnet skarn with iron ore concentrations. The zinc ore is distinctly younger than the iron ores and their skarn masses and has

been deposited in the central limestone body that remained after the alteration of the iron ores to skarn iron ores. In the zinc ores there are here and there remnants of limestone. The gangue of the rich zinc ores is mainly quartz and fluorspar. Metasomatic alterations can be observed both in the older iron ore skarn, with tremolite, humite minerals, plogopite, and so on as new minerals, and in the leptites, which are locally altered to ore quartzites with cordierite and almandine. Several amphibolite dikes can be stated to be younger than the skarn iron ores, but older than the sulphide ores and the metasomatic alterations following them.

In the *Saxberget mines* there are two different ore types. A straight fissure is filled with a fine-grained compact ore essentially consisting of sphalerite, galena, and chalcopyrite, together with pyrite and pyrrhotite. The ore is "durchbewegt" and contains smaller and larger rounded pieces of ore quartzite, skarn, dolomite, and even of pegmatite. South of the straight fissure a strongly folded limestone body has been altered to dolomite, and this rock then to a large degree replaced by skarn minerals, such as diopside, tremolite, anthophyllite, forsterite, humite minerals, spinel, talc, and serpentine, and against the boundaries chlorite, biotite, and hornblende. In the skarn masses and in some degree also in the dolomite the same ore minerals as in the fissure ore occur, but in essentially lower concentrations, and with very irregular distribution. The leptite surrounding the dolomite-skarn ore body is strongly altered to ore quartzite rich in cordierite and gedrite, often also in almandine. The leptite north of the fissure is on the contrary unaltered. Pegmatite dikes intersect the skarn and dolomite ores. That these pegmatites appear as rounded pieces in the compact fissure ores must have depended upon later tectonic movements younger than the pegmatites, which are clearly younger than the metasomatic alterations that gave us the sulphide ores.

The ores in the *Saxberget mines* contain on average 4.5 % Zn, 3 % Pb and 0.9 % Cu.

In the *Kalvbäcken mines* two small stocklike ore bodies together only 200 m² have been mined down to about 420 m. The interesting feature here is the form of the ore bodies. In both bodies remnants of dolomites occur in such a manner that it is clear that original limestone layers have been deformed in connection with the folding of the leptite formation, the limestone plastically flowing into the folding axes of two folds. In connection with the metasomatic alteration the sulphides were precipitated in the limestones and the ore quartzites surrounding the limestones. The dominating sulphides are sphalerite and galena.

The *Lövåsen mine* has a small, but geologically very interesting deposit. In a limestone body intercalated with thin leptite layers there are skarn iron ores with varying but often relatively high amounts of quartz. These iron ores locally show a good banded structure indicating a sedimentary origin, the skarn minerals having been formed through reactions between the ore layers and the carbonates.

The iron ores, the limestones, and the leptites are intruded by a great many greenstone dikes.

The impregnations with sphalerite and galena are younger than the greenstone dikes and the iron ores intruded by them. They appear in the iron ores, in the skarn masses or in the limestones, and have been formed through metasomatic

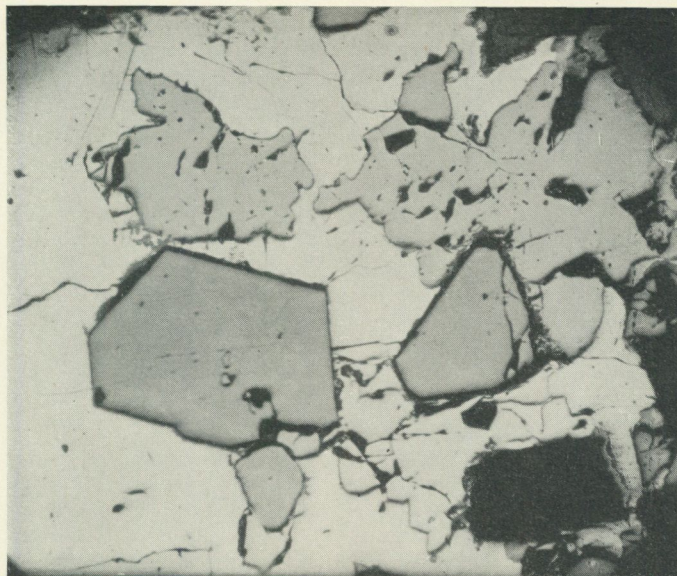


Fig. 27. Magnetite crystals in a groundmass of pyrrhotite (darker grey) and chalcopyrite (white-grey). Polished section $\times 15$. Ljusnarsberg mines. (After N. H. Magnusson.) The sulphide ores of these mines have been formed through metasomatic solutions which have wandered into a limestone body in which an old skarn-magnetite-iron ore existed. Together with pyrrhotite and chalcopyrite also sphalerite and galena are essential constituents of these sulphide ores. It is often a difficult problem to decide whether the magnetite appearing in the sulphide ores of the Falun type has come from old preexisting iron ores or not.

alterations that have given new skarn minerals in the limestones, and have altered the thin leptite layers more or less thoroughly to ore quartzites. The richest ores have been found where the ore-bearing complex has been folded.

The copper ores of the *Ljusnarsberg mines* were found at the beginning of the 17th century, but the zinc and lead ores which appear with the copper ores have been mined only on a small scale. The mining is, however, at present totally concentrated upon such ores, which occur in irregular skarn masses in a strongly folded limestone-dolomite body. The skarn masses consist of tremolite, actinolite, anthophyllite, forsterite, humite minerals, and against the boundaries hornblende, biotite, and chlorite. The boundary itself is marked by sköl rocks with biotite and chlorite, and the surrounding leptites are altered to ore quartzites with almandine, cordierite, and gedrite. Together with sphalerite and galena there appear smaller amounts of pyrite, pyrrhotite, chalcopyrite, and cubanite. The magnetite appearing in large masses here and there may have been derived from older iron ores, which have got a totally new development and have been impregnated by the sulphides named above.

The ores mined in Ljusnarsberg contain on an average 5.5 % Pb, 8.5 % Zn, and 0.5 % Cu.

In the vicinity of Ljusnarsberg the *Kavelltorp mines* are situated. Four strongly

folded and deformed limestone layers have been altered in connection with intense metasomatic processes to dolomite, ophicalcite, and skarn. The most interesting feature here is a distinct zoning, with hornblende and biotite towards the boundaries of the limestones against the surrounding cordierite-gedrite-quartzites, and especially in their narrowing terminations, and with diopside, tremolite, anthophyllite, cummingtonite-skarn in the central parts. In this latter skarn a more Mg-rich mineral always has crystallized later than minerals with lower amount of Mg. The sulphides with iron (pyrite, pyrrhotite, chalcopyrite, and cubanite) are concentrated in the dark iron-bearing hornblende-biotite skarn, sphalerite, and galena on the contrary in the light diopside-tremolite-anthophyllite-cummingtonite skarn. Galena is more usual in the dark skarn than sphalerite, chalcopyrite more usual than pyrite and pyrrhotite in the light skarn. There, thus, has been a separation in fractions in the following order: Fe→Cu→Pb→Zn. The order of crystallization in each fraction has been: pyrite→pyrrhotite→sphalerite→chalcopyrite→galena.

The *Sala mines* produced most of the lead and silver in Sweden before 1920. The ore minerals, sphalerite, and galena, appear together with skarn minerals, particularly diopside and tremolite, in a large dolomite body. The larger and richer ores are always associated with more skarn than the smaller and poorer ones. In connection with the ores, there also appear sköls consisting of talc, serpentine, and chlorite, together with skarn minerals and silica, and often including fragments of dolomite and skarn. It seems clear that these sköls are the old highways for the solutions from which the ore and the skarn have been precipitated. Later, tectonic movements have, however, taken place along the sköl zones.

The dominant potassic leptonite in the *Riddarhytte field* has over large areas been metasomatically altered into cordierite-mica schists, and this alteration has locally reached the iron ores. The quartz-banded iron ores have thus been altered to quartziferous magnetite ores with biotite, cordierite, and almandite. The ore bodies are locally bounded by almandite-quartzite and have been impregnated with pyrite, pyrrhotite, chalcopyrite, cobaltite, and fluorite.

The manganiferous iron ores in the *Dannemora mines* are locally impregnated with sphalerite, pyrite, pyrrhotite, and galena. The same has happened in the manganiferous iron ores in the *Stollberg mines*.

Smaller concentrations of sulphides have been found here and there in the iron-ore-bearing region of central Sweden, usually followed by magnesia-metasomatic alterations. Such alterations are not found as a continuous zone of alteration products but as local smaller or larger isolated areas. The altering solutions must have been driven before the granite front and must have sought their way into such regions where the tectonic conditions have been favourable. The sulphides have been concentrated to areas rich in schistosity planes, fissures, and fractures, to marked fold axes and especially where limestones and iron ores appear in such areas.

The magnesia-metasomatic alterations imply that Ca must have been to a large extent driven out from the limestone bodies simultaneously with an abundant supply of SiO₂. The dolomitization and the formation of ophicalcite and skarn minerals rich in magnesia indicate also an abundant supply of Mg. It is probable that also a certain supply of Fe has taken place. Larger skarn

masses rich in Fe have often been explained as being due to the rearrangement of older iron ores. That the minerals rich in Al in the main appear at the contacts with the leptites seems to indicate that it must have been mainly the feldspars in the leptites that have furnished the necessary quantity of this element. The appearance of humite-minerals and fluorite indicates a considerable supply of F.

The alteration of the leptites to mica schists and quartzites also implies a removal of Ca and alkalis, above all Na, while K to a larger or lesser extent remains bound in the micas. Furthermore, there must have been, as in the limestone bodies, an abundant supply of Mg and a certain supply of Fe while existing Al can be in all essentials the Al of the destroyed feldspars. It is furthermore probable that SiO_2 has been supplied in large amounts in addition to the quantities that already existed in the leptites. A certain amount of F has also been fixed in the quartzites and the mica schists.

The Sulphide Ores of the Åmmeberg Type

In the central part of the Sörmland region all rocks are altered to veined gneisses and interwoven with smaller and larger pegmatite and granite masses orientated in the same direction as the schistosity. In an outer zone the pegmatite and the granite material become more concentrated, and appear as more rounded granite masses and more distinct pegmatite dikes, usually cutting the schistosity at large angles.

The alteration to veined gneisses was caused by high temperature in connection with the directed pressure and by granite emanations and solutions coming from deeper zones in the earth crust, where the palingenic processes were stronger. The whole complex, altered to veined gneisses, acted as a filter causing an increase in aluminium, iron, and magnesium, and a reduction above all in silica and alkalis. The pegmatites and the granites in the intrusion zone above the veined gneisses are concentrated segregation products. The main mass has come from deeper parts of the earth's crust. Partly, however, they must have come from the rocks now accessible for investigation. In connection with these processes several metals have been driven out from the sediments and from older sulphide ores and concentrated outside the front of the veined gneisses (the migmatite front) in the intrusion zone. In this way among other metals also zinc and lead have been precipitated especially where the migmatite front is relatively sharp as in the Åmmeberg Field and on the northern part of Utö in the southern archipelago of Stockholm.

In the Åmmeberg Field the veined gneisses are situated to the south of the ore-bearing zone. Taken as a whole the area of the veined gneisses is of a rather monotonous character, but very heterogeneous, when regarded in detail, with irregular bands and veins of a pegmatitic or granitic character. Pegmatites and granites from this area have been intruded as protuberances into the ore-bearing zone in the north.

The rocks of the southern veined gneisses often also contain cordierite, andalusite, or sillimanite, and were, no doubt, originally argillaceous sediments.



Fig. 28. Strongly folded sphalerite ore resulting from the replacement of fine-bedded leptite of which occasional beds still remain. Ore = grey. Leptite = dark grey to black. Skarn and limestone = white to light grey. Scale 1 : 16. Nygruvan mine, Ämmeberg. Courtesy of Å. Henriques, who is preparing a monograph on the Ämmeberg ore-bearing region.

To the north, the central ore-bearing zone is limited by a homogeneous red leptite rich in potassium. This leptite must be of volcanic origin.

The central ore-bearing zone presents a very great diversity of rock types. The dominating grey leptites are in most cases distinctly banded. This structure is especially characteristic of the border rocks of the ore layers and of the limestone layers, intercalating with the banded leptites. Even in the leptites themselves there is usually a certain amount of calcite and dolomite as thin layers or evenly distributed isolated grains. This amount was originally considerably greater, most of the carbonates having been through reactions with the intruding granitic solutions, and with the surrounding minerals replaced by



Fig. 29. Skarn-banded leptite in the foot-wall of the ore layers. Leptite = dark grey to black. Skarn and limestone = white to light grey. Scale 1 : 10. Nygruvan mine, Ämmeberg. Courtesy of Å. Henriques.

skarn minerals such as diopside, garnet, hornblende, and in the vicinity of the migmatite front, also wollastonite and vesuvianite. These minerals in the skarn-bearing zones are mixed with quartz, microcline, andesine, or labradorite and zoisite, or epidote as alteration products of the plagioclases.

Intercalated with the limestone and skarn layers of the banded leptites there are also more gneissic rocks rich in biotite and with a low amount of cordierite, andalusite, and sillimanite. These rocks were undoubtedly sediments rich in alumina. The banded leptites with their high content of feldspar were probably ash tuffs, intercalated with limestones and mixed with limestone material.

Sulphide minerals, pyrrhotite, sphalerite, and galena, are finely disseminated

throughout the grey banded leptites of the central belt, and are here and there more concentrated in layers most suitable for their precipitation. In most cases the skarn minerals and the sulphides appear in the same layers in a manner indicating that they have been formed by the same process.

The intensity of the sulphide precipitation and the skarn-forming processes increases in a high degree in the southern part of the central belt against the migmatite front and it is only here that ores rich enough in zinc and lead for mining appear.

The migmatite front coincides with the southernmost calcareous layer. This layer has been impregnated with pyrrhotite, appearing with a small amount of skarn minerals in the gneissic rock. North of this pyrrhotite-impregnated layer the limestone-banded leptite contains large amounts of skarn especially wollastonite and diopside, together with smaller amounts of the other minerals named above.

Immediately north of the wollastonite zone or separated from it by a thin layer of grey leptite the main zinc and lead ore layer is situated. It begins with a skarn layer essentially composed of pyroxene with some garnet, hornblende, and mica, and remnants of limestone. In this skarn layer pyrrhotite, which does not occur in the zinc and lead ore itself, has been precipitated with some pyrite, sphalerite, and galena.

The zinc and lead ores appearing immediately north of this pyrrhotite-skarn zone are impregnations of sphalerite and galena in a delicately banded leptite and the gangue of the ore consists essentially of microcline and quartz, with a variable amount of pyroxene, garnet, and calcite. Also wollastonite and vesuvianite have been found locally in the ore.

The richest ore varieties contain 40 to 50 per cent of zinc, which is the dominating metal. From this all gradations in composition are found, down to ordinary leptite. The ores mined in 1958 had on an average 10.5 % Zn and 1.4 % Pb. In the richest ores there are often remnants of leptite as thin layers or irregular pieces. Even limestone has been found as remnants.

The ore mined at present appears on the large scale as one or two distinct layers. In detail there are, however, many irregularities, and especially in the western part of the field where the ores appear as strongly and irregularly folded, often lens-shaped bodies. Even in the eastern more continuous part, such curvings and foldings are usual. The broadest and richest ore appears in the curved and folded parts, and here also the pyrrhotite-bearing skarn zone in the south is broader than usual. It seems to be clear that the tectonic deformation is older than or contemporaneous with the sulphide-forming processes.

In the ores there is often a distinct zoning with sphalerite towards the migmatite front and galena in the opposite direction.

As mentioned before, granitic and pegmatitic protuberances, coming from the migmatite front in the south, can be seen here and there to intrude in a diffuse manner in the ore-bearing zone. This is especially the case where the richest ores appear. The ores then become more coarse-grained than usual. In the richest ores there have also been found remnants of pegmatites in such a manner that it is quite clear that the pegmatites cannot be younger than the ores. Instead, the observations indicate a close genetic connection between the pegmatites and both the ores and the skarn. The sulphide- and skarn-forming

solutions and the pegmatites have come from the migmatite front in connection with the palingenic processes that altered the rocks in the south to veined gneisses. An alteration in the same direction can also be seen here and there in the central belt, especially in the more gneissic rocks rich in biotite, but the alteration here is much weaker.

The stronger migmatitization here locally stopped against the limestone-banded and calcareous central zone in which the palingenic solutions caused the formation of skarn and the precipitation of sulphide minerals. The precipitation occurred at some distance from the migmatitic front, where suitable rock series were situated and suitable temperatures and pressures existed during the palingenic processes. The tectonic movements surely also played a great role in locating the broadest and richest ores in the folds and in the curved parts of the layer complex.

According to Å. Henriques, who has made thorough investigations in the Ämmeberg Field, it is not quite clear that the author is right in his opinion about the origin of the sulphide ores of the Ämmeberg type. The lack of magnesia-metasomatic alterations, so characteristic for the ores of the Falun type, may depend upon the absence of the conditions precedent for such alterations. The ores may therefore be older than the palingenic processes that originated the veined gneisses. In connection with these processes material with granitic composition has been mobilized and has locally gone into the ores and has taken away smaller parts of the ore layers. In the depth the ores have also been more and more diluted with granitic material, and at last they cease towards the roof of the veined gneisses.

In the vicinity of Ämmeberg, in the *Vena field*, there occur fahlbands with impregnations of cobaltite, smaltite, and chalcopyrite together with pyrrhotite, sphalerite, arsenopyrite, and galena. These fahlbands have been mined for cobalt and copper.

The *Tunaberg copper-cobalt ores* appear in a limestone in a region rich in granites and pegmatites, and granitic material has been mixed with the limestone giving a pyroxene skarn with feldspar, quartz, scapolite, orthite, titanite, and cobaltite and chalcopyrite.

Between Ämmeberg and Tunaberg there are several small fahlbands with sphalerite, galena, and pyrrhotite. Outside of this zone with zinc-lead-copper-cobalt impregnations there are other fahlbands with above all pyrite and pyrrhotite.

On the island *Utö*, in the continuation of the zone from Ämmeberg to Tunaberg, there are zinc-lead ores as fahlband-impregnations in a banded complex of limestone layers and hällflint-layers. The latter layers are ash tuffs often mixed with carbonate material. The ores consist of sphalerite, galena, and pyrrhotite in varying proportions and in connection with the sulphide invasion the limestone and the limestone-bearing hällflintas were altered to skarn essentially consisting of diopside, tremolite, and scapolite. The migmatite front is situated north-west of the ore-bearing zone, and this front has, as in the Ämmeberg Field, been stopped by the boundary of a limestone-rich, markedly banded complex, into which the solutions and emanations that carried material for the formation of skarn and sulphides continued. The sulphide-impregnations have with the outermost offshoots reached the skarn-bearing jaspilite-iron ores

of this island. Above all, in these ores and near them, the sulphides mentioned above have been accompanied by chalcopyrite, pyrite, chalcocite, arsenopyrite, and bornite. Fahllands with sparse impregnations of pyrite and pyrrhotite appear north of the zinc-lead ores.

The Scheelite and Molybdenite Ores of Central Sweden

The younger, late orogenic granites rich in quartz and microcline which appear outside the veined gneisses are, in my opinion, dome-shaped offshoots on the top of underlying veined gneisses. In these young granites and in pegmatites accompanying them such minerals as molybdenite and scheelite together with fluorite have locally been found here and there in central Sweden but only in low amounts.

In the region south-west of Grängesberg, however, in the *Yxsjö mines*, relatively large concentrations of scheelite have resulted in limestones in such positions that pegmatite materials from an underlying granite could find their ways into the limestones, which have for the greater part been replaced by a chaotic mixture of pegmatite, skarn, ore minerals, and fluorite. Both quartz and feldspar appear in large amounts, sometimes as pegmatitic masses. The feldspars are partly microcline, partly a relatively acid plagioclase. The skarn minerals are hedenbergite, garnet rich in grossularite, and an amphibole rich in alkali and iron. Often one of these minerals dominates. In other spots they are mixed together in varying proportions. The skarn- and pegmatite-minerals have often grown to large dimensions. Quartz and hedenbergite specimens more than one metre long have often been found. These large specimens have also often good idiomorphic crystal forms. The amount of fluorite is high, about 5 %.

The economically most important mineral, the scheelite, constitutes only a small part of the skarn-pegmatite masses. The amount of scheelite corresponds to 0.3—0.4 % WO_3 .

In the skarn there are often relatively large amounts of sulphides, above all pyrrhotite, but also some chalcopyrite and pyrite. The ores were in older times considered as copper ores. Since scheelite was discovered they have been considered as scheelite ores, from which, as a by-product, chalcopyrite concentrates have been produced.

It is worth mentioning that small amounts of magnetite, apatite, and titanite appear in the ores and that an older iron ore with actinolite-skarn has been found. This ore is not accessible at present. But it is clear from older observations that this iron ore and its skarn is older than the amphibolite dikes. These are on the contrary older than the scheelite-bearing skarn and pegmatite masses.

In the *Hörken mines*, nearby, there was found, in connection with exploration works, the same hedenbergite-garnet-amphibole skarn. This is mixed with pegmatite minerals (quartz, microcline, and plagioclase), a high amount of fluorite and pyrrhotite, as well as small amounts of pyrite and chalcopyrite. Besides, these masses contain small amounts of both scheelite and molybdenite. The



Fig. 30. Scheelite (the large white crystals below in the figure) in hedenbergite-skarn rich in fluorite 4/5 natural size. Yxsjö mines, parish of Ljusnarsberg. (After N. H. Magnusson.) The ores in this mine can be characterized as a chaotic mixture of pegmatite minerals (quartz, plagioclase and microcline) and skarn minerals (garnet rich in grossularite, hedenbergite, and amphibole rich in iron and alkali). In this mixture scheelite and some sulphide minerals appear together with a high amount of fluorite.!

amounts of these minerals correspond to 0.10 % MoS_2 and 0.08 % WO_3 . As the areas were small these occurrences were not considered worth mining.

It is interesting to note that two older ore types were found, namely, a skarn-banded iron ore and a sulphide ore of the Falun type with galena and sphalerite in limestone, ophicalcite, and tremolite-diopside skarn. Both these ore types are intersected by several amphibolites (metadiabases) in such a way that they and their skarn minerals must be considered as older than the amphibolites. These are on the contrary strongly influenced by the scheelite-molybdenite-bearing skarn pegmatite masses which must be younger.

Field guide

The excursions will start in Stockholm on August 6th and 26th with departure by bus via Enköping—Sala—Krylbo for *Norberg*. (Address: Bergmansgården, Kärrgruvan).

August 7th and 27th. After breakfast demonstration of rocks and ores of the Norberg region: leptites, mica schists, granites, diabases, quartz-banded iron ores, skarn iron ores poor in manganese, and manganiferous iron ores. Visits in the Nygruvan mine on 155 m level with quartz-banded hematite iron ores and in the Bondgruvan mine on 190 m level with quartz-banded hematite iron ores in part altered into a skarn-magnetite iron ore rich in talc and with remnants of quartz-banded iron ores. The adjoining leptites are altered to mica schists and to quartzites with cordierite, gedrite, and almandite.

After lunch a visit in the Kallmorberg mine on 230 m level with quartz-banded hematite iron ores passing into a banded series with dolomite, skarn, magnetite, and quartz in varying proportions, locally even hematite and skarn-magnetite iron ores with remnants of quartz-banded hematite iron ores. Visit to Åsgruvan open pit with skarn-magnetite iron ores. Visit to Klackberg and Kolnberg with manganiferous magnetite iron ores.

August 8th and 28th. After breakfast departure by bus via Hedemora to *Garpenberg*. Demonstration of leptites, cordierite mica schists, amphibolite dikes, dacitic and andesitic leptites, granites of different types, spilites, agglomerates.

After lunch a visit in the Garpenberg mines on 260 m level with all transitions from leptite to mica schists and quartzites containing such minerals as cordierite, gedrite, andalusite, almandite, and staurolite. In schlieren of coarse-grained quartz occur pyrite and chalcopyrite together with fluorite. The muscovite and biotite in the mica schists are often concentrated in "schlieren". Sköls of biotite and chlorite form a real network in the mica schists. Such sköls also appear at the contacts of the carbonate bodies, which have been altered to dolomite, opicalcite, and skarn, especially tremolite, humite minerals, and serpentine. The dominating ore minerals, sphalerite and galena, appear both in the carbonate-skarn bodies and in the mica schists together with subordinate amounts of chalcopyrite. Chalcopyrite alone has been mined in the Överberget ore type. The Rödgruve type is rich in pyrite and pyrrhotite. The Latvind type is a "durchbewegt" ball ore.

The weathered ores will be demonstrated on the 110 m level.

After dinner, departure by bus to *Falun* (Address: Grand hotel, Falun).

August 9th and 29th. After breakfast a short demonstration of the geology of the region. Visit in the mine on the 145 m level with leptite, mica schists, quartzites with cordierite, gedrite, and almandite, the great sköl at the contact of the ore body. This sköl consists of talc, chlorite, anthophyllite, and tremolite in varying proportions. Pyrite ores with sphalerite and galena, sometimes also pyrrhotite and magnetite and subordinate amounts of chalcopyrite. Some ores are localized in the old carbonate bodies and contain remnants of dolomite, and are accompanied by opicalcite and skarn minerals, especially tremolite, others are localized in quartzite and accompanied by anthophyllite and cumingtonite and concentrations of quartz. The copper hard ores are schlieren

and spots of chalcopyrite in quartzite together with very small amounts of the other ore minerals. They occur outside the great sköl.

Visit on the 65 m level. Demonstration of some old parts of the mine. After lunch a visit to the museum and then demonstrations in the open pit and a short excursion to the Näverberget and Skyttgruvan mines.

August 10th and 30th. After breakfast, departure by bus via Borlänge, Domnarvet, Idkerberget, and Ludvika to *Grängesberg*.

After demonstrations in the museum a short excursion in the field. Leptite with marked linear structure, olivine-diabase (dolerite), granites, pegmatites, and dacite-andesite dikes will be demonstrated.

After lunch a visit in the mines with magnetite-apatite-iron ores and hematite-apatite-iron ores, intersecting dacite-andesite dikes, pegmatite dikes, and alteration of hematite to magnetite at the contacts between pegmatites and hematite ores, concentrations of apatite towards the hanging wall, impregnation ores in the red leptites in the foot wall.

After dinner departure by bus to *Kopparberg* (Address: Laxbrogården, Kopparberg).

August 11th and 31st. After breakfast, by bus to *Mossgruvan* mine. Demonstration of the banded limestone iron ores in Sköttgruvan and the soft ores in Mossgruvan with siderite ores and magnetite-martite-siderite ores with subordinate amounts of limonite and silica in the form of chalcedony and opal.

After some refreshments departure by bus to the *Ställberg* mines. Visit on the 750 m level. Demonstration of the skarn-bearing limestone-banded leptite complex in the foot wall of the ores and a profile through the ore body. The ores are manganiferous with manganese in the form of carbonate and knebelite and sometimes even dannemorite.

After lunch, departure by bus to *Yxsjön*. Demonstration of the ores and their minerals: Scheelite and some sulphides such as pyrite, chalcopyrite, and pyrrhotite in a chaotic mixture of pegmatite minerals (quartz, microcline, and plagioclase) and skarn minerals (garnet, hedenbergite, and amphibole), fluorite, and remnants of limestone. The surrounding rocks are leptites. The ores are younger than the greenstone dikes (meta-diabases).

Departure for *Kopparberg* again. Dinner at Laxbrogården hotel.

August 12th and 1st September. After breakfast departure by bus to *Stripa*. Visit in the Stripa mines on 310 m level. Demonstration of the double-banded hematite iron ores with 4—7 cm thick hematite bands and 3—4 cm thick quartz bands, both the hematite bands and the quartz bands exhibit interior stratification. The simply-banded ores have hematite and quartz bands of approximately the same thickness, about 0.2 to 0.5 cm. Between these two ore layers there appears a thin leptite layer. The quartz layers are in varying degree replaced by skarn minerals (actinolite and diopside, more seldom epidote or garnet). The ores sometimes pass into rich magnetite ores with low amounts of quartz.

Demonstration of the leptites, the younger granite, and of the unusually clear tectonic features. Uranium minerals such as uraninite, libergite, anderssonite, and schrókingerite appear along fissures within a small area on this level.

After lunch departure by bus for *Stråssa*. Visit in the mines on the 80 m level.

Demonstration of the varying ore types: Quartz-banded magnetite ores with or without hematite, in part skarn-banded; quartz-banded hematite ores with subordinate magnetite, in part skarn-banded; inhomogeneous hematite-magnetite ores with varying mineral proportions, sometimes with "schlieren" and sköl structures and the banding more or less destroyed, and lastly, skarn iron ores with remnants of banded ores.

Demonstration of the tectonic features, which are much more complicated than in the Stripa mines.

After dinner, departure by bus for *Örebro* (Address: Stora hotellet, Örebro.)

August 13th and 2nd September. After breakfast, departure by bus for Zinkgruvan, *Ämmeberg*.

After arrival at the mine a short demonstration of the geology of the region will be held at the office. Visit in mine on the 500 m level, where a section through the ore-bearing zone will demonstrate migmatite, grey leptite impregnated with pyrrhotite, grey leptite, skarn-banded leptite, skarn, main ore, grey leptite, parallel ore, and grey leptite in the order mentioned. The ores will also be studied at some higher level.

After lunch departure for *Kantorp*. Visit in the Kantorp mines. Demonstration of the ore types: The pegmatite-iron ores, the skarn-pegmatite iron ores, and the quartz-anthophyllite ores. These ores are alteration products of quartz-banded iron ores developed in connection with the alteration of the surrounding rocks to veined gneisses containing anthophyllite and cordierite.

After the demonstration, departure for Stadshotellet, *Katrineholm*. Dinner and lodgings for the night in this hotel.

August 14th and September 3rd. After breakfast, departure by bus for *Stockholm*. Demonstration of some outcrops of veined gneisses.

Lunch in Stockholm.

SWEDEN

Guide-book h

Key map, see inside of this cover

PRINTED IN SWEDEN

Price 6 Sw. crowns