SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 643 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 63 NR 6

NILS H. MAGNUSSON

THE ORIGIN OF THE IRON ORES IN CENTRAL SWEDEN AND THE HISTORY OF THEIR ALTERATIONS

PART I: TEXT

STOCKHOLM 1970

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"THE HISTORY OF THE IRON ORES IN CENTRAL SWEDEN IS IN REALITY THE HISTORY OF THEIR ALTERATIONS"

HJALMAR SJÖGREN (1906)

WITH ONE MAP IN TWO SHEETS INSIDE BACK COVER
AND
293 FIGURES FOLLOWED BY INDEX IN A SEPARATE VOLUME

STOCKHOLM 1970

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PREFACE

The present book in the first hand gives a survey of the iron ores in Central Sweden, their genesis and alterations. I began my investigations of these ores in 1920. Under the aspects given in my book lies a continuous work during fifty years including chiefly my own investigations in many parts of the iron ore regions in Central Sweden, upon which is also based the essential content of facts presented. In addition, I have used investigations made by many other geologists, above all P. Geijer and N. Sundius. Sundius' description of the rocks in the Grythyttan field has been of fundamental importance for the interpretation of the genesis of the hälleflintas and leptites, in which all the iron ores of Central Sweden appear. Moreover, Geijer's papers on the magnesia-metasomatic alterations and the sulphide ores of the Falun type have been of greatest importance. Concerning the iron ores, Geijer's works about the well-preserved quartz-banded hematite ores of the jaspilite type have been of considerable value.

Geijer's and my monograph on the geology of the ores of Central Sweden published in 1944 has been of great importance, especially as it includes our complete knowledge at that time on all small and big mines in Central Sweden. However, many questions regarding the alterations of the primary iron ores could not be answered in this book. Consequently, I have afterwards concentrated upon these alterations in various parts of the region during all available time..

S. Hjelmqvist's and G. T. Lindroth's contributions to the monograph of 1944 have been very useful for the present book. Hjelmqvist's investigations on the geology and iron ores of the Striberg and Norrbärke areas are worth special mentioning.

Among papers published after 1944 I have in the first hand collected data from Å. Henriques' Åmmeberg monograph, H. J. Koark's investigations on the Stråssa and Falun ores, P. H. Lundegårdh's discription of the Hofors-Torsåker ore field in Gävleborg County and N. Pilava Podgurski's report on Utö in the southern Stockholm Skerries.

During fifty years I have been able to study most iron mines of Central Sweden both as a scientist and a consultee to various mining companies. I could then compare the results arrived at by other geologists with my own experience, and I could also make numerous new investigations.

Because the present book in the first hand has been written for foreign geologists, I have used many pages for descriptions of the rocks around the ores as well as their alterations. Furthermore, it has been necessary to include in the book a review of the sulphide ores of Central Sweden, especially as many of these have been developed simultaneously with the magnesia-metasomatic alterations in the iron ore-bearing areas and most frequently appear together with iron ores.

I have considered it very important to illustrate the data and aspects given in this book as plentiful as possible. In order to make the 293 illustrations easily accessible, they have been collected in a separate volume. Most maps have been taken from Geijer's and my monograph of 1944, though many of them have been revised. Mrs Elisabeth Björk has made these revisions and also drawn a great number of new illustrations in an excellent manner. The bulk of photos have been collected from older publications, and only few new ones have been added.

Dr. Per H. Lundegårdh, Chief Editor of the Geological Survey of Sweden, has spent much time on revision of the text and has also made the layout of the book. Without the assistance given by Dr. Lundegårdh and Mrs. Björk I do not think this book should have appeared in print.

Stockholm October 28th, 1969.

Nils H. Magnusson

CONTENTS

A Short Introductory Survey of the Geological History of Central Sweden in Svecofennian Time

(MAGNUSSON 1960 b)

The Svecofennian epoch began with the formation of supracrustal rocks – volcanics and sediments. The dominating volcanic rocks are known as leptites and hälleflintas, the difference between them being in the grade of metamorphism, the hälleflintas having dense and the leptites fine-grained, recrystallized groundmasses. The leptites are in effect more or less metamorphosed hälleflintas and were, to use international terms, rhyolitic lavas and corresponding volcanic sediments (tuffs and agglomerates).

The predominating acid leptites vary from potassic to extremely sodic types, quartz-keratophyres. Intermediate rocks are subordinate. The leptites and hälleflintas 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-hälleflinta complex, are unknown in comparable quantities in other parts of the world. The lavas and tuffs of the leptite-hälleflinta type also include dacites and andesites but in inferior amounts.

Intercalations of limestone and dolomite are common in the leptites and hälleflintas. They appear as layers or lens-shaped bodies and vary from limestones poor in magnesia to dolomitic limestones and dolomites. By thermal metamorphism the limestones and dolomites have been altered to crystalline rocks (marble). The impurities have given rise to new minerals, particularly calcium-magnesium bearing silicates.

The iron and manganese ores in Central Sweden always occur in connection with the volcanic rocks and never in the true clastic sediments which form an upper division. After the volcanic period in which the hälleflintas, limestones, and dolomites as well as the 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 best preserved parts of the slates display original clastic structures. The predominant rock in such areas is light grey or greenish grey in colour and similar in chemical composition to typical post-Precambrian 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 slate there sometimes appears a dark slate rich in graphite and pyrite and resembling the post-Precambrian alum shales.

In the greywacke-slate division and sometimes also below it, in the upper part of the volcanic division, there occur effusive greenstones of basaltic composition. These rocks have been developed as scoriaceous breccias, less commonly as lava flows rich in amygdules. The infilling of the vesicles as well as the cement of the breccias usually consist of calcite. These greenstones include true spilites and keratophyres together with rocks with more calcic plagioclase. They 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 hälleflinta regions have the structure and mineralogical composition of saussurite-diabases.

In the lower, volcanic division dikes of hälleflinta as well as dacite-andesite and greenstone dikes have been found, and in some mines greenstones appear flanking hälleflintas in composite dikes.

The supracrustal complex ought to have been originally horizontal or nearly horizontal. It was later intensely folded, and the strata now usually show high 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 more accentuated topography, the sediments of the Larsbo series in southern Dalecarlia and the Mälar series around Lake Mälaren seem to have been deposited. These sediments show stronger variations in grain size and composition than the previously mentioned sediments belonging to the Grythyttan series. In the Larsbo series quartzites are also common.

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

It is often uncertain whether the linear structure, which is characteristic for great parts of the ore-bearing region, is entirely due to the main folding. In some areas with high dips it may have been formed by later movements along schistosity planes. In such cases the stocks usually have higher dips than the original foldaxes.

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 Svecofennian synorogenic or syntectonic granites. There is often conformity between the contacts of these granites and the parallel structures of the supracrustal rocks, indicating that the granite magmas intruded the supracrustal rocks along schistosity and bedding planes. Over large areas, however, the synorogenic granites brecciate the orebearing formation and its limestones, dolomites and ores. In the northeasternmost part of this formation the synorogenic granites greatly predominate, the supracrustal rocks appearing only as larger and smaller remnants. The synorogenic granite group is differentiated into grey oligoclase-granites (tonalites), intermediate granites (granodiorites) and red microcline-granites (granites proper). The intermediate granites are most frequently "augen" granites. Gabbros and diorites are forerunners to these granites.

The synorogenic granites caused the thermal metamorphism, and by a merging of the aureoles this metamorphism became regional. It was by a combination of folding, pressure and thermal metamorphism of varying intensity that the highly varying grain-size, mineralogical composition and structure of the volcanics and sediments in the ore-bearing region originated. The slates, for instance, which in the best preserved regions consist of quartz, plagioclase, sericite and chlorite, have been altered by thermal metamorphism to quartz-biotite rocks rich in cordierite, andalusite and sillimanite. The hälleflintas have, at the same time, lost their original groundmass structures and are now granoblastic with or without preserved phenocrysts.

Solutions from the advancing granites altered the volcanic rocks over both small and large areas to mica-schists and quartzites rich in such minerals as cordierite, almandite, andalusite, gedrite, anthophyllite, and cummingtonite. The solutions ought to have been rich in silica and magnesia and have been responsible for the magnesia-metasomatic alterations, which have played an important role in the iron ore regions of Central Sweden. These alterations are especially connected with the sulphide ores of the Falun type. The magnesia-metasomatic solutions were driven in front of the granites and the material was taken from the rocks which the granites replaced.

In the intra-orogenic period that followed, the folded supracrustal rocks and the synorogenic granites were intruded by basic magma forming numerous greenstone dikes. From a mineralogical point of view these are amphibolites, but here and there an ophitic texture has been traced indicating that the greenstones have been originally diabases.

There followed a regional sinking over large areas, whether orogenic or epeirogenic is not known. Accordingly, great part of the bedrock of Central Sweden descended to depths where palingenic processes predominate. Whith 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 and contain 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. These include sediments, leptites, iron ores, synorogenic granites 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 hand with the vein pegmatites and with the younger palingenic granites of the Fellingsbro–Stockholm group on the other. The author regards these late Svecofennian granites as palingenic products formed by a selective fusion of preexistent rocks with or without the help of squeezing. They are rich in both silica and potash and are unaccompanied by more basic rocks, whereas the synorogenic granites are differentiated and accompanied by gabbros and diorites. The synorogenic granites are hardly ever accompanied by pegmatites in the same way as the palingenic granites. The intrusive pegmatites are usually rich in silica and potash like the palingenic granites but the compositon 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 associated granites ought to have come from deeper zones where more complete fusion occurred.

I have also come to the conclusion that intense pneumatolytic and hydrothermal alteration preceded the intrusion of the pegmatites and the palingenic granites. The alteration involved solution of the most soluble substances and enrichment in the stablest constituents. In this case there was a reduction of silica, alkalies, and lime and an increase in alumina, iron, and magnesium originating minerals such as cordierite, andalusite, sillimanite and almandite. The same alteration occurred even in the slates, gving these a higher percentage of the minerals just mentioned as compared to normal ones. The slates, therefore, cannot have been the only source of the components enriched in the gneiss complex, and the latter ought to have acted as a filter during the process of alteration.

That large amounts of pneumatolytic and hydrothermal solutions passed through the gneiss complex, as indicated above, is shown by the character of the iron ores as well as the limestones and dolomites. In the case of the carbonate rocks, large masses of skarn minerals originated by exchange with the surrounding silicate rocks and by addition from pegmatites and wandering solutions. In these limestones and dolomites the skarn minerals occur as irregular spots and strings. Serpentine, olivine, chondrodite, pyroxene, spinel, scapolite and mica are among the minerals present. Such marbles have not been found outside the regions of the veined gneisses. The alterations in the iron ores in the veined gneisses will be described later.

The granite material passing through the veined gneisses in these filter processes assembled in the roof of the gneiss complex to give rise there to independent granite massifs and associated pegmatites. Rounded massifs of such palingenic granites appear outside and especially north of the veined gneisses. These granites are, in my opinion, offshoots from a zone of veined gneisses at depth.

With the alteration of large parts of the supracrustal rocks to veined gneisses and the formation of the palingenic granites and pegmatites the Svecofennian epoch ended about 1 750 million years ago in Central Sweden (Magnusson 1960 c).

The Rocks of the Grythyttan Region

The Grythyttan region is well-known thanks to NILS SUNDIUS (1923). The results of his investigation will be summarized as follows.

The supracrustal Svecofennian rocks of Central Sweden are best preserved in the Grythyttan field. They can in this field be divided in the following chief stratigraphic divisions: the hälleflintas, the slates and the conglomerates. Of these the conglomerates represent the youngest members and the hälleflintas the oldest.

The hälleflintas are quantitatively the predominant members. They are divisible into two subgroups – the lower division, including dominantly rocks rich in albite, and the upper division, stratigraphically following concordantly above the former and comprising as its dominant components rocks of an alkali-intermediate composition, or rocks extremely rich in potash. Besides the hälleflintas there appears in both subgroups a number of limestone layers, more or less dolomitic, although the larger occurrences are restricted to the upper division. Also the slates are divisible into two stratigraphic divisions, the lower of which, however, is represented only in parts of the field. At the lower boundary of the lower slate, or within this rock, there further appear greywackes which in part form layers of considerable thickness.

The hälleflintas are very acidic rocks predominantly made up of quartz and alkali feldspar or of these minerals combined with minor quantities of dark mica up to about 15–20 % of volume at the most. In the members rich in potash light sericite is frequent and has been secondarily formed at the expense of the microcline. This mica does not seldom to the greater part replace the latter mineral, thus forming sericitic schists. Carbonate (dominantly calcite) is often intermingled in the rocks. In the sedimentary parts of the hälleflintas, calcite in many cases can be proved to be a primary constituent. The named minerals are finely distributed and form dense masses, in which coarser phenocrysts of quartz and feldspar appear in varying amounts.

The hälleflinta rocks are crystalline throughout and no remnants of primary glass remain; on account of the slight structural alteration, however, the primary structural features to a great extent are well preserved, allowing us to recognize the original character with certainty. This is especially the case in the upper division. It can here be stated that the layer complex is made up partly of effusives of rhyolites, partly of tuffaceous sediments, the latter quantitatively predominating. Well distinguishable micropoikilitic structures in the groundmass of the lava rocks have often been found, sometimes combined with the development of reticulating quartz. Varieties of the hälleflintas containing allotriomorphic, dense groundmasses are probably true porphyries and may be interpreted as recrystallized obsidians. In some places the lava-flows are accompanied by coarse breccias with porphyritic material as the dominant inclusion material. Worth mentioning is also the occurrance of spherulitic amygdules with quartz lying in the centre.

The sedimentary hälleflintas of the upper division to the greater part have a rhyolitic composition and then represent recrystallized pure tuffs, laid down *in situ* or somewhat rearranged; the material in the latter case not having been subjected to any perceptible change of composition. Locally, however, and especially in banded parts of the rocks, there appear facies with a higher content of finely and uniformly distributed mica (dark and light) which should be interpreted as derivates from chemical decomposition products. In these cases a partial decomposition through chemical weathering or an intermingling with decomposition products during the transport must be supposed. In the banded parts of the rocks, there also occur layers very rich in fragmental individuals of quartz and feldspar and sometimes containing a greater amount of porphyry fragments. These layers resemble greywackes and evidently in most cases represent the products of normal sorting action. Less common are crystal or lithic tuffs, the groundmass of which is poor in decomposition products.

The microscopical appearance of the hälleflintas in many instances directly confirms the conception of their tuffaceous origin in showing traces of vitroclastic structures in the groundmasses. In other cases somewhat greater fragments of rhyolitic, trachytic or keratophyric rocks have been mixed with the small pumice-particles or are present alone. The dominant part of the tuffaceous hälleflintas, however, shows no traceable relicts of clastic structures in the groundmass; the clastic character of the rocks nevertheless being apparent through the fragmental forms of the phenocrysts. Also by the field works, the sedimentary origin is manifested in those parts where banding is present.

In layers containing chemical decomposition products there are in a few cases found graphite, which on account of its banded arrangement must be derived from primary deposits of organic substance. The graphite-bearing layers occur as bands alternating with limestone, or contain considerable amounts of calcite as a primary component.

The hälleflintas do not seldom contain larger fragments of similar older layers. At several places in the bottom layers of the upper division genuine agglomeratic breccias have been developed by abundant accumulation of fragments. These agglomerates have the character of true explosion products *in situ* or in part redeposited. The material of the inclusions is to some extent porphyritic and to some extent composed of sedimentary hälleflintas. Very often pieces of limestone are intermingled with the hälleflinta inclusions.

Structurally there is some difference between the hälleflintas of the upper and the lower division, the latter in part showing a somewhat coarser crystallinity.

In slides, porphyritic rocks structurally identical with the porphyries in the upper division have been observed, however, and the clastic origin of other examined samples is recognized. The rocks in the lower division as a consequence of the somewhat stronger metamorphism do nowhere exhibit the delicate vitroclastic structural features known from the upper layers. Varieties of the hälleflintas of this division in which the material of the phenocrysts is very richly aggregated have been found here and there. These rocks represent in most cases volcanic tuffs.

Chemically, the hälleflintas of the lower division form a very peculiar type, characterized by the extreme dominance of sodic feldspar. In fact, these rocks do represent the most extreme examples of this kind known from extrusive rocks. The mineral composition of the extremely albitic rocks is made up of quartz and albite with insignificant amounts of chlorite or biotite and some rutile or titanite, magnetite and zircon as accessories. In a minor part of the rocks, the amount of the dark mica is higher, up to some 15–20 % of the volume. The albitic rocks dominate in the greatest part of the lower division.

When plotting the analyses of the hälleflintas of the Grythyttan field in a diagram showing the proportions of the feldspars one finds that they form a long suite along the line of the alkalies from the Ab-corner to the immediate neighbourhood of the Or-corner.

The facts gathered within the Grythyttan field make it evident that the whole complex of hälleflintas displays a huge accumulation of volcanic products deposited rather continuously, although the composition of the products has radically changed during the period of volcanic activity.

The limestones and dolomites are not restricted to any special horizons in the rock sequence, nor are there found any limestone-dolomite beds of general extension in the Grythyttan field. The deposition of the carbonates seems to have occurred at different places during the whole volcanic period, but the largest beds are those laid down in the upper division.

On the southeastern side of the great slate area greywackes form a transition zone of considerable thickness between the hälleflintas and the slates. Similar layers are also found in the lower slate division at other places and locally in the highest part of the hälleflinta complex. The rocks prevailing represent mixtures of clayey decomposition products and fresh porphyritic or hälleflintoid material, the latter being derived from older eroded beds or deposited from contemporaneous volcanic outbursts. The rock material shows a well-sorted condition. The coarser fragmental part has generally been washed out and concentrated in separate bands alternating with dense layers more or less rich in slaty material. By this sorting action the coarser material has been deposited as composite beds separated from the adjoining beds through sharp boundaries, along which erosion of the underlying surfaces is often visible.

The fragmental material consists of feldspars (predominatingly albite) and quartz, small grains of quartz-porphyry, trachyte, keratophyre and quartzite, these rocks all being identical with the various facies of the hälleflintas described and with the fragments occuring in the coarser clastic hälleflintas. Further there are fragments of dense hälleflinta-slate rocks of local origin, produced by the bottom erosion during the sedimentation. In the greywacke zone there are also found rock layers which exhibit typical vitroclastic structures and should be considered as mixed tuffs furnished by contemporaneous volcanic action. These rocks represent the last products of the fading rhyolitic activity in the field.

The considerable greywacke zone indicates the first downwarping of the crust in the synclinal zone and the beginning deposition of slate material on a greater scale. This was followed by a general sinking of the ground upon which clayey material was deposited. The slates followed as a rule concordantly above the hälleflintas. A very evident transition is developed through the greywacke zone. Locally, however, there are traces of some erosion at the bottom of the slate formation. This, however, must be local and insignificant.

The slate first deposited is a dark, generally graphitic and pyrite-bearing rock. This slate lacks in the western and northern part of the field. The dark slate is concordantly overlain by the predominant variety, the lighter greenish gray upper slate. Both members very often show a well-developed banded structure caused by the appearance of pale intercalations richer in quartz and albite than the surrounding rock. Partly, these minerals are very finely distributed; in other cases the grain size is coarser and the fragmental character of the grains is recognizable. The material of the intercalations in these cases corresponds to a fine clayey sand (average dimensions of the fragments 0.015–0.020 mm). To the fragmental components mentioned are in these layers also added coarser scales or particles of muscovite and chlorite which may be of primary origin. Material of this coarser composition plays an important role in the upper slate. In the lower it is restricted chiefly to the lower parts adjoining the greywacke zone.

The dense facies of the upper slate can be interpreted as a derivative of normal clayey decomposition products. An analysed, typical dense upper slate has been calculated to contain 26.58 % quartz, 20.15 % chlorite, 44.05 % muscovite (sericite) and 7.81 % albite. An analysed coarse band has been calculated to contain 34.87 % quartz, 18.94 % chlorite, 19.23 % muscovite (sericite) and 25.06% albite. The composition of a graphitic pyrite-bearing slate has been calculated to 22.50 % quartz, 41.50 % chlorite, 18.01 % muscovite (sericite), 16.14 % albite, 0.13 % FeS and 0.55 % C. The composition shows a peculiar richness in FeO (appearing in the chlorite).

In the graphite-bearing slate there are often found pebble-like inclusions of dense, cherty quartz, interpreted as derivatives from flinty concretions. At some places are found in the dense quartz mass peculiar nodules of graphite-impregnated apatite, possibly representing derivatives of small phosphorite bodies. No recognizable traces of fossils, have been detected in the slates, however.

At the time of the deposition of the lower slate, the rhyolitic volcanic period was followed by the extrusion of considerable amounts of basic rocks of basaltic composition. The epoch of greenstone formation had started still earlier, however, as shown by the appearance of greenstone breccias in the bottom layers of the upper hälleflinta division and by the existence of spilitic inclusions in the greywackes. The greater part of the basaltic magma, however, did not reach the surface but congealed at some depth as concordant sheets or irregular bodies. Basic intrusions are numerous in the hälleflinta complexes but very rare in the slates as well as in the conglomerates. The majority of the basic bodies ought thus to have been intruded before the deposition of the upper slate. The old age of the greenstones is also shown by the presence of pebbles of this rock in the conglomerates.

The extrusive basic rocks in the slate formation have been developed as scoriaceous breccias or lava flows more or less rich in amygdules. The cavities of the vesicles as well as the interstitial mass in the breccias consists predominantly of carbonate. In the breccias from the upper hälleflinta division scoriaceous material is wanting. The inclusions consist of dense or coarser, compact greenstone, sometimes intermingled with sparingly represented fragments of hälleflinta. The intrusive greenstones have the mineral composition of saussurite diabases and are frequently accompanied by acidic quartz-albite-secretions or albite-syenitic rocks poor in quartz. These long in solution remaining fractions of the congealing magma occur as schlieren, dikes or also somewhat larger masses in the greenstones themselves, rarely as intrusions in neighbouring rocks.

After the deposition of the slates the supracrustal rocks were folded and deformed to the present position of the layers. The relations of the conglomerates indicate that the chief features of the present tectonics existed before the development of the conglomerates, though a strong lateral compression in W–E can be shown to have occurred later.

In the western half of the field, the occurrences of conglomerate form a probably somewhat discontinuous zone, about 27 km in length. The relatively young age of the zone is shown by the composition of the pebbles, in which most of the rocks described are represented. The predominant rocks are slate and quartzitic varieties of slate. Upper hälleflinta is also relatively abundant, pebbles of lower albitic hälleflinta on the other hand are uncommon. This indicates a rather superficial erosion of the older layers. Pebbles of granite, older or younger, have not been found. The compression of the conglomerate and contemporaneous compressions in other parts of the field (especially recognizable in the slates) are the last manifestations of orogenesis.

Apart from the conglomerate the same supracrustal rocks and the same stratigraphy have been found over large areas in the iron ore-bearing region of Central Sweden. The iron ores always appear in the volcanic complex. No iron ores have been found in the greywackes and slates resting upon the volcanic rocks, a fact of great importance when discussing the origin of the iron ores.

For the greywacke-slate series of Grythyttan type Swedish geologists usually use the term *Grythyttan series* and for the volcanic complex the term *Leptite-hälleflinta series*. The hälleflintas with dense groundmasses are well preserved only in the Grythyttan field, some parts of the Saxå field and parts of the iron ore districts of Persberg and Långban, west of the Saxå field. Outside these regions they only occur essentially in the Uppsala and Los regions (Lundegårdh 1956 and Th. Lundqvist 1968). Usually the hälleflintas have been recrystallized by regional metamorphism to leptites with more than 0.03–0.05 mm grain size in the groundmass, hence the name leptite-hälleflinta series. The leptites are metamorphosed hälleflintas. In connection with the folding and the appearance of the synkinematic granites the supracrustal rocks became more or less strongly metamorphosed by deformation and recrystallization and by magnesia-metasomatic processes. At the end of the Svecofennian time both the supracrustal rocks and the old synkinematic granites underwent regional alteration to veined gneisses over large areas. At the same time young, palingenic granites were formed and have also caused alterations. This complicated history explains the great difficulties often encountered by geologists when making investigations in the Svecofennides of Central Sweden.

The Rocks of the Filipstad Region

(MAGNUSSON 1925)

In the hälleflinta complex of the Grythyttan region several occurrences of iron ores appear. Those in the upper division are manganiferous and those in the lower division are poor in this element. The present author will return to these occurrences when he has described the iron ores and rocks of the Filipstad region.

In 1925 I published a description of the rocks of the Filipstad region, including the Saxå field and the ore districts of Persberg, Långban, and Nordmark in the west of the Saxå field. In the same book the iron ores of the Persberg district were also included. The description of the ores of the Nordmark district was published in 1929 and the description of the ores of the Långban district in 1930.

Where the grey and dark slates and the greywackes are well preserved within the Saxå field, they are quite similar to the corresponding rocks in the Grythyttan field. Young palingenic granites have, however, intruded the sediments of the Saxå field. Within the greater part of this field, therefore, the grey slate has undergone considerable metamorphism and has a peculiar appearance, due to the presence of abundant dark spots of cordierite. This cordierite-spotted grey slate consists essentially of quartz, albite, cordierite, and biotite. The layers rich in fragments of quartz and albite are poor in cordierite and in some of them cordierite is lacking. As to the structure, one can trace an incipient recrystallization, even of the fragmental grains of quartz and albite. Both cordierite and biotite appear as porphyroblasts, the central parts of the larger biotites, however, being massive. In the immediate vicinity of the contacts of the late Svecofennian palingenic granites the grey, cordierite-spotted slate has become entirely recrystallized and displays a coarse granoblastic structure. In these gneissic cordierite-spotted schists large muscovite porphyroblasts also appear.

In the dark graphite-rich slate in the Saxå field not only pyrite but also pyrrhotite and chalcopyrite have been found, chalcopyrite, however, only locally. This rock consists essentially of quartz, feldspar, biotite, muscovite, sericite and more rarely chlorite. Where the metamorphism grew higher, chlorite disappeared and cordierite, andalusite, hypersthene, and almandite were developed in varying proportions instead. Of these minerals cordierite is found in dark slates relatively poor in FeO and almandite in the dark slates rich in FeO. Characteristic of the dark slates are here as in the Grythyttan field the rounded, apatite-bearing, pebble-like concretions of quartz, which are sometimes met with in great quantities.

On the western side of the slate area the greywackes form a continuous zone. On the eastern side, on the contrary, they have been found only sporadically. The rocks consist of fragmental grains of quartz and feldspar (albite, perthite and predominantly microcline) and subordinate small grains of hälleflinta, quartzitic rocks, dark slates, and spilitic greenstones in a more fine-grained groundmass sometimes rich in micas. Locally the rock fragments are so large and numerous that the rocks themselves appear conglomeratic.

Chlorite has only been found locally in the greywackes of the Saxå field. As a rule it has been altered to biotite on expense of a corresponding quantity of muscovite. Between the fragments calcite and clinozoisite are often found.

In the north, the greywackes of the Saxå field are more strongly metamorphosed, due to a total or partial granulitization of the rock fragments and the grains of quartz and feldspars, and a recrystallization of the groundmass. In the feldspars small rounded plugs of quartz appear, and between plagioclase and microcline rims of myrmekite are usual. The whole rock has often good "pavement" texture. The original rounding of the grains has then totally disappeared. In the northernmost part of the Saxå field the greywackes have a granitic appearance.

Below the greywacke division, within this division and in the lower parts of the dark slates, a great number of greenstone bodies have been met with. These are in part intrusive, in part effusive. A thick greenstone below the greywacke division has been traced continually around the syncline in which the slates and greywackes are preserved. It is massive throughout and probably displays a gigantic sill. Where it has escaped strong metamorphism it has the texture and mineralogical composition of a saussurite-diabase. Where most metamorphosed it has an amphibolitic appearance. All other older greenstones in the Saxå field are effusive and have been developed as scoriaceous breccias, more seldom as lava flows rich in amygdules. The filling of the vesicles as well as the cementing mass in the breccias consist of calcite. Where the effusive greenstones have been strongly metamorphosed, the calcite has reacted with the greenstone itself and a great number of new minerals has resulted. These include diopside, actinolite, hornblende, clinozoisite, garnet, and carbonate-scapolite. The effusive greenstones often pass into keratophyric types.

	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %
SiO_2	80.28	78.25	79.85	76.62	76.83	73.69	70.82	77.59	74.41
TiO_2	0.15	0.19	0.22	0.15	0.16	0.36	0.24	0.17	0.16
Al_2O_3	11.35	12.27	12.09	13.20	12.78	13.57	13.21	11.61	12.61
Fe_2O_3	0.07	0.05	0.11	0.08	0.35	0.42	1.04	0.92	2.86
FeO	0.28	0.57	0.14	1.16	1.22	0.62	2.08	0.24	0.18
MnO	0.01	0.01	0.01	0.04	0.06	0.02	0.11	0.01	0.01
MgO	1.18	1.22	1.20	1.41	1.95	1.70	1.66	0.50	0.36
CaO	0.35	0.35	0.23	0.49	0.06	0.36	0.14	0.13	0.10
Na_2O	5.94	6.33	5.97	5.85	4.31	3.75	1.89	0.27	0.95
K_2O	0.26	0.33	0.30	0.61	1.92	5.25	8.79	8.82	7.97
P_2O_5	spår	spår	0.05	0.09	spår	0.06	0.01	spår	spår
S	0.02	0.02	–	–	–	–	–	0.11	–
H_2O	0.42	0.60	0.40	0.25	0.42	0.32	0.43	0.11	0.41
	100.31	100.19	100.57	99.95	100.06	100.12	100.42	100.48	100.02

1. Soda leptite, Persberg Odal field (Anal. G. Nyblom)
2. „ „ „ „ „ (Do.)
3. „ „ „ Högberg field (Anal. N. Sahlbom)
4. „ „ Nordmark Odal field (Do.)
5. „ „ „ Finnmossen (Do.)
6. Intermediate leptite, Nordmark, Finnmossen (Do.)
7. Potash leptite, Nordmark, Jakobsberg (Do.)
8. „ „ Långban (Do.)
9. „ „ south of Långban (Do.)

In the Långban, Persberg, and Nordmark iron ore districts the leptites and hälleflintas are the main components of the supracrustal complex. Within the districts named above the size of the grains in the groundmasses of these rocks is often between 0.03 and 0.05 mm. The dominant volcanic rocks are, over large areas, such transitional types between hälleflintas and leptites. Here and there textures such as spherulites, micropoicilitic quartz sponges, and reticulating quartz as well as fluidal and granophyric development have been met with. The easily damaged vitroclastic texture has, on the other hand, never been found, and such groundmass textures as the above-mentioned ones occur only sporadically. Most of the rocks are leptites with a more or less typical granoblastic texture. The leptites and hälleflintas are in part porphyritic with phenocrysts of quartz and albite, more rarely microcline. The quartz phenocrysts in the weakest metamorphosed lava rocks are idiomorphic and often corroded, and the albite phenocrysts have a tabular habit. In the stronger metamorphosed lava rocks even the phenocrysts have become granulated.

The composition of the leptites and hälleflintas is shown by the analysis in the table above. Thus the dominant leptites are alkaline and belong to two divisions, one extremely rich in soda, the other extremely rich in potash or alkaliintermediate in character. Accordingly the volcanic complex can, as in the Grythyttan field, be divided stratigraphically into two divisions. The lower division is composed chiefly of sodic leptites or, as in the Nordmark district, sodic leptites alternating with leptites of alkaliintermediate character and sporadically also with leptites rich in potash. The upper division is composed of predominantly potassic leptites, varying from leptites extremely rich in potash to types more alkali-intermediate in character.

The ore region of Filipstad with the districts of Persberg, Långban, and Nordmark is rich in limestones and dolomites. In the upper leptite division such rocks mainly occur at the top of the complex in the form of thick lenses, often abundantly intercalated with thin leptite layers. The carbonate rocks in this division are mainly dolomites, as at Långban. In the Gruvåsen carbonate stock, however, the central dolomite in the local anticline is flanked by limestones, which should be regarded as a primary stratigraphic feature.

In the lower leptite division carbonate rocks occur as thin layers which only at some places reach a thickness comparable with that of the dolomites and limestones of the upper division. Instead the limestone-dolomite layers are more frequent and thin carbonate and leptite layers often alternate. The carbonate rocks in the lower division are generally relatively poor in magnesia, but sometimes even dolomitic limestones and dolomites occur. In the carbonate stock on the Getön island the lower central part consists of pure limestone surrounded by dolomite. Even here it is quite clear that this distribution corresponds to the original stratigraphy.

When investigating the Filipstad region the present author came to the conclusion that both limestones and dolomites existed when the regional metamorphism began, and it seems quite certain that the same applies to other parts of the leptite-hälleflinta series in Central Sweden.

The problems concerning alterations in the primary magnesia content of the carbonate rocks of this series will be discussed later on, in connection with the description of the magnesia-metasomatic alterations and the genesis of the sulphide ores of the Falun type.

In the uppermost part of the lower leptite-hälleflinta division in the Persberg district extremely sodic rocks occur which are rich in quartz and albite in the form of angular or somewhat rounded grains. These are very similar to greywackes but differ in the angular form of the grains. The same types of rocks in corresponding stratigraphic position have been found in the Nordmark district.

The Iron and Manganese Ores of the Filipstad Region

(MAGNUSSON 1925, 1929, and 1930; pp. 179–210 in GEIJER and MAGNUSSON 1944)

In 1923 P. Geijer published his description of the Riddarhyttan region with its regional magnesia-metasomatic alterations. In this paper he considered the skarn iron ores in Central Sweden to have been formed by metasomatic alterations of this sort, the iron-bearing solutions coming from the synorogenic Svecofennian granites.

In the same year (1923) N. Sundius published his investigation on the Grythyttan field. His work lead him to the opinion that the skarn iron ores had metasomatic origin and that the iron material came from the same source as the volcanic rocks (the hälleflintas and leptites). The formation of the skarn minerals was according to Sundius contemporaneous with the deposition of the iron material.

In 1920 the present author began his investigations of the iron and manganese ores of the Filipstad region. In 1925 he published a description of the rocks of this region and of the skarn iron ores of the Persberg district (Magnusson 1925). In this district he found good indications that the skarn iron ores were originally sediments deposited together with silica, limestone or dolomite and that the skarn minerals had been developed by reactions between these original sedimentary components during the regional thermometamorphism. At the boundaries of the hälleflintas and leptites also reactions took place. New skarn minerals then originated through magnesia-metasomatic alterations.

In the Persberg Odal field in the lower leptite-hälleflinta division the dominating ores are of the Storgruvan type with magnetite more or less irregularly distributed in skarn masses composed of andradite and pyroxene belonging to the diopside-hedenbergite series. Usually the diopside component dominates over hedenbergite. Together with these minerals actinolite and hornblende also appear. Hornblende occurs especially in the vicinity of the leptite walls, often also in the walls themselves, and sometimes together with epidote.

The limestone and dolomite, the ore material and the silica contained all the elements necessary for the formation of andradite, pyroxene and actinolite. The alumina and alkali necessary for hornblende and epidote were taken from the surrounding leptites. In the Alabama mine the ores are more schistose and consist of magnetite together with anthophyllite and talc. In these ores the present author has found so many remnants of garnet-pyroxene ores of the Storgruvan type outwards altered to anthophyllite-talc ores that it is quite clear that the Alabama ores, as regards mineralogical composition, are somewhat younger than the Storgruvan ores. Between the two types are often found zones dominated by tremolite. Near the large masses of garnet-pyroxene-ores, actinolite may also occur in such zones. In the Alabama ores there is hardly any CaO. If these ores are alteration products of the Storgruvan ores, large masses of CaO must have been driven out. The author has also found anorthite-rich plagioclase (oligoclase and andesine) in the surrounding albite-leptites at some distance from the Alabama mines. The adjacent leptite often also contains rounded cordierites and bundles of anthophyllite or gedrite. Along fissures the leptites in the mines have been altered to micaceous sköl zones with cordierite and gedrite. Along other fissures, which pass into the garnet-pyroxene ores, the latter have become changed to talc-anthophyllite ores. Along the leptite contacts no hornblende and epidote have been found. Instead, an intensified alteration of leptite and of skarn into mica sköls essentially consisting of biotite, chlorite, and talc in varying proportions has occurred. The appearance in these sköl zones of cordierite and gedrite indicates mineral development by means of magnesia metasomatism. We have thus in the Persberg Odal field older reaction skarn originating from already existing material and younger magnesia-metasomatic skarn formed by alteration of the former. In connection with this alteration the iron of the garnets and the pyroxenes entered newly formed magnetite, the ores then becoming enriched in magnetite.

Where no silica was deposited, limestone-dolomite-magnetite ores without skarn were formed as in the Skärstöten mines. Where only small amounts of silica were present, as in the Gustav Adolf mines, orthosilicates such as olivine and its alteration product serpentine were formed together with scattered individuals of pure tremolite and pure diopside with magnesia taken from the dolomites. Sometimes good parallel arrangement of the magnetite grains is seen in these carbonate-magnetite ores.

Between the Skärstöten ores and the Storgruvan ores, magnetite ores extremely rich in andradite were mined. The contents of other skarn minerals were very low. This indicates that the carbonate rock was here origininally a relatively pure limestone. Where dolomitic limestone existed, enough magnesia was present to permit the formation of the garnet-pyroxene and pyroxene ores.

In the pyroxene-andradite-magnetite ores the present author has often found that andradite and magnetite both containing Fe_2O_3 have substituted for each other. Thus, when the content of andradite is high the content of magnetite is low, and vice versa.

The limestones, dolomites and iron ores in the lower division of the Persberg district occur at five horizons which can be followed over the whole district. The ores of the four lower horizons vary in the same way as in the Odal field which belongs to horizon four from below. Where magnesia-metasomatic alterations took place outside the Odal field, they always followed contacts with leptites or fissures crossing the ore bodies. Good parallel arrangement of the magnetites has been found, especially in the Högberg ores, east of the Odal field. Skarn layers there alternate with layers rich in magnetite.

The ores of the highest horizon, on the other hand, are rich in free quartz, indicating that an excess of silica was present in the original sediment when the skarn reactions took place. Such skarn iron ores are called quartz-skarn-iron ores. Even these have sometimes been changed by magnesia-metasomatic solutions. Such solutions have also reached the clastic leptite at the top of the lower leptite-hälleflinta division mentioned above. Here scattered grains of cordierite and gedrite occur, but the solutions never gave rise to new iron ores in these rocks. The iron material existed already in the original sediments in the five horizons but not in the pyroclastic horizon on the top of them.

On the northern part of the Getön island, the magnesia-metasomatic alterations were strong. The cordierite- and gedrite-bearing leptite here passes into cordierite-gedrite-quartzite, which has been formed along fissures in the leptite. Moreover, the dolomite has been altered to ophicalcite with pure diopside, tremolite, chondrodite and serpentine. The magnetite appears together with anthophyllite and cummingtonite or tremolite as well as abundant chalcopyrite, pyrrhotite, galena, and sphalerite. The ores rich in sulphides have been mined for zinc and lead and are of the same type as the sulphide ores in Falun. They belong to the sulphide ores of the Falun type which will be described later.

In the Gåsgruvan field there is a large limestone body locally containing thin dolomite layers altered to brucite-bearing limestone. In the brucite the present author found by microscopical investigation kernels of periclase (MgO) formed by dissociation of $MgCO_3$ in the dolomite. Later on, MgO was hydrated to $Mg(OH)_2$. Brucite and also wollastonite were found long ago at other places northwest of Gåsgruvan. All these localities are situated near the sharp boundary of the Gothian Värmland granites, which mark the limit of the ore-bearing regions of Central Sweden towards the west.

Between the Persberg district and the Nordmark district (Magnusson 1929), several small ores are situated in remnants of leptite enclosed in the Gothian granites or in a narrow zone of leptite between the synorogenic Svecofennian granite to the east and the contact of the large Gothian granite mass to the west. Usually these small ore fields are included in the Nordmark district. In the Finnshytteberg field, ores of the Persberg Storgruvan type and magnesia-metasomatic alterations of these existed before the intrusion of the Gothian granites. The garnet-pyroxene skarn has here been altered to a large extent into hornblende-epidote skarn. The anthophyllite and cummingtonite have locally been altered into hypersthene. In the limestones coarse-grained grossularite-hedenbergite-wollastonite skarn and in the dolomites brucite-spotted limestone were formed near the Gothian granite. Spinel and considerable amounts of mica also seem to be of Gothian origin.

In the Lindbom mines (Magnusson 1928), a limestone-magnetite ore and the surrounding limestone have been altered to a skarn mass consisting of quartz, calcite, garnet rich in the grossularite component, pyroxene rich in the hedenbergite component, and amphibole rich in alkali and iron. The most interesting feature is that magnetite has been consumed during this young skarn formation.

The dominating skarn in the Ormberg ores is a garnet-pyroxene skarn which shows the same alterations as in the Finshytteberg ores. The limestones and dolomites appearing together with the ore and skarn contain scattered grains of several minerals. The present author has found magnetite, garnet, serpentine, biotite, chlorite, pyrrhotite, vesuvianite, wollastonite, scapolite, and orthite. This skarn association shows an obvous influence from the granites on both sides.

The Haborshyttan field is situated between synorogenic Svecofennian granite with intrusions of younger palingenic granite in the east and a rounded massif of palingenic granite in the west. The ores in this field are intersected by a great many granite dikes which have given rise to intense variations in the mineralogical composition of the skarn masses. The dominating skarn consists of garnet and pyroxene but passes here and there into magnesia-rich types. The palingenic granite has given origin to a coarse-grained skarn consisting of quartz, garnet, hedenbergite, epidote, hornblende, calcite, and abundant sulphide minerals (pyrrhotite, pyrite, chalcopyrite, and arsenopyrite). The same minerals also appear in fissures. Several minerals occur in two generations.

In the central part of the Nordmark ore district (Magnusson 1929), the compositional variations of the ores are the same as in the Persberg district, i.e. reaction skarn ores and magnesia-metasomatic alterations of these. The latter were accompanied by a rearrangement of the ore material. Mica sköls often formed along the contacts with surrounding leptites. In the Nordmark, Taberg and Finnmossen mines the present author has found that the proportions between the alkalies in the leptites have often been altered so that potash has been more or less replaced by soda. In connection with the development of the mica sköl at the boundary of the ores in the Nordmark mine, for example, potash has been taken from the alkali-intermediate leptite and magnesia from the dolomite. The leptite has been altered to an extremely sodic variety, the dolomite to limestone, and the iron ore between the carbonate rocks and the leptite has become unusually rich in biotite flakes. This is an excellent example of chemical alterations involving exchange of material between rocks on both sides of a boundary in connection with magnesia-metasomatic processes. The rearrangement of the ore material must have occured in connection with folding. In Nordmark the ore material has been concentrated in the crest of a local fold. This rearrangement must have occurred before the formation of the reaction skarn. Such early rearrangements also occurred in the Taberg mines, where the ore material was concentrated on both sides of a strongly compressed fold. Later rearrangements of the ore material were caused by the magnesia-metasomatic alterations. The result has been great variations in the areas of the ores from level to level. The ores rich in magnesia have been better concentrated than the garnet-pyroxene ores in Taberg. In the ores rich in magnesium in this mine the magnetite appears in a skarn consisting of diopside, tremolite, chlorite, mica, talc, and serpentine, sometimes also anthophyllite and cummingtonite more or less altered to talc.

Such rearrangements inside the skarn- and carbonate-iron ores have been found by the present author at several places in Central Sweden.

The Uddeholm ores in the Taberg field have been strongly weathered to about 110 m depth. This weathering has caused the formation of martite, limonite, a little siderite, and chalcedony. The character of the weathering process will be discussed later on, in connection with the description of the weathered ores in Mossgruvan in the Ljusnarsberg region.

In the descriptions of the iron ores in the Nordmark district the author has given only the dominant minerals. The Nordmark district is, however, next to the Långban district richest in Central Sweden in minerals, as stated by several mineralogists and geologists. At first we got the minerals belonging to the reaction skarns and neigbouring rocks. Then came the minerals formed in connection with the magnesia-metasomatic alterations, and finally the minerals developed simultaneously with the intrusions of the late Svecofennian palingenic granites and the Gothian granites. In comparison with the central part of the Persberg district, the Nordmark district is rich in these intrusive granites, and consequently the ores and their neighbouring rocks in Nordmark have becamc rich in new minerals and elements as shown by the table below.

The investigations made by the present author in the Nordmark district became of great importance for himself. When trying to solve the problems concerning the origin of the skarn-iron ores in Central Sweden, he found it was necessary to get a look behind the disguise in which they now appear.

In the Långban mines (Magnusson 1930), iron and manganese ores are closely associated but at the same time well separated from each other. Together

Minerals found in the skarn iron ores poor in manganese and their surrounding rocks in the Nordmark and Persberg Districts

Minerals in the reaction skarn and surrounding rocks	Minerals formed in connection with the magnesia-metasomatic alterations	Minerals formed in connection with the Late Svecofennian and Gothian granites
actinolite	andalusite	apatite
albite	anthophyllite	apophyllite
biotite	biotite	argentite
calcite	calcite	arsenopyrite
diopside	chalcopyrite	augite
dolomite	chlorite	axinite
epidote	chondrodite minerals	biotite
garnet	cordierite	bismuth
hornblende	cubanite	bismuthinite
magnetite	cummingtonite	brucite
microcline	diopside	calcite
muscovite	fluorite	chalcopyrite
olivine	galena	chlorite
plagioclase	garnet	cobaltite
pyroxene	magnetite	cosalite
quartz	muscovite	datolite
rutil	olivine	epidote
tremolite	orthite (allanite)	fluorite
	phlogopite	galena
	pyrite	galenobismuthite
	pyrrhotite	garnet
	quartz	hedenbergite
	serpentine	hematite
	sphalerite	hornblende
	spinel	hypersthene
	talc	kainosite
	tremolite	magnetite
		microcline
		molybdenite
		niccolite
		orthite (allanite)
		periclase
		pyrite
		pyrosmalite
		pyrrhotite
		quartz
		safflorite
		scapolite
		scheelite
		sphalerite
		spinel
		titanite
		vesuvianite
		wollastonite
		wurtzite

they constitute more or less irregular concentrations in dolomite. The iron ore minerals are crystalline hematite and magnetite. The former is accompanied by quartz and constitutes the main part of the iron ore bodies. The quartz has often the form of ferruginous quartz. From the uniformly red ferruginous quartz all transitions exist to normal grey quartz. Macroscopically and microscopically one can study how the grey quartz has originated by removal of the fine hematite grains of the ferruginous quartz, that is, through a concentration of the hematite material to form larger grains. The rich ores seldom had more than 10 % SiO_2.

In the surrounding dolomite hematite and quartz are usually replaced by magnetite and skarn silicates. In the transition zone between magnetite and hematite ores, magnetite usually appears as comparatively large porphyroblasts in the hematite ores. In several places one can follow how the magnetite and the skarn masses have been developed by metamorphism of the original hematite-quartz-dolomite association. The magnetite ores as well as the skarn masses often show relicts of hematite and ferruginous quartz. The skarn silicates usually accompanying the magnetite include andradite, diopside, and tremolite-actinolite. This skarn is thus a typical reaction skarn.

In the vicinity of the manganese ores there often appear skarn silicates rich in manganese in the hematite ores. These skarn silicates agree with the corresponding minerals in the manganese ores and brecciate the hematite ores in such a way as to show that the iron and manganese ores were once better separated than is now the case. During the metamorphism, exchange of material occurred between the two ore types.

The manganese ores consist of braunite and hausmannite, braunite constituting the central parts of the larger ore concentrations, hausmannite the outer parts of the larger and the whole of the smaller concentrations. At the boundaries between the braunite and hausmannite ores, the hausmannite usually occurs as relatively large porphyroblasts in the braunite masses. Hausmannite has been formed from braunite by thermal metamorphism in the same way as magnetite has replaced hematite. Not all hausmannite, however, can have this origin. Where hausmannite appears as scattered grains in dolomite, braunite has surely never existed. Probably this hausmannite derives its origin from primary manganese carbonate directly or with manganosite (MnO) as an intermediate stage. Manganosite now and then appears in the outer parts of the hausmannite ores and also in carbonate masses rich in MnO. Cores of manganosite in hausmannite have occasionally been found. Together with hausmannite there also appear transitional types between hausmannite and magnetite, such as jakobsite and manganese magnetite.

The manganese ores are accompanied by skarn minerals like the iron ores. In this case it is especially the braunite ores that are accompanied by larger skarn masses. The braunite is more closely related to the skarn silicates than the hausmannite. Its composition is $3\ Mn_2O_3 \cdot MnSiO_3$ and it is thus itself silica-bearing. The skarn minerals have developed in a braunite matrix, and therefore the silicates often contain rounded inclusions of braunite.

The usual skarn silicates accompanying the manganese ores in Långban are garnets, pyroxenes, amphiboles, micas, and olivine minerals. The garnets are yellow or red and more or less rich in the spessartine component. The monoclinic manganese pyroxenes in Långban can be divided into two groups: schefferites and urbanites, the latter rich in Na_2O and Fe_2O_3. After the monoclinic pyroxenes the most common skarn silicate is the triclinic pyroxene rhodonite. Rhodonite containing about the same amounts of manganese and calcium are referred to as bustamite. Most of the manganese amphiboles have to be classed as richterite. The amount of mica in the manganese ores is dependent upon the leptite "sköls" present as layers in the ores. In the iron ores the micas are biotites, in the manganese ores manganophyllites. Olivine minerals are relatively common in the manganese ores, most of them being tephroite. Picrotephroite rich in MgO may also occur together with them.

The above-mentioned manganese silicates can be regarded as manganese-rich equivalents to the skarn silicates accompanying the common skarn iron ores poor in manganese as described above from the Persberg and Nordmark districts.

The chemical and mineralogical variations in the manganese ores of Långban are further increased by the presence of several elements rare or uncommon in the skarn iron ores poor in manganese. These include lead, arsenic, antimony, and barium. Several lead silicates are known from the Långban mines, and of these five belong to the compact skarn masses, namely kentrolite, melanotekite, hyalotekite, ganomalite, and molybdophyllite. Lead and barium have also been found in the carbonate mass as original components. All good analyses of manganese ores from Långban show small percentages of arsenic, mainly derived from the minerals berzeliite, caryinite and hedyphan. The latter is a quite common mineral. Antimony is, in comparison with arsenic, a subordinate element in Långban. The antimony minerals belonging to the compact skarn masses are långbanite, monimolite, and atopite (= weslienite). Titanium and boron also seem to be primary elements. The rare titanium minerals magnetoplumbite and pyrophanite, the beryllium minerals trimerite, phenakite, and bromellite as well as the boron mineral pinakoilite have also been found.

Of the greatest mineralogical interest are the vug and fissure minerals formed under conditions of falling temperature after the regional thermal metamorphism had given the manganese ores (and the iron ores) their essential mineralogical compositions.

The most frequent vug and fissure minerals in Långban seem to be calcite and barite. They have often been found also in the compact ores and in the skarn masses as late fillings between the other minerals. No sharp boundaries, however, can be drawn between the vug and fissure minerals. Several skarn minerals also appear in vugs and many minerals appear in both vugs and fissures. The minerals present in vugs in the manganese ores often occur in fissures in the hematite ores. It is not necessary to enter into a discussion of the different vug and fissure minerals in the present book.

Several sulphide minerals have been observed in the Långban mines. They play, however, a subordinate role. First we have the sulphides common in Central Sweden, namely pyrite, chalcopyrite, galena, sphalerite, and molybdenite. Less common sulphides include bornite and chalcocite. The sulphides are late impregnations in the ores and in the dolomite. The skarn has often been altered in connection with the sulphide impregnation. In the dolomite the sulphides, especially galena and sphalerite, are accompanied by a mineral association consisting of diopside, tremolite, phlogopite, penninite, clinohumite, and spinel. This association is a common one in the sulphide deposits of the Falun type in Central Sweden. Several of the sulphides also appear as fissure minerals in the iron ores. Bornite and chalcocite only appear in the manganese ore bodies or in their vicinity.

North of the Hyttsjö granite, which borders upon the dolomite with its iron and manganese ores to the north, several small sulphide occurrences have been mined. They are all of the Falun type. The author found pyrite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite and galena in dolomite, skarn or quartzite. The quartzite is of the common magnesia-metasomatic type including cordierite, biotite, gedrite, and hypersthene. At the leptite boundaries mica-chlorite sköls with spots of scapolite have been found at several places. Among the skarn minerals garnet, pyroxene, hornblende and also serpentine have been found, and together with these minerals some fluorite. Fluorite also occurs in the mica-chlorite sköls. Two iron ores in the same region have been richly impregnated with the sulphides named above, and the same magnesia-metasomatic alterations have gone over them.

The present author is convinced that the sulphide invasion in the Långban ores south of the Hyttsjö granite advanced at the same time and that the magnesia-metasomatic solutions played an important role in connection with the formation of many of the minerals in Långban.

An interesting feature is the occurrence of native metals such as lead, copper, silver, and bismuth in the manganese ores. Conditions here existed that caused an oxidation of sulphur and a removal of the element from part of the sulphides. Bornite and chalcocite are intermediate stages in this process. Native lead and copper are most common. The oxidated sulphur caused the formation of sulphate minerals such as barite, gypsum and thaumasite. Barite in particular usually accompanies the native lead and copper. The necessary oxygen was taken from Mn_2O_3-bearing minerals and from arsenates and antimonates resulting in the formation of manganese hydroxides, arsenites and antimonites.

The composition of the carbonate mass surrounding the ores comes very near to the theoretical composition of dolomite, with equal amounts of $CaCO_3$ and $MgCO_3$. In the ores, the amount of $CaCO_3$ is always greater than that of $MgCO_3$. The preponderance of $CaCO_3$ is greater in the manganese ores than in the iron ores. In the former there is often twice as much $CaCO_3$ as $MgCO_3$.

This should largely depend upon replacement of $MgCO_3$, by other carbonates, especially $MnCO_3$, in connection with the ore-forming processes. Small amounts of $BaCO_3$ and $PbCO_3$ also ought to replace $MgCO_3$ isomorphically. Of independent carbonate minerals only barytocalcite has been observed.

The numerous leptite layers in the Långban mines are always more or less altered at the boundaries to sköl rocks rich in mica. The thinner layers have often undergone complete alteration. The thicker layers, however, have as a rule remained unaffected in their central parts. Between these parts and the mica sköls proper there are relatively broad transitional zones rich in alumina and magnesia minerals, such as andalusite, sillimanite, cordierite, and gedrite. The mica sköls themselves often show minerals rich or relatively rich in CaO, such as hornblende, scapolite, plagioclase, and epidote. There are also remnants of the original minerals quartz and microcline. The skarn masses at the contact of or near the mica sköls have usually got much influenced by the leptite material, so that besides predominant mica and many common skarn minerals appear several minerals otherwise unusual in the skarn, such as feldspars, scapolites, epidotes and hornblendes. Among the feldspars there appears, besides microcline and plagioclase, also hyalophane, and among the epidotes piemontite, the latter often displaying an alteration product of scapolite. The scapolites examined are chlorine scapolites rich in marialite.

The sköl-forming processes have mainly implied an exchange of material between the leptite layers on the one side and the ore bodies, skarn masses and dolomite on the other. Fig. 66 illustrates the transport of material between these parts of the bedrock. Fig. 67 elucidates the transport of material in such a contact zone between skarn and leptite during the sköl-forming processes. We find that SiO_2, Al_2O_3, Na_2O and K_2O have been taken from the leptite and transported into the surrounding rocks, and that MgO, CaO, MnO and FeO have been transported from the skarn masses into the leptite. We also find that silica and alkalies have been taken further afield than alumina, and that magnesia has penetrated into the leptites to a greater depth than lime, all of which is in agreement with the chemical and mineralogical investigations. The origin of minerals rich in alumina in the transitional zone depends on the removal of more alkalies than alumina and the origin of minerals rich in magnesia upon the fact that this oxide has been more able to penetrate into the transitional zone than the other oxides.

From the description given above it is clear that an eventful geologic history has given the Långban deposits their present complicated mineralogical assemblage. Originally, the ore material was deposited at low temperatures near the surface or at the surface itself. The sharp separation of iron and manganese can be explained only by the assumption of a rich supply of oxygen which explains why the main portion of silica has been deposited in the dolomite together with the iron ores. The conditions assumed caused the precipitation of nearly all iron and most silica before the precipitation of manganese and several other elements could occur.

Later, the regional thermal metamorphism related to the folding and intrusion of the synorogenic Svecofennian granites brought about the reactions between existing material concurrently with the formation of reaction skarn in both the iron and manganese ores. At the same time the magnetite in the iron ores as well as the braunite and hausmannite in the manganese ores were formed from, respectively, primary hematite and Mn_2O_3 or $MnCO_3$.

The thermal metamorphism was immediately followed by the sköl-forming processes and the invasion of the sulphide material which contributed several new minerals to the leptites as well as to the ores and skarn masses. Most of the vug minerals originated in connection with the later stages of the sköl-forming processes. The vug fillings in the Långban deposits seem to be only another aspect of the sköl-forming processes. Fissure-fillings are direct continuations of the former processes. Observations have been published of skarn minerals appearing as late fissure minerals in what may be called a second generation. These minerals include yellow garnet, hematite, and hausmannite. Their appearance as a second generation shows that the conditions for the development of skarn and ore minerals, such as high temperature, have returned at least once after the beginning of the fissure mineral period. The second generation of skarn and ore minerals was surely connected with the intrusion of the late Svecofennian palingenic Hyttsjö granite, immediately north of the Långban deposits. It is also possible that the Gothian granites north of Långban can have supplied material for some of the more unusual elements. Experiences in the Långban mines during the years 1922–1929 played a great role for the present author when starting his regional investigations of the iron ores of Central Sweden. Processes worth special mentioning are particularly the alteration of the hematite-ferruginous quartz iron ores occurring in dolomite into magnetite ores rich in skarn silicates of the reaction skarn type, further the different results of the sulphide invasion in the iron ores and in the pure dolomite on the one side and in the manganese ores on the other; finally the influence of the leptite layers on the development of sköls and skarns by exchange of material between the leptites and their surroundings.

In Figs 68 and 69 the writer (Magnusson 1930) has tried to give a paragenetic classification of the minerals in the Långban deposits. The letters signify periods in the entire mineral-forming process. To period A belong the primary minerals now appearing as relics, recrystallization products of primary minerals, and the earliest reaction skarn minerals. To period B belongs the main part of the reaction skarn minerals, that is the pronounced high-temperature minerals. If the thermometamorphism had been still stronger, all or nearly all older minerals should have disappeared. To period C belong the minerals that appear as vug fillings. To the same period belong also the minerals that have originated during the sköl-formning processes. An important part during this period was played by the sulphide invasion. This invasion must belong to a later section of period C. The beginning of the sulphide invasion divides period C in two parts C1 and C2. The results of the sulphide invasion can be traced during the whole fissure mineral period, here marked with D.

Since 1930 several interesting papers about new minerals in Långban have been published. These minerals are: Aminoffite $Ca_3(Be,OH)_2Si_3O_{10}$ – Banalsite $BaNa_2[Al_2Si_2O_8]$ – Barytocalcite $BaCa(Co_3)_2$ – Benstonite $Ba_6Ca_7[Co_3]_{13}$ – Blixite $Pb_2(O,OH)_2Cl$ – Brandtite $Ca_2Mn[AsO_4]_22H_2O$ – Celsian $Ba[Al_2Si_2O_8]$ – Dixenite $Mn_5Al_2[O_6/SiO_4]H_2O$ – Ericssonite $BaFe^3Mn_2(Si_2O_7)O\,OH$ – Eveite Mn_2OHAsO_4 – Flinkite $Mn^2_2Mn^3(AsO_4)(OH)$ – Hoernesite $Mg_3(AsO_4)_2 \cdot 8H_2O$ – Jagoite $Pb_8Fe^3_2[(Cl,O)/Si_3O_9]$ – Joesmithite $(Pb,Ca)Ca_2Fe^3Mg_4[Si_2O_6]_2[Si(O,OH)_4]_2(OH)_4$ – Magnussonite $(Mn,Mg,Cu)_5[(OH,Cl)/AsO_3]$ – Mendipite $Pb_3O_2Cl_2$ – Nadorite Pb, Sb_4O_2Cl – Norethite Ba,Mg $(CO_3)_2$ – Perite Pb, BiO_2Cl – Orthopinakiolite $Mg_3Mn^2Mn^3_2B_2O_{10}$ – Rhodochrosite $MnCO_3$ – Parwelite $(Mn,Mg)_5Sb(Si,As)_2O_{10-11}$ – Roeblingite $PbCa_7(OH)_9(SO_4)_2[Si_2O_4]$ – Sahlinite $Pb_{14}[Cl_4/O_9/(AsO_4)_2]$ – Senarmontite Sb_2O_3 – Sjögrenite $Mg_6Fe_2[(OH)_6/CO_3] \cdot 4H_2O$ – Stenhuggarite Ca,Fe$(SbO)(AsO_3)_2$ – Stolzite β - $Pb[WO_4]$ – Synadelphite $Mn_3(AsO_4)(OH)_3(H_2O)$ – Trigonite $Pb_3Mn \cdot H \cdot [AsO_3]_3$ – Wickmannite $Mn[Sn(OH)_6]$.

The Pajsberg and Harstigen manganese ores in in the Persberg district (Magnusson 1925), are situated in the same stratigraphic position as the Långban ores and resemble these also in having iron and manganese ores side by side. The manganese ores are in Pajsberg hausmannite with manganese skarn (rhodonite, schefferite, and manganophyllite). The iron ores are quartz-banded hematite often accompanied by ferruginous quartz. In Harstigen two thin parallel ore layers were mined, one of them a manganese ore with hausmannite in dolomite and a skarn consisting of schefferite, richterite, manganophyllite, garnet, hedyphan, tephroite, rhodonite, and barite. The iron ore is hematite with ferruginous quartz. The hematite has been partly altered into magnetite. At the same time the ferruginous quartz has lost its red colour. In fissures both in Pajsberg and in Harstigen several rare minerals have been found.

In the Nordmark district Jakobsberg (Magnusson 1929) displays an occurrance of the Långban type. The manganese ore is here hausmannite-bearing dolomite together with manganophyllite, ganomalite, native copper, native lead, and jakobsite in a skarn of schefferite, manganophyllite, richterite, yellow garnet, and several rare skarn and fissure minerals. The manganese skarn borders on a magnetite-bearing andradite-pyroxene skarn with remnants of hematite and ferruginous quartz.

The manganese ores of the Nordmark Odal field (Magnusson 1929) consist essentially of hausmannite. In the peripheric parts they pass into a mixture of hausmannite and manganosite, the grains of both minerals being surrounded by dolomite rich in manganese. In part the ore passes into cavernous masses of rodochrosite, pyrochroite, and calcite. Together with the hausmannite there occurs barite, manganostibiite, and adelite. The manganosite is accompanied by brucite and the pyrochroite by several rare minerals. In some concentrations manganosite and pyrochroite are the essential minerals.

A representative for the Långban type has also been found east of the Grythyttan syncline, in Sjögruvan (Magnusson 1944). The manganese ores in this mine consist of hausmannite and braunite together with tephroite, rhodonite, garnet rich in the spessartine component, and manganophyllite. Several arsenic and antimony minerals occur, and pyrochroite, pumboferrite, native lead, and barite have been found. The iron ore situated side by side with this manganese ore consists of hematite with ferruginous quarts partly altered to magnetite ore with skarn minerals (andradite-garnet, diopside and tremolite). Ferruginous quartz from this ore has been found as pieces in an agglomerate in the vicinity.

In the Gåsborn field (Magnusson 1930) east of the Långban mines and east of the Saxå slate-greywacke syncline occurs a small representative of the Långban type displaying an iron ore of hematite and ferruginous quartz, more or less altered to magnetite ore with grey quartz. These ores are associated with a skarn rich in manganese and consisting of garnet rich in the spessartine component, rhodonite and tephroite.

As will be described later on, there exist in some places far from Långban skarns rich in manganese silicates of the Långban type and accompanying quartz-banded iron ores.

The Iron Ores of the Grythyttan and the Hjulsjö-Järnboås Regions

(SUNDIUS 1923 and MAGNUSSON 1944)

In the hälleflinta complex of the Grythyttan field manganiferous iron-ores occur in the upper division and iron ores poor in manganese in the lower division.

The most interesting occurrence in the upper hälleflinta-division is Sjögruvan with its hausmannite-braunite ores. These have been described above together with the Långban ores in the Filipstad region. The other iron ores in the upper hälleflinta-division are magnetite ores with carbonates or silicates rich in manganese.

The magnetite ores of the Brunsjö mine occur in a limestone with about 14 % $MgCO_3$ and 16 % $MnCO_3$ and in a skarn essentially consisting of knebelite and dannemorite.

The iron ores in the Silvergruvan mine can be characterized as a skarn-carbonate mass with magnetite and sulphides, in which knebelite, dannemorite, biotite, and garnet rich in spessartine appear in varying proportions. An analysis of the black carbonate gave 64 % $MnCO_3$, 21 % $FeCO_3$, 10 % $MgCO_3$, and 5 % $CaCO_3$. The sulphides were pyrrhotite, arsenopyrite, pyrite, chalcopyrite, sphalerite, and galena. These ores have been mined for lead and silver. We have here an older, iron-manganese ore and a younger invasion of sulphides. N. Sundius, A. Parwel, and B. Rajandi (1966) have recently found pyrosmalithe and cassiterite in these ores.

The ores of the Järnås mine have been rich in manganese (about 4–5 % MnO). In spite of this Sundius could not find any typical manganiferous skarn minerals, only minerals typical for iron ores poor in manganese such as diopside, garnet, olivine, actinolite, hornblende, and epidote. Together with the skarn ores there were also carbonate ores. Perhaps the ores analysed were those rich in manganese carbonate. It is also possible that some manganese has been included in the magnetite.

The ores of the Kextjärn mines are rich in manganese, with an average of 5.15 % Mn. They are skarn iron ores rich in carbonates and the skarn minerals hornblende, dannemorite, cummingtonite, or anthophyllite. In an agglomerate above the ores there are fragments of hälleflinta and ore. Between the ore and hälleflinta fragments, reaction skarn of biotite, chlorite, and garnet has formed. The agglomerate ought to be younger than the iron ores in this mine, and the skarn-forming processes should be even younger than the agglomerate.

Of special interest among the iron ores in the lower leptite division are the jaspilite ores in the anticline between the clastic sediments in the Saxå field in the west and the Grythyttan field in the east. Of special interest are also the limestone-dolomite-hematite ores and the hematite ores in hälleflinta east of the sediments of the Grythyttan syncline.

In the jaspilite ores in the Sången area the hematite appears as layers about 1 mm thick alternating with limestone and ferruginous quartz, sometimes even with thin hälleflinta intercalations. These ores were, as stated by Sundius, originally sediments. Reactions between the original materials caused skarn silicates, such as garnet, epidote, actinolite, and hornblende, to develop. Chlorite and biotite have also been found.

In the limestone-dolomite-hematite ores on the eastern side of the syncline dolomitic limestones dominate. Hematite, ferruginous quartz, and hälleflinta appear as intercalations in the dolomitic limestones, and these different materials occur in variable proportions. There are also hematite ores alternating with hälleflinta alone.

From these sedimentary ores free from skarn there are all transitions to iron ores with more or less skarn minerals. These occur where ferruginous quartz and ore material has been deposited together with the carbonate rocks. We have here the best opportunities of studying the alteration to skarn iron ore with magnetite instead of hematite. There are also all transitions from such ores with well-preserved banding to skarn ores, where the banding has been destroyed by rearrangement of the material within the limestone-dolomite bodies.

Sundius (1923) came to the conclusion that the skarn minerals in the jaspilitic ores in the west were secondary and formed by reactions between already existing materials. The skarn minerals in the skarn-bearing iron ores in the east were, according to him, on the contrary primary skarn developed together with the ores, and these were also metasomatic ores formed at relatively high temperatures. There exist, however, as the present author has found, all transitions between them. I therefore think that they are all sediments and that the skarn silicates are secondary in both cases. Good support for this opinion I have found (Magnusson 1944) in the Kextjärn occurrence, as mentioned previously, but I have also found evidence in favour of the same opinion in the Sirsjöberg mines.

Most interesting features of the Sirsjöberg mines are dikes of hälleflinta and greenstone which cut the ores in several places. These dikes are often composite with hälleflinta in the central parts and greenstones on both sides. There are also older amphibolite dikes, which have intruded the ores in an irregular way. The dikes are all younger than the ores but older than the skarn-forming processes, which have attacked them, too.

The essential skarn minerals in the Sirsjöberg ores have been pyroxene, often altered to actinolite or actinolitic hornblende, and garnet. Where the amount of magnetite was low, the amount of andradite was high and vice versa. These two minerals have acted as substitutes for each other in the same way as in the Storgruvan ores in Persberg.

The hälleflinta of the dikes are quartz-keratophyres or, less frequently, keratophyres with albite as the only feldspar, the former usually containing phenocrysts of quartz and albite, the latter with phenocrysts only of albite. The greenstones consist essentially of hornblende and plagioclase. The usual skarn minerals in the greenstone dikes close to the ores are hornblende and epidote. Deeper in the greenstones and also in the hälleflintas behind the greenstones hornblende and epidote have formed skarn breccias.

The small Haggruvan ores at Grönhult are situated in the vicinity of the Sirsjöberg mines. Locally, a good banding has been preserved with alternating layers of skarnbearing magnetite ore, skarn layers with some magnetite, quartz layers, and hälleflinta layers. The magnetite has sometimes the crystal form of hematite and the quartz sometimes a reddish colour due to the presence of small flakes of hematite. The hälleflinta layers have locally been broken into small pieces on all sides attacked by skarn. An agglomerate in contact with the ores contains not only pieces of hälleflinta but also pieces of ore. All these observations indicate that these ores represent sediments and that they were once hematite ores with ferruginous quartz and carbonate layers. Some quartz has also been found in the Sirsjöberg ores, locally assembled into layers broken into pieces.

The ores of the Finnberget mines have been stratified – composed of alternating layers of skarn and ore. Quartz-banded ores have also been common as well as limestone-dolomite banded types. The ores have often appeared as rectangular pieces in the carbonate rocks, which were frequently skarn-spotted or skarn-banded. Now and then layers of hälleflinta have also been found. The quartz of the quartz-banded ore-layers has often had the colour of ferruginous quartz. Obviously we have here to deal with a formation originally composed of layers of hematite, ferruginous quartz, limestone–dolomite in varying proportions, and hälleflinta. The skarn minerals should have formed by reactions within this pre-existing material under the condition of a regional thermal metamorphism. The skarn minerals in mine described have been actinolite hornblende, chlorite, and biotite.

In the Högborn mines banded iron ores have dominated, particularly skarn-banded types. Carbonate- and quartz-banded ores have also occurred. In the carbonate-banded types dolomite has dominated over limestone. All transitions have existed between these banded types and types with magnetite more or less irregularly distributed in compact skarn masses with remnants of the banded types and with isolated quartz grains or with limestone or dolomite remnants. It is quite clear that the whole of the magnetite-bearing complex was originally banded and that the banding to a large extent disappeared in connection with folding and thermal metamorphism. The skarn minerals found in the Högborn ores are tremolite, actinolite, hornblende, epidote, garnet, biotite, chlorite, and talc. The ore-bearing complex is situated between hälleflinta in the hanging wall and greenstone in the foot wall. At the contact with the hälleflinta a mica sköl has sometimes been observed, and at other places epidote has appeared. In the greenstone epidote and hornblende have been formed at the contact by exchange of material between the greenstone and the iron-ore-bearing complex. Talc appears in the vicinity of the mica sköls.

The ores mined in Halvtroberg and Tappberg have been carbonate and carbonate-skarn-bearing. In the most fine-grained types quartz has as a rule been found, occurring either as isolated grains or as spots. One could also frequently find thin layers of skarn and of ore and thin hälleflinta layers often broken into pieces by tectonic movements. The essential feature is that silica was deposited here as well as in all other skarn iron ores in the Grythyttan field, and its presence was necessary for the formation of reaction skarn.

The examples now given from a region with a very weak thermal metamorphism show that iron material, limestone or dolomite, and silica in varying proportions have been deposited where we now have skarn iron ores. Furthermore, a banded sediment originally existed in most cases but usually lost its banding due to processes of skarn formation. Even magnetite ought to be a product of the metamorphism.

Long ago, geologists maintained that the iron ores rich in manganese occupied a higher stratigraphic position than those poor in manganese. In the Filipstad region the combined iron and manganese ores of the Långban type appear highest in the leptite-hälleflinta complex, near to the sediments in the Saxå field. The uppermost part of the lower leptite division in the Persberg, Långban and Nordmark districts contains, as mentioned before, skarn iron ores rich in quartz and known as quartz-skarn-iron ores. In the anticline between the Grythyttan and Saxå synclines an etage with quartz-banded iron ores outcrops. Hence the etage with skarn iron ores rich in quartz probably occurs beneath it but is not exposed. On the eastern side of the greywacke-slate syncline of Grythyttan appears, east of the zone with ores rich in manganese, a zone with quartz-skarn iron ores. This zone includes Finnberg–Halvtroberg–Tappberg- and Högborn mines. The etage with quartz-banded iron ores is missing both west of the Saxå field and east of the Grythyttan field. These ores have thus been deposited in a limited area.

Stratigraphically beneath the etage of the quartz-skarn-iron ores is situated the etage of the skarn-iron ores free from quartz or with very small quantities of this mineral.

It has thus been possible to distinguish four etages in this part of the ore-bearing region of Central Sweden (Magnusson 1961 b). The present author has tried to follow them over the whole of the ore-bearing part of Central Sweden. In the highest etage, nearest the synclines with the greywacke-slate sediments of the Grythyttan series, there always occur iron ores rich in manganese – the so-called manganiferous iron ores, or combined iron and manganese ores of the Långban type. The three lower etages are characterized by iron ores poor in manganese. Only small, insignificent forerunners to the iron ores rich in manganese have been found in these etages, characterized by one or several minerals of the Långban type such as braunite, rhodonite, schefferite, yellow garnet, manganophyllite, feldspar rich in barium, and the lead-manganese-silicate kentrolite. Most of them are closely connected with quartz-iron ores and are, in fact varieties of these. Usually they display well-stratified hematite ores, the quartz layers being, however, replaced by braunite or manganese silicates. They thus belong to the highest etage in the complex of the iron ores poor in manganese. This etage contains the quartz-banded iron ores. Locally, where limestone or dolomite have been deposited together with them or where magnesia-metasomatic alterations have affected them, they have been more or less altered to skarn ores. These ores have also to be included in the etage of the quartz-banded iron ores.

The lowermost etage is characterized by skarn-iron ores poor in quartz. These ores nearly always appear in limestones or dolomites. The initial silica was so low that all or nearly all of it was consumed during the production of the skarn masses.

These etages are separated by an intermediate etage containing skarn iron ores rich in quartz. The proportion between siliceous and carbonatic rocks in these ores has been such that much quartz remained when the skarn-forming processes had finished.

These four etages can be followed over the whole ore-bearing region of Central Sweden (Magnusson 1961 b). The quartz-banded ores have been originally deposited in local basins, and the etage they represent is therefore missing in several sequences. The same is true for the skarn iron ores rich in quartz. These ores, too, seem to have been formed in local basins. The sequence between the four etages is, however, always the same.

From the Grythyttan field a syncline with skarn iron ores rich in quartz stretches southeast into the Nora region (Magnusson 1944). The central part of this syncline belongs to the etage with quartz-banded iron ores but these ores are here very small and unimportant. East of this syncline there is a broad anticline. In this anticline the iron ores of Sirsjöberg and Haggruvan at Grönhult, described above, are situated. Another very interesting mine is Ösjöberg, where the ores consist of magnetite with calcite, pyroxene, and actinolite. Towards the foot-wall they pass into garnet-pyroxene skarn. The boundary zone towards the hanging wall is rich in tremolite, talc, and chlorite. The actual boundary with the leptite has the appearance of a mica sköl. The solutions that caused the magnesia-metasomatic alterations have thus followed the hanging wall. Near the sköl the leptite of this wall is rich in micas. The ores are cut by old greenstone dikes which have, in connection with the skarn-forming processes, been more or less incorporated in the skarn masses. They are younger than the original ores but older than the skarn-forming processes. Younger amphibolitic greenstone dikes (metadiabases) traverse the whole complex.

All other iron ore occurrences in the broad anticline are unimportant carbonate or skarn iron ores poor in manganese but with magnetite in limestones, dolomitic limestones, dolomites, or skarn masses with varying mineralogical compositions. The main skarn minerals are actinolite, hornblende, and pyroxene frequently accompanied by garnet, epidote, chlorite, and biotite. The formation of chlorite and biotite has usually been intensified towards the leptite and has often been accompanied by hornblende sometimes containing remnants of pyroxene. Such remnants have often been found in the actinolite, too. Consequently, the original skarn should have consisted mainly of pyroxene with some garnet. The ore layers are usually thin and have been influenced by the leptite enclosing them. The chlorite-biotite skarn developed at the contacts only seldom passes into products of more intense magnesia-metasomatism. Where such alterations have occurred minerals rich in magnesia have developed including pure diopside, pure tremolite, talc, phlogopite, serpentine, and members of the humite group. Anthophyllite, cummingtonite, and secondary quartzites are only rarely found together with these minerals.

More interesting is the presence of quartz and hematite in some mines. In the Gunnarsberg and Fallgruvan mines, quartz occurs as stripes and lumps. It is quite clear that the ores were originally stratified as is indicated by the presence of layers of ore, quartz and hälleflinta locally preserved in the limestone-dolomite body. Owing to tectonic deformation these layers have been broken into pieces and rotated in the incompetent, plastic carbonate mass. This brecciation of the layers is older than the skarn-forming processes.

In Björksjö both limestone-dolomite-magnetite ores and quartz-bearing skarn-magnetite ores have been mined. The limestone-dolomite-iron ores showed all transitions between well-banded types and types with the magnetite irregularly distributed. The banding is in part thick, in part thin. The carbonate-iron ores contain quartz layers, which have been broken into pieces by tectonic deformation. These pieces are often rounded and have sometimes aggregated into irregular lumps. Sometimes the quartz-layers are well-preserved but folded. The skarn minerals include pyroxene, actinolite, and hornblende. The pyroxene has dominated in the larger skarn ores. Of interest is the abundance of quartz and quartz layers in the skarn iron ores. These layers are better preserved than in the carbonate iron ores and are often concordant though folded and often broken into pieces. Layers of hälleflinta have been found in the complex and these, too, have often been brecciated. As the pieces of quartz and hälleflinta have rims of skarn, the latter must be younger than the tectonic deformation.

Around the Rösberg mines the hälleflinta-leptite rocks have been altered to mica schists. The mica is essentially biotite. The ores are skarn-iron ores with actinolite and subordinate pyroxene or tremolite with inferior anthophyllite and cummingtonite or biotite, chlorite, and particularly talc. Chlorite is an alteration product of biotite and talc an alteration product of skarn minerals rich in magnesium. The carbonate rocks are rich in skarn minerals (pure diopside, pure tremolite, mica, talc, humite minerals, and serpentine). The ores have been fine-grained and usually so rich in talc that they could be described as talc schists with magnetite grains. Towards the leptites dark, biotite-chlorite-hornblende sköls or mica schists rich in talc have been formed.

In the Slåtterberg mines the skarn iron ores are characterized by actinolite-tremolite skarn with remnants of pyroxene. This skarn has to a large extent been changed to talc and chlorite, especially when bordering upon leptite at places where talc-chlorite sköls have been developed.

The Rösberg and Slåtterberg mines are the only ones in the region now described where magnesia-metasomatic alterations have played an essential role. Sulphide ores of the Falun type have not been found in the region.

The Iron Ores of the Nora and Viker Regions

(MAGNUSSON 1944)

In the Nora-Viker region and its northerly continuation the Linde-Guldsmedshyttan and Ramsberg regions, a 40 km long and relatively narrow syncline rich in dolomite accompanied by some limestone and containing iron-ores rich in manganese forms the central part of the hälleflinta-leptite series. In the northern part of this syncline P. Geijer (1944) discovered a small area of slate belonging to the Grythyttan series. Beneath the slate are found on both sides a light grey hälleflinta. Interstratifications of hälleflinta occur in the basal part of the slate formation. The ores rich in manganese have been concentrated to the dolomites but also appear in a thin zone, where hälleflinta-leptite layers alternate with limestone-dolomite rocks. This zone occurs at the bottom of the dolomites and contains in the southernmost part of the syncline the Vikersgård ores. These are banded magnetite ores with skarn and carbonate in varying proportions in their layers. The carbonates contain both iron and manganese together with magnesium and calcium. The skarn minerals are knebelite, dannemorite, biotite, and manganiferous garnet. Small magnetite grains sometimes appear as dust in both the skarn minerals and in the carbonates. Transitions exist to more coarse-grained skarn iron ores with larger irregular magnetite individuals in the skarn.

On the eastern side of the syncline a zone with quartz-banded iron ores can be followed all the way from the southern to the northern end of the syncline, though with two marked interruptions. In the Nora-Viker region the Pershyttan ores are the most important. In the Linde-Guldsmedshyttan-Ramsberg regions this zone can be followed through the Högban field to the Stråssa and Blanka mines. The Pershyttan ores are fine-grained, often schistose quartz-hematite ores in which the hematite has been more or less altered to magnetite. Some ores are rich in leptite material. This material was originally vitroclastic and deposited together with the ore material. The surrounding leptites have been recrystallized and locally mobilized in connection with the intrusion of the young palingenic pegmatites, which have also supplied the ores with small amounts of material to form such minerals as tourmaline, beryl, and orthite. Tourmaline is especially common in the pegmatites. The original ore sediment ought to have contained some limestone-dolomite material, since skarn silicates such as garnet, pyroxene, actinolite, epidote, and hornblende have been found here and there, though only in small quantities. The best preserved ores show good banding – layers of hematite with small quantities of quartz alternate with layers of ferruginous quartz with a red colour. As a consequence of strong folding, regional thermal metamorphism, and the invasion of pegmatites, the banding has largely disappeared, especially where the hematite of the ores has been altered to magnetite. The red colour of the ferruginous quartz to a large extent disappeared with increasing metamorphism of the ores. Instead, the quartz got a greyish blue colour which is particularly common in the Pershyttan ores. Schistose types of these ores are rich in micas. The ores then have a high content of alumina. A strong zigzag type of folding is common in the central part of the Pershyttan field.

On the western side of the syncline there is no continuous zone with quartz-banded ores, but west of Nora city an area of such ores stretches about 5 km westwards, nearly perpendicular to the central zone of the syncline. In this area, the Striberg field, S. Hjelmqvist (1942) has carried out thorough investigations. The strong metamorphism of the rocks and the ores depends here, as in the Pershyttan field, upon the intrusion of late Svecofennian palingenic granites and pegmatites. These have caused intense granitization and alteration of the leptites to mica schists, often including the formation of subordinate amounts of cordierite and sillimanite, occasionally also anthophyllite. The granitization has locally given origin to granite-looking rocks frequently rich in muscovite. The mica schists wedge from south and southeast into the better preserved rocks. We have here the outermost alterations connected with the formation of the veined Sörmland gneisses. The same is true for the pegmatitization in the Pershyttan field as described above.

The quartz-banded ores in the Striberg field are beautifully developed and consist of hematite with some magnetite. Sometimes the hematite ores have been totally transformed into magnetite ores. The skarn minerals are garnet and epidote. The occurrence of these minerals indicates that limestone material has been deposited together with the ores. It is interesting to note that in two places in the mines limestone-banded hematite ores have been found as remnants.

The Åsboberg ores are situated in a broad zone of mica schists, and the quartz-banded hematite ores have here been altered to scaly hematite ores with quartz, micas, and chlorite. Here and there, however, the original banding has been preserved even in these ores.

The quartz-banded ores in Striberg and Åsboberg occur in a horizon of leptites rich in potash, which has been folded to a short, closed basin dipping towards the northeast. This basin has later been cut by several nearly vertical faults orientated northeast-southwest. Movements along the faults have separated the ore layer into several units.

In Åsboberg a layer no more than about two meters thick has been duobly-folded, and the folds have been forced together to a stock with an area of about 500 m², which has been followed to a depth exceeding 600 m.

North, west and southwest of the quartz-banded iron ores in the Striberg field occur several quartz-skarn-iron-ores in sodic leptites. The etage with these ores is a continuation of the syncline mentioned above and extending southeast from the Grythyttan field. The same etage also appears south of the Pershyttan field with its quartz-banded ores. The author was able to study the quartz skarn iron ores in the Klacka-Lerberg and Dalkarlsberg mines several years ago before they were abandoned (Magnusson 1944).

The ores in Klacka-Lerberg have been very fine-grained magnetite ores rich in quartz together with actinolite, biotite, chlorite, and very subordinate epidote and garnet. Hematite ores rich in quartz, often with a red tint and then reminiscent of ferruginous quartz, have been found locally as relics. The author has never found banding in these ores, and it seems quite clear that the original ores were dense hematite ones with a high percentage of ferruginous quartz. The ores worth mining in Klacka-Lerberg passed into large quartz masses poor in magnetite. Even here remnants of hematite and of red ferruginous quartz could be observed. Along the leptite contacts the ores were rich in micas in a narrow zone. Microscopic investigations show the ores to have been originally uniformly dense but with larger grains formed during thermal metamorphism. The larger grains are thus later recrystallization products. The ores were most probably precipitated in a colloidal form as very small grains of hematite. These were later changed to magnetite which grew in grain size with rise in temperature.

In the Linsgruvan ores northwest of Klacka-Lerberg the percentage of skarn was higher and among the skarn minerals pyroxene, garnet, and actinolite dominated. The percentages of CaO and MgO were thus considerably higher than in the Klacka-Lerberg ores. No hematite has been found in the Linsgruvan ores, but the same recrystallization process as in Klacka-Lerberg has originated magnetite grains ranging from very small to relatively large sizes. Even here it is quite clear that the original ores must have been very dense and that the quartz was of the ferruginous type. Very fine-grained remnants point in this direction. Even these ores have been hematite ones

The Dalkarlsberg ores are situated in a broad zone of mica schists resembling the mica schists described above from the Striberg field. The difference is that the alteration of the leptites to such schists was much stronger in the Dalkarlsberg field. This alteration was obviously connected with late Svecofennian palingenic processes. Late Svecofennian pegmatites also appear in the mica schists, which consist chiefly of biotite, chlorite, and talc and are also rich in orthite, tourmaline and apatite.

The Dalkarlsberg ores show many variations. They must once have been of the same type as the Klacka-Lerberg ores. In connection with the intense alteration of the leptites to mica schists the ores have been altered to coarse-grained quartziferous magnetite ores with coarse-grained remnants of hematite ores.

In both the magnetite ores and the hematite ores the author has found remnants of more fine-grained ores suggestive of the Klacka-Lerberg ores. In transition types between magnetite and hematite ores the author has observed magnetite as isolated larger grains in more fine-grained hematite ores and larger grains of hematite in more fine-grained magnetite ores. The percentage of quartz has been high. The essential skarn minerals are the same as in the mica sköls. The high percentage of new-formed apatite has made the ores in the Dalkarlsberg mines much richer in phosphorus than the Klacka-Lerberg ores. The phosphorus content in the Dalkarlsberg ores has varied between 0.030 and 0.230 % with an average of 0.085 %, whereas the Klacka-Lerberg ores had only between 0.003 and 0.020 %. Tourmaline and orthite has occurred in the ores and in the schists. Apatite has been present in very variable quantities growing higher where the alterations were greater. The plasticity of the schists and the skarn caused great difficulties in mining at lower levels.

The Iron Ores of the Linde-Guldsmedshyttan and Ramsberg Regions

In the Linde-Guldsmedshyttan and Ramsberg regions described by GEIJER (1944), quartz-banded iron ores appear on both sides of the syncline with its slates, hälleflintas, dolomites, and iron ores rich in manganese. The best preserved quartz-banded iron ores in the whole Central Sweden are those in the Stripa mine (Geijer 1938), west of the syncline. The dominating ore type here is beautifully and regularly quartz-banded hematite ores, in which magnetite appears as porphyroblasts in the hematite layers. The hematite is always granular, never scaly. The quartz has been ferruginous and is still often well-preserved. Skarn silicates often appear irregularly distributed in the ore layers or concentrated to contacts between ore and quartz layers. These silicates are actinolite, pyroxene, and sometimes epidote. Garnet is rare. In the rythm marked by the alternation of hematite and quartz bands, two different types can be easily discerned in the main ore body. The one of these may be characterized as doubly-banded with comparatively thick bands, the other as simple-banded with thinner bands. The doubly-banded ore consists of hematite bands with thin intercalations of skarn and often also thin layers of quartz containing small amounts of minute hematite grains and narrow intercalations of hematite. Large parts of the main ore body are made up of this type, the hematite bands usually measuring 4 to 7 cm in thickness and the quartz bands 3 to 4 cm in thickness. Single bands may have thicknesses decreasing to about 2 and 1 cm respectively. The simple-banded ores have hematite and quartz bands of approximately the same thickness, about 0.2 to 0.5 or up to about 1 cm. A tendency for the development of internal stratification is, however, sometimes evident.

Slumping phenomena have locally been observed in the Stripa ores. In addition to the common porphyroblastic development of magnetite in the hematite bands, attention should be paid to the occurrence of quartz-banded ores in which the iron mineral is entirely magnetite, generally in the state of rather small grains. Most of the magnetite ores in Stripa seem to have undergone a secondary enrichment process which, when carried to its conclusion, has resulted in a very rich, coarsely crystalline magnetite ore. However, high-grade hematite ore has also resulted from a similar enrichment but is much rarer. The enrichment process has included a gradual disappearance of the quartz-bands. This description of the Stripa ores has been condensed from P. Geijer (1938).

At the 350 m level uraniferous minerals have been found filling several fissures in the ores. According to E. Welin (1964), these fissures and the uraniferous minerals as well should be younger than the late Svecofennian palingenic granite, which has intruded the iron ores.

In 1927, P. Geijer published a paper about the ores in the Stråssa mine. Later H. J. Koark (1960) has made additional investigations for the Gränges Company, which owns the mine.

The Stråssa ores can, according to Koark, be divided into the following types:

1. Quartz-banded magnetite and hematite ores accompanied by variable amounts of skarn minerals (hornblende, diopside, epidote).

2. Homogeneous quartz-magnetite and hematite ores with variable proportions of magnetite: hematite.

3. Non-homogeneous quartz-magnetite and quartz-hematite ores rich in mica, streaky, and rich in sköls.

4. Magnetite-hematite ore in diopside-actinolite-grossularite-epidote-calcite-quartz skarn. The magnetite has often been martitized along the edges.

5. Magnetite ore in diopside and green hornblende skarn. Mostly without striation. Often considerable "sköl" formation.

Sometimes there are sulphides (pyrite, chalcopyrite, pyrrhotite) in the homogeneous quartz-magnetite-hematite ores and in the diopside – green hornblende skarn iron ores.

The iron content of these ores varies between 25 and 45 %. The ones mentioned under 1) and 2) have, on the whole, the highest iron contents. Apart from the ores mentioned above, there also occur large quantities of leptites which are impregnated with hematite and magnetite to a lesser or greater extent. Their iron content is, however, too low (10–25 %) to permit mining.

Magnetite as the general successor to hematite shows idioblastic development throughout. There are sometimes porphyroblasts up to 10 mm diameter within the hematite ores. In some single cases magnetite porphyroblasts occur also in potash leptites. Magnetite concentrations as reaction products are usually found at the boundaries between the hematite ore and the leptite. There are also rich magnetite formations in the contact aureoles round the pegmatites. These, however, belong to a much later phase (Late Svecofennian) which has no part any more with the extremely ample Svecofennian metamorphic recrystallization.

In the Stråssa ores of Storgruvan and Nygruvan, the sedimentary structures have been preserved reasonably well in spite of strong recrystallization. In the Öster mine, on the other hand, pronounced foliation has completely annihilated the sedimentary structures. Not all deformation structures need to be of post-diagenetic age, however. Apart from the formation of breccias in the ores of the Öster mine, only a paradiagenetic slumping horizon, has been affected at the edge by the later foliation of the Öster mine ore. The quartz lump deposits observed can also be interpreted as paradiagenetic formations.

The Blanka ores 1.7 km south of Stråssa are according to Koark presumably situated at the same stratigraphic horizon as the Stråssa ores, or perhaps somewhat higher. They consist in part of coarse crystalline magnetite mixed with quartz, chlorite, and mica. Sometimes they are not particularly rich. Richer hematite ores with magnetite crystalloblasts have also occurred and have been more interesting from a mining point of view. In both types of ore it was possible to detect relicts of previous quartz banding.

The ore configuration in the Blanka mine shows poorer stratification than at Stråssa, displaying concordant columns and stocks without any particular stratigraphic connection. The ores have been frequently influenced tectonically as well as by pegmatites and by recrystallization at the contacts. The sköls characteristic for Blanka are zones of shear and pressure movement with or without recrystallization.

Pitchblende and uranium hydrates were found in the sköl-formations in the Blanka mine. This mineralization can, according to Koark, be connected with the numerous Late Svecofennian pegmatites. E. Welin (1964) has, however, found that the fissures and uraniferous minerals are younger even than the pegmatites, as in the Stripa mines.

The Grönvåld and Högban fields are situated south of Stripa and Stråssa, the former on the western side, the latter on the eastern side of the syncline. In 1944, Geijer has characterized the ores in these fields as thin, fine-grained, relatively rich hematite ores, and sometimes showing a diffuse banding. These rich ores alternate with layers of greenskarn with some ore minerals: magnetite or hematite, poor quartz hematite ores, leptite layers, and layers of dolomite and limestone. The skarn layers in Högban, essentially actinolite and diopside, are a few dm thick. In the skarn layers there are, here and there, remnants of leptite indicating exchange of material between the ores and the carbonate rocks on one side and the leptite layers on the other. The fragments of leptite in the Högban ores are often impregnated with hematite. In the richer hematite ores the quartz sometimes has the character of ferruginous quartz. In the Grönvåld ores the skarn minerals include diopside, actinolite, and garnet. According to B. Santesson (1889) rich, fine-grained hematite ores were once mined here, but Geijer's study of the dumps has indicated the existence of magnetite ore alternating with skarn layers and carbonate layers sometimes with magnetite and tremolite, sometimes with ophicalcite and serpentine. Quarz layers have also been found in skarn and ore. Sometimes a leptite richly impregnated with hematite and some magnetite and with fragments of pure leptite was the dominant type.

In the Vildgruvan mines in the northern part of the Grönvåld field the best ore was a magnetite one with actinolite-pyroxene skarn containing some garnet and alternating with carbonate rocks rich in ophicalcite. The complex of magnetite ore, skarn and carbonate layers appears in a leptite richly impregnated with hematite but with pieces of pure leptite also. This leptite has been considered as a poor hematite ore.

In these two fields there must have been a quickly varying sedimentation of ore material, dolomite, ferruginous quartz and volcanic tuff material, formed at the same time as the ore material. The tuff material locally passes into volcanic breccia with ore material.

Between lake Usken and lake Rossvalen there is, in the central part of the syncline belonging to the uppermost etage among the four iron-ore-bearing etages in Central Sweden, a 9 km long horizon with iron ores rich in manganese. These occur as thin layers in dolomite. Some of the ores are magnetite-carbonate-ores, others are magnetite-skarn-ores. The carbonate is dolomite containing iron and manganese in varying proportions. The characteristic skarn mineral is knebelite. Against the leptites there is sometimes a manganese-bearing skarn of biotite together with garnet, hornblende, and pyroxene. Sometimes quartz and microcline occur in this skarn as remnants of the leptites. The irregular impregnation of sulphides, particularly sphalerite, galena and chalcopyrite, is unfortunate. At a few places, however, these minerals are concentrated into small bodies of sulphide ore, the best known being the Siggeboda, Mårshyttan and Fanthyttan ores in the southern part of the horizon.

Manganiferous iron ores of the same type and at the same horizon occur in the large dolomite body south of Stråssa and in smaller dolomite layers in leptite in the vicinity. The ore mined in Tyskafall has been a relatively fine-grained magnetite ore in skarn of varying composition. Knebelite is formed in dolomite and in the leptites, hornblende, garnet, and mica. In Smällberg dannemorite was the dominant skarn mineral in the magnetite ores. Ores with lower percentages of manganese had frequently pyroxene as their dominant skarn mineral. The Håkansboda iron ores have about the same compositions as the Tyskafall-Smällberg ores. Apart from magnetite, sulphides (pyrrhotite, pyrite, galena, sphalerite, arenopyrite, cobaltite, glaucodote) are often present in the Håkansboda mine. The manganese content characteristic for the deposits is about 4 % and is contained in silicates, carbonates, and magnetite. In the hanging wall of these magnetite ores the Håkansboda copper-cobalt ores are situated. They occur as so called hard and soft ores. The hard ores lie in a leptite horizon which has been changed metasomatically to quartz schist. They consist of chalcopyrite, cobaltite, glaucodot, arsenopyrite, pyrrhotite, pyrite, sphalerite, galena, and native bismuth. Certain pieces of this ore contain 400 g/ton of uranium. The soft ore onsists of chalcopyrite in schlieren in ophicalcitic dolomite.

At the same horizon but on the western border of the syncline the Guldsmedshyttan silver ores are situated. These contain galena, sphalerite, pyrite, pyrrhotite, and arsenopyrite in manganiferous iron ores with dannemorite skarn and dolomitic limestones as thin layers in the hällflinta complex.

The manganiferous iron ores in the Jönshyttan mines are situated at the same horizon. We know, however, very little about them.

At its northern end the syncline branches into two. One passes through the Gränshyttan field with its quartz-banded iron ores and north of this field skarn iron ores rich in quartz. The other branch passes from Stråssa through Riddarhyttan and Fagersta to Norberg.

The ores in the Gränshyttan field (Geijer 1944) are partly hematite ores, partly magnetite ores. The hematite ores are quartz-banded, partly with scaly hematite grains, partly with small rounded hematite grains. The magnetite ores are sometimes massive, sometimes quartz-banded, and show all transitions to the quartz-banded hematite ores which usually form kernels in the magnetite ores. It is quite clear that the magnetite ores are alteration products of the hematite ores. The percentage of quartz is often lower in the magnetite ores than in the original quartz-banded hematite ores. The percentage of iron has therefore been higher in the magnetite ores than in the hematite ores, a normal feature for the quartz-banded iron ores of Central Sweden.

The leptite has been altered extensively to a coarse-grained biotite schist rich in sillimanite. This schist sometimes passes into almandite-gedrite-quartzite. Pyrite and subordinate chalcopyrite are common in the magnetite ores but have never been found in the hematite ores. Both alteration of the original hematite ores to magnetite ores and introduction of sulphides occurred in connection with the metasomatic alterations which gave birth to the schists and the quartzites. The whole has been cut by numerous late Svecofennian palingenic pegmatite dikes from the large granite body in the west.

The Ingelsgruvan mine (Geijer 1944) is situated between the Gränshyttan field and Stråssa. The quartz-banded hematite ores and the surrounding leptites are intersected by a great many late Svecofennian pegmatites. The hematite ores in contact with the pegmatites have been altered to magnetite ores, the banding of which has usually disappeared. At the same time some quartz was driven out of the ores richer in iron. Assimilation of ore material occurred only on a small scale. On the contrary pegmatite material has sometimes gone into the ores. The leptite is normally schistose and the pegmatites have had a great influence, the solutions wandering along the schistosity planes. The result has been the formation of muscovite schists often together with quartzitic rocks rich in sillimanite. In other places the leptites became enriched in newly formed microcline. Pyrite and chalcopyrite appeared, especially in the magnetite ores. In one mine, the Springa mine, the content of copper minerals was so high that it was possible to mine for copper. This ore also contained bornite and fluorite.

In the Gränshyttan field and the Ingelsgruve mines it is difficult to decide whether the sulphides were introduced in connection with magnesia-metasomatic alterations which have been reworked by the palingenic processes simultaneously with the intrusion of the pegmatites, or have accompanied the pegmatites that are connected with the large massive of young Svecofennian palingenic granites to the northwest. There is much in the Gränshyttan and Ingelsgruvan fields that reminds of the pegmatite invasion in the Kantorp ores. The alterations have, however, been much more intense in the Kantorp field.

Southwest of the Gränshyttan field there are in the Nyberg field (Geijer 1925 and 1944) several small occurrences of skarn-banded hematite ore with manganese silicates. They are, according to Geijer, quartz-banded iron ores in which SiO_2 has been associated with manganese to such a degree that the ores are nearly free from quartz. They have about the same percentage of Mn and Fe, about 15 to 20 % of both. The mineralogical composition is, according to Geijer, essentially hematite and rhodonite assembled into thin, alternating layers. A yellow garnet is also a common component.

The Rocks and Iron Ores of the Ljusnarsberg Region

(Magnusson 1940 and 1944)

In the Ljusnarsberg region, described by the present author in 1940, it is difficult to distinguish between original lavas and tuffs in the volcanic complex. This depends on strong deformation and recrystallization. However, here and there remaining primary structures occur, facilitating identification. These are idiomorphic quartz and feldspar phenocrysts in ancient lavas. The ash-structures of the tuffs have disappeared, though the larger grains show here and there boundaries of clastic character, sometimes also a clastic rounding. Even macroscopically the tuffs are observed to have retained part of their stratification, which has often got rather pronounced owing to intercalated layers of limestone and dolomite. However, the best proofs are supplied by coarse agglomerates, which occur here and there.

As found by the author previously in the Filipstad region, the intensity of metamorphism increases when approaching the contacts of the old synorogenic and young palingenic granites. Phenocrysts in the lavas and larger clastic grains in the tuffs also disappear, the leptites thus acquiring a uniform granoblastic texture. When approaching the late Svecofennian palingenic granites with their pegmatites, the texture gradually becomes nearly granitic. All traces of the original textures have then been removed.

Folding and deformation of the leptite complex in combination with re-recrystallization gave its rocks a more or less pronounced linear structure. However, still younger recrystallization brought about by the late Svecofennian palingenic granites caused the minerals over large areas to take on new orientations.

Potash leptites form an upper zone but also occur subordinately in the lower zone, where sodic leptites predominate. The upper zone is, as usual, characterized by iron ores rich in manganese. All iron ores in the lower leptite zone are poor in manganese. The leptites are crowded with intercalations of limestone and dolomite of varying thickness. The upper parts of the leptite complex are especially rich in carbonate rocks. With the exception of a few quartz-iron ores, all iron ores of the Ljusnarsberg region occur together with or in limestones and dolomites.

In a zone rich in agglomerates within the uppermost parts of the leptite complex, scoriaceous greenstones have also been found. These appear either as fragments in the agglomerates or as coherent beds. The latter occur together with massive greenstones characterized by a plagioclase rich in anorthite, whereas the plagioclase of the scoriaceous greenstones is rather low in anorthite and often albitic. The amygdules of the scoriaceous varieties are usually filled with calcite. In other varieties this mineral is entirely or partly replaced by skarn minerals, particularly pyroxenes and amphiboles.

The uppermost zone of the supracrustal complex consists of greywackes and slates. The greywackes occupy a very thin zone between the leptites and the slates, which are here the highest stratigraphic members of the supracrustal rocks and correspond to the grey slates in the Grythyttan and Saxå fields. No black slates have been observed. The grey slates are characterized by biotite, muscovite, andalusite, cordierite, and sillimanite. Andalusite occurs in the least metamorphic types in the south and sillimanite in the most metamorphic varieties in the north. The slates and the greywackes show textures intermediate between clastic and granoblastic. When recrystallization was sufficiently strong, the larger grains became split up into smaller grains with sizes about equal to the surrounding grains. The microcline grains have, as usual, been broken and have recrystallized first, then the quartz grains. The plagioclase has been more capable of resisting recrystallization. Where the amount of micas is higher than usual, the original rounding of the quartz and feldspar grains has been best preserved.

The greywackes consists of quartz, feldspar, and subordinate micas (biotite and muscovite). In thin intercalations the amount of mica can be as high as in the slates. The larger feldspars usually consist of plagioclase and vary from albite to albite-oligoclase, sometimes even to oligoclase. The groundmass, however, is often rich in microcline. Originally larger microclines have frequently been incorporated in the groundmass.

The stratigraphy is thus about the same as in the Grythyttan and Saxå fields and their surroundings. The black slate is missing ,however, and in the lower leptite division a higher percent of alkali-intermediate leptites appears together with the soda leptites which here dominate in the same way as in the Nordmark district of the Filipstad region.

The iron ores rich in manganese in the Ställberg and Bastkärn mines appear in a complex of alternating limestone-dolomite and leptite layers. Often layers approaching 1 mm in thickness alternate with each other. Of the limestone-dolomite layers only a few contain iron ore, and even there the ore is a subordinate constituent. These circumstances indicate that the deposition of carbonate rocks has been a more regional and the formation of iron ore a more local phenomenon.

In the Ställberg ores the content of iron is about 50 % and the content of manganese about 5 %. The content of silica (SiO_2) is between 6 and 10 %. Only about half the manganese is bound in silicates, particularly in knebelite and in the more subordinate dannemorite. The other half is present as manganese carbonate together with carbonates of calcium, magnesium, and iron or in the magnetites. G. T. Lindroth has found 2.41 % Mn in a collection of separated magnetite grains from Ställberg.

In the Bastkärn ores the amount of iron varies between 32 and 51 %. About 3.9 % manganese is present. The amount of silica is high, sometimes more than 20 %. The content of manganese carbonate is therefore very low but the amount of manganese silicates, knebelite and dannemorite high. G. T. Lindroth has found 2.51 % Mn in a collection of separated magnetite grains and 1.55 % Mn in another collection.

At boundaries between leptite layers and iron ores rich in manganese exchange of material has taken place producing reaction skarn. This skarn consists of garnet, amphiboles (either hornblende or dannemorite), pyroxene, and biotite. The garnet contains the spessartite, grossularite, and almandite molecules in varying proportions and mixed with small amounts of andradite. Leptite layers in the Bastkärn ores have in such a way frequently been replaced by skarn layers with remnants of leptite. Large grains of microcline have often grown in this reaction skarn. The material for microcline was naturally taken from the potash leptites.

That the skarn mentioned is a reaction one younger than the ore itself is quite obvious from the fact that several leptite dikes in the Ställberg mine and the Hagruvan mine, southwest of Ställberg, are younger than the ores. Furthermore reaction skarn of the same type as occurs close to the leptite layers has been developed between the dikes and the ores. We have here convincing evidence that the formation of the ores is one process and the formation of the skarn another, the latter being younger.

A characteristic feature of the best preserved iron ores of the Ställberg-Bastkärn type is that the magnetite often appears as a fine powder in both carbonates and silicates. This powdering disappears where the metamorphism has been stronger. Here the magnetite material has been collected in larger grains in the same way as in the quartz-skarn-iron ores in the Klacka-Lerberg and Linsgruvan ores as well as in the ferruginous quartz in Långban and other places. The primary ores in Ställberg and Bastkärn ought thus to have been very fine-grained.

The Ställberg ores terminate as rounded or less regular magnetite-skarn concentrations of varying size. The Haggruvan ore have such rounded ore layers on a large scale. In the Svartvik ores, in the southern part of the same horizon, the ores display parallel-orientated stocks in a iron-ore-bearing carbonate bed. It is quite clear that a continuous ore layer existed here and became later, in connection with the folding, divided into separate stock-like bodies.

East of the Ställdalen greywacke-slate syncline, the Sköttgruvan-Mossgruvan ore layers have the same stratigraphic position as the Ställberg and Bastkärn ores. In Mossgruvan subordinate knebelite-dannemorite ores formed. Towards the south-west they pass into a limestone-banded magnetite ore in Sköttgruvan, which normally has between 0.35 and 0.70 % Mn. The amount of silica is only 1.8–4.1 %.

Owing to pre-glacial weathering, most of the ores in Mossgruvan have been altered to soft ores with more or less martitized magnetite, limonite, and siderite. Is has been found that all or most of the limonite has been developed by 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. Afterwards, surface waters percolating downwards more or less completely oxidized the siderite to limonite and parts of the remaining magnetite to martite.

The largest masses of siderite occur in the Mossgruvan mines. In the other mines with soft ores in Central Sweden, 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. Simultaneously with this alteration, the neighbouring leptites, granites, and diabases became kaolinized. The quartz grains of the granites have frequently been preserved. Silica has, however, been dissolved on a relatively large scale and transported downwards as colloids, later on precipitated as opal and chalcedony. In the

Mossgruvan mines the deposition of these minerals penetrated deeper than the formation of siderite and is traceable even in the massive ores underneath the soft ores.

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

Martitization followed the octahedral faces as well as fissures and surfaces of the magnetite grains. At the same time limonite replaced siderite and later also martite and magnetite. In the Mossgruvan mines the original ore had between 0.5 and 3.0 % Mn. In the soft ores the manganese content has always been about 3 % Mn.

According to old mining records the manganiferous ores in the Silkesberg mine in the northwestern part of the Ljusnarsberg region were thoroughly altered to soft ores near the surface. The present author has also found in several small ores in the western part of Ljusnarsberg the magnetite grains to be more or less altered to martite.

The westernmost part of the Bastkärn ores has been altered to soft ore consisting of magnetite more or less changed to martite, limonite, kaolinite, and very little siderite. The colour of the weathered ores is yellow, brown or nearly black.

The iron ores poor in manganese and also poor in quartz in the Ljusnarsberg region show the same variations as the corresponding ores in the Persberg district west of the Saxå field and in the broad Hjulsjö-Järnboås anticline east of the Grythyttan field. The western part of the Ljusnarsberg region can be considered as a direct continuation of this anticline. A noteworthy feature is that small amounts of quartz have often been found as remnants in the ores belonging to the lowest etage in the Ljusnarsberg region. In one case it had the appearance of ferruginous quartz. In another occurrence hematite has been found as a remnant mineral.

The magnetite is in most cases accompanied by a pyroxene which is usually more diopsidic than hedenbergitic. Varying quantities of hornblende generally occur together with the pyroxene. The pyroxene-hornblende association may be said to be characteristic of the Ljusnarsberg skarn-iron-ores poor in manganese. The hornblende is largely a metamorphic product after pyroxene and is mainly found close to granite veins cutting the ores and towards leptite boundaries. The leptites themselves have been intruded by skarn veins consisting chiefly of hornblende. Small quantities of actinolite, garnet, and epidote generally occur in addition to the above-mentioned minerals. The actinolite has often been metamorphosed to hornblende, and the epidote often replaces garnet.

In the southern part of the Ljusnarsberg region quarts-skarn-iron ores are frequent. These are often beautifully banded and locally also contain hematite as an ore mineral. In a few occurrences the quartz resembles ferruginous quartz. Nowadays the quartziferous ores largely occur as remnants in the skarn ores, and it is evident that they were originally much more extensive. They were largely consumed during the formation of the skarn masses, which evidently post-date them. A well preserved, persistent bedding is found, particularly in the Salboberg mines in the southwestern part of Ljusnarsberg. In this occurrence there was originally an alternation of leptite strata, quartz- and feldspar-bearing limestone-dolomite strata, rather pure limestone-dolomite strata, limestone-dolomite iron ores, quartz-iron ores, and pure quartz beds. The limestone-dolomite strata as well as the quartz and leptite were to a great extent consumed during the subsequent skarn formation. Where this was more intensive, the bedding was entirely destroyed and skarn-iron ore bodies of irregular shape resulted.

The present author thus considers it quite clear that the skarn-iron ores with preserved bedding were deposited as sediments with a primary alternation of more or less siliceous ore beds, calcareous ore beds, pure limestone-dolomite and silica beds, and leptite beds. The present mineralogy was developed by the regional metamorphism accompanying the appearance of the synorogenic Svecofennian granites.

In some cases primary stratification is lacking and ores are irregular throughout or have irregular boundaries. In other cases an irregular distribution of ore, skarn, limestones, and dolomites prevails. In such cases and when studied empirically without reference to the surroundings, the skarn and ore could be considered primary and of the same age. Both should then be the result of metasomatic processes at high temperature. The development and mineralogical composition of the skarn, however, are just the same as in occurrences where the bedded ores were metmorphosed into more irregular, massive ores during the process of skarn formation.

The ores poor in manganese so far described have all been rich in lime. In many places they change into types poor in lime but rich in magnesia. The mineralogical composition then undergoes a considerable change. Instead of pyroxene, actinolite, hornblende, garnet, and epidote, we find pure diopside, pure tremolite, anthophyllite, cummingtonite, phlogopite, biotite, chlorite, talc, olivine, chondrodite, and serpentine. The list of minerals shows that the ores rich in magnesia have a much more complicated composition than those rich in lime. The variation is also very much greater from one point to another in each ore body. Water and fluorine also play an important part in the development of the skarns rich in magnesia. Fluorite and orthite are among the minerals occurring in small quantities in these skarns.

Where anthophyllite and cummingtonite occur in large quantities, it is found that the neighbouring leptite has been transformed into leptite rich in quartz or into quartzite containing minerals such as gedrite, cordierite, and mica. Where no quartzite has been formed, a metamorphism in that direction has been established, marked by the occurrence of scattered gedrite individuals or an irregular formation of mica in the leptite. At the boundary between skarn and iron ore on the one side and leptite on the other there is usually a sköl zone rich in mica. Similar though weaker sköls are sometimes also found close to the ores rich in lime and are here the only signs of the kind of alteration usually called magnesia-metasomatism. An increased strength of the latter should have required the entrance of more magnesia in the ores at a later stage of the petrological evolution.

Where the magnesia-metasomatic processes have been most intense, the leptites have been changed to mica schists and quartzites characterized by minerals such as cordierite, almandite, and gedrite or anthophyllite. The older limestone and dolomite bodies within the alteration areas have simultaneously got minerals rich in magnesia accompanied by sulphides such as pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. At boundaries between the original carbonate bodies and the leptites now altered to quartzites and mica-schists great sköl zones occur.

In the Ljusnarsberg region a great many sulphide impregnations and concentrations have been found. Only two concentrations have been mined, however, in recent time, namely the Kaveltorp and Ljusnarsberg sulphide ores. In the former, magnetite was only found sporadically. In Ljusnarsberg, on the other hand, it was a normal constituent of much of the sulphide ore. The present author could establish by microscopical investigations that the magnetite had always crystallized before the sulphides, the latter having the following crystallization sequence: pyrite, pyrrhotite, sphalerite, chalcopyrite, galena and, lastly, some bismuth minerals. It is therefore possible that the magnetite in this association was formed by the same process as the sulphides. In large parts of the sulphide ores the content of magnetite is essentially higher than the content of sulphides and is sometimes sufficiently abundant to be called iron ore. This is especially the case at the northern boundary of the Ljusnarsberg occurrence, where it has been test-mined. The content of chalcopyrite and other sulphides was, however, too high. These iron ores rich in sulphides pass northwards into skarn-iron ores and well-banded quartz-skarn-iron ores. Some of these have been hematite ores or hematite-magnetite ores and the skarn minerals garnet, epidote, pyroxene, and actinolite. Here and there sulphide impregnations have been found, sometimes together with more magnesiarich skarn minerals and cordierite-gedrite quartzites. The sulphides in this zone are pyrite, pyrrhotite, and chalcopyrite.

The magnetite in these ores and in the magnetite concentrations in the northern part of the Ljusnarsberg occurrence no doubt originates from older iron ores. It is therefore difficult to determine how much of the magnetite has been developed together with the sulphides. It must, however, be a very small quantity in comparison with the quantity that has come from the old iron ores.

The many small sulphide impregnations and sulphide concentrations present in other magnetite iron ores in the Ljusnarsberg region indicate the same thing. Hardly any magnetite has come from outside. Instead, observations on the sulphide-impregnated ores from Perrabacken and Blyberg and microscopical examinations of material from these clearly indicate that the silicates and magnetite together acted as a unit before the introduction of the sulphides. The latter forced their way into the magnetite by dissolution, leaving only remnants behind. In connection with the dissolution of the magnetite, pyrite was formed. In these mines pyrite appears only where irregular remnants of magnetite are present. It is therefore very probable that the iron in the pyrite was taken from the magnetites of the iron ores.

While the sulphide ores of the Falun type are connected with the synorogenic svecofennian granites, the sulphide ores of the Yxsjö-Hörken type are genetically connected with the young palingenic granites and their pegmatites. Especially in the pegmatites and in rocks intersected by these molybdenite and scheelite together with fluorite have been found at various places in Central Sweden though usually only in small amounts.

In the Yxsjö mines (Lindroth 1924 and Magnusson 1940), in the northern part of Ljusnarsberg, comparatively large concentrations of scheelite have been introduced into limestones affected by pegmatite materials from an underlying granite, however. Most of the limestone has 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 places they are mixed together in varying proportions. The skarn and pegmatite minerals are often large, and quartz and hedenbergite specimens more than one metre long are often 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 old times, considered as copper ores. Since scheelite was discovered they have been mined 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 iron ore is not accessible at present but it is clear from older observations that the ore and its skarn are older than the amphibolite dikes. The latter are in their turn older than the scheelite-bearing skarn and pegmatite masses.

In the nearby Hörken mines (Magnusson 1940), the same hedenbergite-garnet-amphibole skarn has been found in connection with exploration. The skarn has got mixed with pegmatite minerals (quartz, microcline, and plagioclase), a large amount of fluorite and pyrrhotite, as well as small amounts of pyrite, chalcopyrite, scheelite, and molybdenite. The amounts of these minerals correspond to 0.10 % MoS_2 and 0.08 % WO_3. As the areas are small, these occurrences were not considered worth mining.

It is interesting to note that two older ore types were found in the Hörken mines, 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 older than the amphibolites. The latter, on the contrary, are strongly influenced by the scheelite-molybdenite-bearing skarn-pegmatite masses which ought thus to be younger.

In the northern part of Ljusnarsberg, around and between Yxsjö and Hörken and in adjacent parts of Dalecarlia, small occurrences with the same skarn minerals and with scheelite and/or molybdenite have been found. Often scheelite and/or molybdenite have entered the iron ores as isolated grains. Scheelite and molybdenite belong neither to the reaction skarns nor to the magnesia-metasomatic alterations. They are younger palingenic products.

In the east the Ljusnarsberg district is occupied by the western part of the large Malingsbo granite massif. This massif belongs to the late svecofennian palingenic granites which here contain an abundance of more or less assimilated remnants of leptites, older granites, carbonate rocks, and iron ores. From the large massif aplite and pegmatite dikes and veins intersect the supracrustal rocks. Towards the west, southwest and northwest smaller rounded massifs of young palingenic granites appear. They are surrounded by pegmatite dikes. According to the present author it is clear that these smaller massifs are connected at depth with the large massif and form an entity from which smaller off-shoots forced their way up. It is with such off-shoots that the Yxsjö and Hörken scheelite-molybdenite ores are connected.

In the remnants of older rocks in the young palingenic granite of the Malingsbo massif occur here and there remnants of skarn- and quartz-iron ores also. All these remnants have been invaded by quartz and feldspar material – forerunners to complete assimilation. The skarn minerals have been replaced by hornblende and epidote, sometimes also by biotite. Where the granite had more completely assimilated the skarn iron ores magnetite, hornblende, and epidote appear as spots and schlieren. Where larger ore remnants occur kernels of skarn-iron ore with pyroxene and sometimes also with garnet have been found with hornblende and epidote close to the surrounding granite. Veins and dikes of pegmatite have intersected the ores, and large parts of these have been assimilated. Some of the ores have been altered by magnesia-metasomatism and have also been more or less assimilated by the granite. Outside the Ljusnarsberg region there are, in the central part of the Malingsbo massif, a great number of skarn- and quartz-iron ores more or less impregnated with granitic material. The assimilation process can here be studied in detail.

H. von Eckermann (1923) has made investigations on a remnant of limestone at Tennberg in the Malingsbo granite. Nearest the central limestone he found a zone with diopside and wollastonite, but near the granite a zone with garnet and vesuvianite.. The granite was altered at the contact to a plagioclase-quartz rock. In the Bastkärn ores the present author found vesuvianite and wollastonite at one place near the late Svecofennian palingenic granite. The author has found that the appearance of these two minerals in limestones and dolomites usually indicates the presence of young palingenic granites and pegmatites.

The Rocks and Iron Ores in the Ludvika Region, and the Silvberg-Säter and Smedjebacken Regions

(Magnusson, Hjelmqvist, Sundius and Lindroth, 1944)

In the Ludvika region north of Ljusnarsberg there are three greywacke-slate synclines belonging to the Grythyttan series. These are the Hellsjö syncline south of Ludvika, the Stollberg syncline northeast of this town and the Grangärde syncline northwest of the same town. The mineralogical composition and the structures are similar to those of the Ställdalen syncline. Andalusite-bearing rocks dominate. The uppermost iron ore-bearing etage with iron ores rich in manganese appears nearest to the sediment synclines: the Hilläng and the Stollberg-Svartberg ores on each side of the Stollberg syncline and the Burängsberg ores south of the Grangärde syncline. The Silkesberg and Tuna-Hästberg ores have no synclines with clastic sediments in the vicinity. They are themselves the highest horizons preserved in their fields. Quartz-banded iron ores appear in a 17 km long zone with a great many mines including Gräsberg in the northern part, Håksberg in the central and the Väsman mines in the southern part. These quartz-banded iron ores are situated on the western side of the horizon with manganiferous iron ores west of the Stollberg greywacke-slate syncline.

East of the manganiferous iron ores situated east of this syncline the quartz-iron ores are missing. They must have been formed in a local basin stratigraphically below the etage with iron ores rich in manganese. There is another local basin with quartz-banded iron ores in the Laxsjö field adjoining the iron ores rich in manganese in the Tuna-Hästberg field. In the lower etages beneath and west of the quartz-banded iron ores there are a great many small occurrences with skarn-iron ore poor in quartz and also a few thin zones with skarn-iron ore rich in quartz with the usual variations.

The ores rich in manganese at Hilläng, Stollberg-Svartberg and Tuna-Hästberg may be described in a few words. The Hilläng ores (Magnusson 1944) have had up to 12 % Mn but only 30–36 % Fe. They have been knebelite-magnetite ores with subordinate dannemorite and manganese carbonate as well as some iron rhodonite. These ores were the richest in manganese of the manganiferous iron ores in Central Sweden. Often they have been strongly impregnated with sphalerite and galena, and contents of 5–6 % Pb and Zn have been reported from the richer ores. The dannemorite often appears as an alteration product of knebelite. Rounded grains of knebelite and aggregates of such grains have often rims of dannemorite and magnetite around them. Such rims also appear between the knebelite grains in the aggregates. The skarn appearing towards the leptites is composed of a mixture of various minerals, particularly garnet, pyroxene, hornblende, and biotite. The most characteristic of these is the garnet, which is a red almandite rich in manganese. The skarn has often forced its way into the interior of the ores as veins and schlieren. It has also forced its way into the leptite, and there it contains microcline and some quartz but less almandite and mica.

The Hilläng ores are situated on the same horizon as the manganiferous iron ores at Bastkärn, Ställberg and Svartvik in the Ljusnarsberg region previously described.

The Stollberg and Svartberg ores (the old Väster Silvberg) are especially interesting. According to S. Hjelmqvist (1944) the manganiferous iron ores are partly carbonate ores and partly skarn ores. The carbonate has contained up to 25 % MnO. The skarn minerals are either rich or poor in manganese. The dominant silicates rich in maganese have been knebelite and dannemorite together with some rhodonite, manganese hedenbergite, and garnet rich in spessartite. The skarn minerals poor in manganese are of the usual type: pyroxene, garnet, actinolite, hornblende, and mica. The ores are richly impregnated with sphalerite and galena together with subordinate chalcopyrite, pyrite, pyrrhotite, and arsenopyrite. The sulphides appear together with garnet, amphibole, and fluorite but also in manganiferous carbonates and iron ores and in quartzites outside the ore bodies. The leptite surrounding these bodies has usually been altered to a fine-grained quartzite which is often almandite-bearing and passes into a coarse-grained almandite-anthophyllite-biotite-quartzite. Cordierite-bearing quartzites and mica schists also occur. These alteration products have been formed in connection with the sulphide impregnations of the ore bodies. The sulphides also form independent ores outside the iron ore bodies.

In the Stollberg field the most important ore, a zinc-lead-bearing manganiferous iron ore with 25–28 % Fe, 4–6 % Mn, 1.5–2 %Pb, and 3.5–5 % Zn has been mined. To the south these ores have passed into a 30 m broad zone in which magnetite has been oxidized to martite (Geijer and Magnusson 1926). The martite ores, in their turn, pass southwards into a large limonite soft ore with varying percentages of Fe and Mn. The manganese has locally been as high as 20 % in the soft ore.

The ore-bearing complex of the Tuna-Hästberg mines (Sundius 1944 and Magnusson 1944) is about 75 m thick and consists of alternating layers of carbonate-magnetite-iron ores, carbonate layers, skarn layers, and layers of leptites and amphibolites. All the iron ores are manganiferous. The percentage of manganese is, however, very variable at all levels. In the carbonate ores the percentage is usually about 1–2 % Mn but can rise to 8–9 % Mn. The highest percentages have, however, been found in a knebelite skarn which occurs as concentrations in the carbonate ores. This skarn sometimes contains magnetite and also a rhodonite rich in iron. The carbonates of the carbonate ores are calcite or dolomite. N. Sundius has found that dolomite can take up to 32 mol.-% iron and manganese carbonate, most of it manganese. In calcite he has found up to 7 mol.-% $MnCO_3$ and 2 mol.-% $FeCO_3$. The skarn silicates are knebelite and dannemorite. At the contact between the carbonate ores and the knebelite skarn on the one hand and the leptite layers on the other skarn zones of manganiferous garnet and hornblende appear. Garnet is the dominant skarn mineral, especially at the boundaries of the ores richer in manganese. The knebelite skarn passes into garnetiferous skarn in which hedenbergite with a low percentage of manganese also occurs.

The carbonate-magnetite-ores have as a rule got their good banding indicative of a sedimnetary origin preserved. G. T. Lindroth has found 18.8 % Mn in a collection of separated magnetite grains from the knebeliteskarn and 3.89 % Mn in such magnetite grains from a poor carbonate ore from Tuna-Hästberg.

The quartz-banded iron ores in the Gräsberg-Håksberg-Ickorbotten-Iviken-Väsman zone (Magnusson 1944) can be followed for 17 km. Several parallel layers are present, the better ores appearing as lens-shaped bodies formed in connection with strong tectonic deformations after the main folding. Strong pressure caused schistosity planes to develop, and these are usually parallel with the ore layers. In connection with the tectonic deformations the quartz-banding has largely disappeared. The present author could study at the surface in the central Håksberg field how the quartzbands had been cut and broken into pieces. From such types there are all transitions to ores without banding and with their quartz evenly distributed. The ores are now in the main magnetite ores often with mica and scaly hematite on the schistosity planes, and all transitions exist between magnetite and hematite ores. Often idiomorphic magnetite individuals have been found in the hematite ores and large hematite crystals in the magnetite ores. Skarn minerals have been observed as separate grains in the ores, especially amphiboles (actinolite, hornblende, anthophyllite, cummingtonite), or as layers of amphiboles, garnet, epidote, and occasionally pyroxene. The ores in the Håksberg field are between 5 and 20 m thick; hematite ores appearing towards the foot wall and skarn minerals towards the hanging wall. The central and main part of the ores consist of magnetite ores with remnants of hematite ore here and there. The surrounding leptites are oligoclase leptites, more or less altered to biotite-chlorite schists. In the most schistose ore types the hematite was scaly and the mica schists contain hematite scales on the schistosity planes. In the Håksberg field and especially in its central part the schists are rich in muscovite, a mineral which has also entered the ores themselves. Muscovite schists occur especially where muscovite-rich pegmatites of the late Svecofennian palingenic type are present. The alteration of the leptites to mica schists was thus more intense in connection with the young palingenic processes than was the case previously.

The Håksberg ores have been much mined in this century. They have had about 34 % Fe, a high phosphorus content (between 0.020 and 0.1 % P, with an average of 0.085 %). We have here a parallel to the Dalkarlsberg ores described previously, where the phosphorus in connection with the late Svecofennian palingenic processes rose to between 0.030 and 0.230 %, averaging 0.085 %.

In the Gräsberg field to the north, the schistosity is not so pronounced. Quartz-banded hematite ores dominate here, often with a skarn consisting of garnet and epidote. Towards the boundaries more coarse-grained, quartz-banded magnetite ores appear. In the hematite ores ferruginous quartz has been found here and there.

In the Källbotten field between Gräsberg and Håksberg four parallel iron ores mined have been particularly rich in a skarn dominated by a brown red garnet. Subordinate components in this skarn have been quartz, epidote, pyroxene, and hornblende. The ores have been magnetite ores with remnants of hematite ores. The author has also found scattered grains of orthite, titanite, fluorite, scheelite, and chalcocite.

In the Ickorbotten field south of Håksberg magnetite ores dominate with schistose hematite ores in the foot-wall. Good banding is uncommon. A relatively high percentage of sulphides is present, particularly chalcopyrite. Bornite and molybdenite have also been found.

In the Iviken mines magnetite and hematite ores alternate, the latter often showing good quartz-banding with a skarn of garnet and epidote. Sometimes also the magnetite ores are quartz-banded. Even here the ores are impregnated with sulphides, in particular chalcopyrite and bornite.

The author is convinced that the sulphide impregnations of the quartz-banded iron ores in the Iviken and Ickorbotten fields were connected with the palingenetic processes that gave birth to the late Svecofennian pegmatites found here and there in the zone. Bornite and molybdenite in particular are good indicators of this. The author has also found scheelite and molybdenite as isolated grains. These minerals are also connected with the late Svecofennian palingenic granites and pegmatites and have nothing to do with the original ore sediments.

The ores south of lake Väsman show variations of the same kind as the ores now described from the zone north of this lake.

The Laxsjö field (Magnusson 1944) west and north of the Tuna-Hästberg manganiferous iron ores contains a large number of quartz-banded hematite ores locally more or less changed to magnetite ores. Some hematite ores have been rich in iron and poor in quartz. Together with the quartz-banded ores there are also leptite-banded hematite ores. These ore layers are usually narrow and occur in a 6 km long and 1 km broad zone, which appears in the same stratigraphic position as the Håksberg ores described above.

The most interesting ores in the region west of the central Stollberg syncline are the apatite iron ores in the Grängesberg and Blötberget fields (Johansson 1910, Magnusson 1938, Looström 1939, Magnusson 1944). The leptites containing these ores are less alkaline than the ones dominant in the Ludvika region. The Grängesberg-Blötberget leptites are all limerich leptites varying from types rich in soda to types rich in potash. The former have grey colours, the latter red. Both types are rich in agglomerates indicating an unusually intense volcanism in the region of the large apatite-iron ores. There are also porphyritic alkali-intermediate leptites with phenocrysts of basic oligoclase or andesine.

The apatite iron ores usually constitute, in horizontal section, lens-shaped bodies orientated conformable to the bedding of the surrounding leptites. The ore bodies terminate as apophyses in the leptites. Small ore dikes have been found here and there brecciating the surrounding rocks. In some occurrences strips of leptite have been found enclosed in the apatite iron ores. In other places compact ores grade into impregnations in the leptites. Thus the apatite-iron ores behave in quite a different way towards the leptites as compared with the iron ores poor in phosphorus, and are younger than the surrounding leptites. They cannot therefore be exhalative-sedimentary ores. They have rather to be regarded as concentrations at lower levels in the volcanic complex. In my paper "Neue Untersuchungen innerhalb des Grängesbergfeldes" (Magnusson 1938) I called them subvolcanic. Perhaps intravolcanic is a better word. They have behaved like genuine magmas towards the leptites, and I have therefore often spoken of them as "magmatic ores" or as "intrusive ore magmas". I have, however, never considered them to be products of normal magmatic differentiation. My opinion is rather that they originated from the same solutions as the ones responsible for development of the exhalative-sedimentary iron ores.

The "ore-magmas" that gave us the apatite-iron ores should have been rich in gases, as they have so often impregnated the surrounding leptites with skarn minerals, apatite, and magnetite. That these impregnations have been isochronous with the "intrusion of the ore magmas" is indicated also by the numerous dacitic and andesitic leptite dikes in Grängesberg, which cut the ores and the skarn impregnations without being impregnated themselves with skarn, apatite, or magnetite. The apatite iron ores are sometimes surrounded in all directions by skarn impregnation. The large Export ore body in Grängesberg, which has an area of 55 000 m², shows, however, skarn impregnations only in the hanging wall. This ore-body is sometimes particularly rich in apatite towards the hanging wall, which has probably also been the original hanging wall, though with a dip less than at present (60° towards the southeast).

The apatite-iron ores are mostly magnetite ones, but hematite ores are often associated with them, as at Grängesberg and Blötberget. Both types seem to be primary. Certain changes in the distribution of magnetite and hematite have, however, occurred by later processes. In Grängesberg, for instance, the hematite has been altered to magnetite at the contacts of the late Svecofennian pegmatites, which intersect the ores abunduntly. Magnetite individuals then frequently appear as large phenocrysts in the hematite ores ("sevenstars ores").

If we could remove the pegmatites and the dacite-andesite dikes from the compact ores in Grängesberg, we should be able to discern the original ore bodies. The dikes make up about one fourth of the tonnage mined in Grängesberg, indeed.

The ore minerals and the apatite in the ores are as a rule accompanied by inferior amounts of quartz and skarn minerals, particularly actinolite. The subordinate minerals include biotite, muscovite, chlorite, epidote, garnet, and locally (especially in Blötberget) minerals rich in magnesia such as tremolite, anthophyllite, cummingtonite, and cordierite, the latter probably developed by 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 have assembled into spots and "schlieren". Towards the apophyses they often form masses poor in ore minerals. In the southernmost part of the Grängesberg Export field R. Looström has mapped in detail ore and skarn brecciations in the leptites. These breccias have been cut by a great many dacite-andesite and also amphibolite dikes, which lack impregnations of skarn. Smaller skarn breccias have been formed at other places in the Export field. The skarn minerals in the hanging wall of the Export field are mainly hornblende and biotite together with apatite and magnetite.

Where the ore minerals, as in the Risberg ores, occur as impregnations in leptites, the ores have a significant content of quartz, biotite, and feldspar. These ores show lower percentages of iron and phosphorus. The compact Export ores average 60 % Fe and 1 % P. The Risberg ores have only 47 % Fe and 0.70 % P.

The skarn breccias and skarn impregnations in the north of the Export and Risberg ores are wide-spread, especially in the agglomerates where they have attacked the fine-grained matrix between the well-rounded leptite-fragments. The skarn minerals are above all actinolite and hornblende accompanied by subordinate garnet and in some zones also biotite. Together with the skarn minerals magnetite, apatite, titanite, and orthite appear at various places. Here and there small magnetite ores very rich in apatite also appear in the skarn breccias, indicating the connection between the skarn breccias and skarn impregnations in the north and the compact apatite-iron ores in the south.

In the foot wall of the Export and Risberg ores appear impregnations of hematite and magnetite in the red, potassic leptites. These Ormberg-Lomberg ores are to be considered as impregnation breccias with remnants of red leptite. From such breccias there are all transitions to more concentrated ores. Owing to the genesis of these ores their minerals have become associated with quartz, feldspar, muscovite, and biotite. The amount of quartz is usually higher in the ores than in the surrounding leptites and increases even more outwards from the apatite iron ores. Simultaneously the amounts of skarn minerals such as garnet, epidote, and amphiboles increase, whereas the content of phosphorus, on the other hand, decreases from 0.20 % to 0.06 %.

The limerich leptites west of the Ormberg-Lomberg ores are also rich in such skarn minerals as garnet, epidote, hornblende, and pyroxene, frequently assembled into rounded aggregates.

The Blötberget and Fredmundberg mines are situated northeast of Grängesberg. The southern part of Blötberget consists of two ore bodies. The Kalvgruvan ores with 58 % Fe and 0.55 % P is a magnetite ore, The Flygruvan ores with 60 % Fe and 0.80 % P is a hematite ore with subordinate magnetite. The main skarn minerals in the Kalvgruvan ores are actinolite, hornblende and biotite. Together with these minerals subordinate quantities of anthophyllite, cummingtonite, chlorite, cordierite, and orthite appear locally. These magnesia-rich minerals occur also in the neighbouring leptites, often in sköl zones, indicating magnesia-metasomatic alterations.

Before 1940 only the Kalvgruvan and Flygruvan ores were mined. At that time the large Hugget ore was found. It is now the central ore in the Blötberget field. The Hugget ore displays a continuation of the Flygruvan ores and is as these composed essentially of hematite. The ores mined at present in the Blötberget field have a total area of more than 20 000 m². Those in the Fredmundberg field form a direct continuation of the Blötberget field. They become smaller and smaller to the northeast and show simultaneously lower and lower percentages of iron and phosphorus. They are impregnation ores, here and there rich in skarn minerals such as garnet, epidote, pyroxene, and hornblende. The amount of quartz increases to the northeast.

North of lake Väsman apatite-iron ore has been mined at Lekomberg (Magnusson 1944). This was a compact magnetite mass with schlieren of skarn, quartz, and apatite. Towards the ends of the lens-shaped body the ore became richer in quartz and skarn simultaneously with a decrease in content of magnetite. The main skarn minerals were actinolite, hornblende, biotite, chlorite, and epidote.

In Idkerberget (Sundius and Magnusson 1944) the apatite iron ores (essentially magnetite ones) display lens-shaped or more irregular bodies, most of which are enclosed in a thick amphibolite. This forms a continuous zone in the field and has sharp boundaries towards the ores. The author has found sharpedged pieces of iron ore in positions indicating that the amphibolite is probably an intrusion post-dating the ore zone. The leptites, which the "ore magmas" originally intruded, are rich in skarn breccias as in Grängesberg. An impregnation zone with poor hematite ores exists even here. Pegmatite dikes are common as in the other apatite-iron ores mentioned previously, and the leptites are largely altered to veined gneisses. The ores mined in Idkerberget have on average 62 % Fe and 0.6–0.7 % P.

In spite of the few occurrences of apatite iron-ores in Central Sweden, the amount of iron in these ores is considerable. The three occurrences Grängesberg, Blötberget, and Idkerberget contain about 40 % of the total quantity of iron in the iron ores of Central Sweden. These three apatite-iron ores have, on average, 57 % Fe, with a variation between 45 % and 63 % Fe. The percentages of phosphorus vary between 0.52 and 1.30 %. Apatite concentrations with up to 9 % P appear, as mentioned previously, along the hanging wall of the Grängesberg apatite ores in the Export field.

The iron ores poor in phosphorus which occur around the apatite-iron ores in Grängesberg-Risberg and Blötberget-Fredmundberg are all skarn-iron-ores lacking free quartz. They thus belong to the lowest of the four etages the author has tried to follow in Central Sweden. Southeast of these skarn-iron ores a horizon with quartz-skarn iron ores appears, the Björnberg and Porkanäs ores being the best known. Similar ores, the Källmoss ores, also appear northwest of the skarn-iron ores. This stratigraphy on both sides of the apatite iron ores indicates, according to the author's opinion that the Grängesberg, Blötberget, and Lekomberg ores are situated in a narrow local anticline.

The synorogenic granites are essentially younger than the apatite-iron ores.

In the hanging wall of the Grängesberg Export field, a small inclusion of this ore type has been found in the granite in the Långblå mine. Observations in the mines have also shown that both the intermediate granite in the hanging wall of the Grängesberg ores and the granite proper in the foot-wall are clearly younger than the ores. The pegmatites all belong to the late Svecofennian granites which form several rounded massifs in the Grängesberg region.

The stratigraphy around the Idkerberget ores is impossible to disentangle owing to the fact that both the synorogenic Svecofennian granites and the palingenic late Svecofennian granites replace too much of the supracrustal rocks.

In the eastern part of the Stollberg syncline with slates, greywackes, and iron ores rich in manganese, the etage with quartz-banded iron ores is lacking. Instead there is a nearly 20 km long limestone-dolomite body at the boundary between the upper potash leptites in the west and the lower soda leptites in the east. Between this carbonate body and a large intrusion of synorogenic granites of Svecofennian age there are a great many occurrences of skarn iron ores poor in manganese (Hjelmqvist 1944). These can be divided into lime-rich and magnesia-rich types. Naturally there are also transitions between them. The ores rich in lime contain mainly garnet, pyroxene, actinolite, hornblende, epidote, and mica. Garnet and pyroxene seem to have been developed during an earlier period and have later been converted into amphiboles and epidote. The amphiboles often contain remnants of pyroxene. Nearest to the leptites skarn minerals rich in alumina, such as hornblende, epidote, and biotite, occur. There are often also sköl zones rich in biotite and chlorite.

In the iron ores rich in magnesia, the characteristic skarn minerals are talc, serpentine, mica, and tremolite. Anthophyllite and remnants of olivine and chondrodite in serpentine are found though more rarely. Over the whole region, on both sides of the large limestone-dolomite body, the leptites have been much altered to cordierite- and gedrite-bearing rocks typical for the magnesia-metasomatic alterations. Simultaneously, skarn minerals rich in lime have been altered to minerals richer in magnesia. These alterations have been connected with a supply of sulphides, which are abundant in the etage with manganiferous iron ores (Hilläng and Stollberg-Svartberg ores described above).

According to S. Hjelmkvist (1944), who investigated the iron ores of the Smedjebacken region, strong magnesia-metasomatic alterations of the ores east of the central limestone-dolomite body are rare. Most of the minerals rich in magnesia have got this component from the dolomites. Quartz-bearing skarn ores and quartz-banded iron ores have not been found in this region. All ores are pure skarn-iron ones showing transitions to carbonate-iron ores only. Ore and skarn usually alternate in the form of schlieren. One cannot speak of a banding proper, but the schlieren could have been formed through destruction of the original banding in connection with strong tectonic deformation of the ore bodies. S. Hjelmqvist has mapped one level in Källgruvan and another in Kanalgruvan, both in the Nyberg field. His maps illustrate in an excellent way how the ores appear as elongated, lens-shaped, concordant bodies in skarn and in dolomite or limestone. In Källgruvan a light green diopside-tremolite skarn dominates, the diopside often appearing as remnants in the tremolite. At leptite boundaries the skarn passes into hornblende skarn with epidote. The skarn in the southern part of Kanalgruvan contains garnet and pyroxene, in the northern part pyroxene and tremolite, locally with talc and chlorite.

The ore bodies in this region east of the large limestone-dolomite layer were often quite wide at the surface but narrowed rapidly at depth. S. Hjelmqvist tried to explain this fact by postulating series of small, shallow folds.

This zone with skarn-iron ores poor in manganese continues towards the northeast into the Silvberg region (Lindroth and Magnusson 1944). Some of the skarn-iron ores of this region, for instance the Bråfall ores, are rich in lime, the skarn minerals including pyroxene and andradite as well as actinolite, epidote, mica, and chlorite. Skarn-iron ores rich in magnesia with pure diopside, pure tremolite, phlogopite, and serpentine as dominant skarn minerals occur especially in the eastern part of the Silvberg region. These ores appear in dolomites of primary origin, the latter having delivered the magnesia necessary for the skarn formation in the same way as in the Skärstöten ores in the Persberg field in the Filipstad region. Only in one of these occurrences magnesia-metasomatic alteration of leptites to garnet-biotite-quartzites has been observed, and here the ore has also been impregnated with pyrite and pyrrhotite.

As G. T. Lindroth (1944) has pointed out, potash leptites flanked by soda leptites occur in the central part of the Silvberg region. The supracrustal formation thus displays a syncline. The iron ores described, among which the Bondhyttan ones are the largest, appear in the soda leptites on the southern flank of the syncline.

In the upper potash leptite there are some manganiferous iron ores of interest. In the Hästhagberg occurrence the magnetite is accompanied by pyroxene, garnet, actinolite, and epidote. The manganese has essentially been captured in garnet but to some extent also in manganese carbonate. The ores in the Tallbotten mine were originally manganiferous carbonate iron ores, subsequently weathered to soft ores. The magnetite has been altered to martite and limonite and the manganese carbonate to pyrolusite and jacobsite. Iron and manganese have in this way been separated from each other.

In the central part of the syncline there is a narrow zone with sulphide ores accompanied by magnesia-metasomatic alterations of the common type. The Öster Silvberg and Vallberg ores are the best known. There are no iron ores in this zone on which P. Geijer (1965) has recently published an interesting description.

In the Silvberg region there are no quartz-banded iron ores. East of the manganiferous iron ore zone, however, a zone with quartz-banded iron ores begins and continues through Säter and Bispberg to Forsbo. In the Bispberg-Storgruvan (Lindroth 1944) the main ore layer was pressed together so intensely that a double fold with three parallel ore bodies resulted. Poorer ores were mined together with very rich ones, the latter having about 64 % and sometimes 66–67 % Fe. In these ores rich in iron but poor in quartz, remnants of quartz-banded ores have been found. In the rich ores the percentage of phosphorus was unusually low, only 0.004–0.006 %. G. T. Lindroth described these ores and maintained that a metasomatic process had taken place, removing most of the quartz. The strong pressure has, according to the present author, played an important role as has the rise in temperature in the vicinity of the late Svecofennian granite intruded immediately southeast of the Storgruvan ores. According to the author solutions from this granite have expelled the quartz. Both southwest and northeast of the Storgruvan ores the Bispberg field displays more normal quartz-banded iron ores. Of the ore minerals magnetite dominates over hematite in the Storgruvan ores. The intense alteration of the original hematite to magnetite observed is also dependent on the intrusion of the Bispberg granite. This granite contains scheelite, molybdenite, pyrite, chalcopyrite, and some bismuth minerals. The same minerals have also been found in the iron ores in the Bispberg field northeast and southwest of the Storgruvan ores.

The ores southwest of Storgruvan have recently (Magnusson 1944) been investigated on the 500, 660, and 810 m levels from a long tunnel driven on the 500 m level from the old shaft at Storgruvan. Two parallel ore layers at least 500 m long surrounded by several smaller, sub-economic layers have been found. The two layers average 4 m in thickness and have about 35 % Fe. The leptites have often been strongly influenced by granitic solutions and it is frequently difficult to distinguish between aplites and leptites influenced by granite.

Northeast of the Storgruvan ores there are also several parallel ore layers with quartz-banded iron ores, in which the hematite has been more or less changed to magnetite and the banding has often been destroyed.

In the Forsbo mine, in the northeasternmost part of the ore horizon, the ore layer has been folded in about the same way as in Bispberg Storgruvan and altered to a rich compact magnetite ore with remnants of quartz-banded ores. The ores in Forsbo are also rich in sulphides, especially pyrite. The small Fjägerås mines in the vicinity are quartz-banded hematite ores more or less altered to coarse-grained magnetite ores.

The narrow leptite zone with the quartz-banded ores described here is bounded on both sides by broad, synorogenic Svecofennian granites. These have assimilated and removed the other ore etages.

A 20 km long, narrow zone of leptite passes north–south through Smedjebacken (Hjelmqvist 1944). It is bounded on both sides by synorogenic Svecofennian granites and contains several small ore occurrences. South of Smedjebacken there are, with few exceptions, skarn-iron ores poor in manganese together with limestone and dolomite. The skarn minerals include pyroxene, actinolite, hornblende, and garnet. The zone containing these deposits has been intruded by late Svecofennian granites and pegmatites and is often rich in sulphides. Scheelite has here been found locally and also north of Smedjebacken but only as isolated grains. Two small deposits of manganiferous ore have been found west of this zone.

North of Smedjebacken, in the Furboberg and Mällsjö mines, there are, together with the usual skarn-iron ores, also quartz-iron ores, sometimes massive, sometimes quartz-banded, in which both magnetite and hematite occur as ore minerals. Moreover, there are sometimes skarn minerals such as actinolite, pyroxene, and garnet. In addition, remnants of limestone and dolomite have been found in the ores. The ore layers have been strongly folded, and two ore etages here occur very close to each other, one etage with quartz-banded and one etage with quartz-skarn iron ores.

East of the Furboberg and Mällsjö deposits another iron ore zone (Magnusson 1944), the Östanberg zone, appears in a narrow leptite remnant in the Svecofennian synorogenic granites, diorites, and gabbros. The Östanberg ores are situated in dolomitic limestone and in skarn consisting of garnet, pyroxene, actinolite, hornblende, epidote, and mica. The garnet-pyroxene skarn is the oldest, the other skarn minerals being alteration products of it. The skarn ores have, in part, been quartzbearing. In the limestone outside the ores appear tremolite and a pale coloured mica. Sköls with talc, chlorite, and biotite also occur. Pyrite, pyrrhotite, and chalcopyrite form late impregnations.

The Östanberg zone can be followed towards the northeast in the form of several small inclusions in the granites. The Broddgruvan ores (Magnusson 1944), which have been the subject of investigations for some years, are enclosed together with some leptite in Svecofennian synorogenic granites, diorites, and gabbros. The ores are in part skarn-banded, relatively coarse-grained magnetite ores with pyroxene, actinolite, and garnet, in part carbonate-magnetite ores, sometimes banded, sometimes more massive with an irregular distribution of magnetite. The skarn-banded ores also pass locally into more massive types. In the vicinity of the granites the pyroxene-actinolite skarn passes into dark hornblende skarn. In the carbonate ores sulphide impregnations occur here and there. The commonest sulphide minerals are chalcopyrite and cobaltite. Analyses have sometimes shown relatively high percentages of bismuth. In connection with the sulphide impregnations, pyroxene and actinolite have been altered locally to cummingtonite.

The Falun and Garpenberg Regions

(Geijer 1917 and 1944, Magnusson 1944, Lindroth 1944, Koark 1960)

In the Ludvika region synorogenic Svecofennian granites and forerunning diorites and gabbros occupy large areas and have assimilated and removed so much of the iron-ore-bearing supracrustal rocks that difficulties exist in connecting the different zones and etages from one region to another. These difficulties increase north and northeast of the Ludvika and Silvberg-Säter regions. Synorogenic granites, diorites, and gabbros are the main rocks, and the supracrustal rocks appear as larger and smaller remnants within them. Of the Grythyttan series a few very small occurrences remain. Iron ores rich in manganese occur in only one important zone, at Garpenberg. In addition have to be mentioned some small, scattered deposits in the Hofors-Torsåker region, at Skällingsberg near the Hofors area and at Lake Runn south of Falun (Skinnaräng and Kråknäs). The only important zone with quartz-banded iron ores is the Bispberg zone, described previously. All other ores belong to the two lowermost etages with skarn-iron ores and subordinate quartz-skarn iron ores, which vary in the same way as the corresponding ores in the Filipstad region as well as in the large anticline east of the Grythyttan field (the Hjulsjö-Järnboås anticline) and its continuation in western Ljusnarsberg.

Falun is the most interesting region, but before describing the sulphide ores here two occurrences of iron ore northeast of Falun will be mentioned. Sjögruvan is situated in relatively well-preserved leptites very near the boundary with a large area of veined gneisses and granites to the north. Vintjärn is situated in the veined gneisses 10 km north of their southern boundary.

According to Geijer (1944) the magnetite in the dominant ore at Sjögruvan has occurred in a dolomitic limestone with ophicalcite, serpentine, and tremolite. To some extent magnetite has also occurred in a diopsidic skarn. The ore has been accompanied by a garnet skarn without magnetite. Geijer here found ludvigite and brucite.

The skarn and carbonate iron ores of the Vintjärn mines (Magnusson 1944) are situated in a narrow leptite zone flanked on both sides by old Svecofennian granites which have also been altered to veined gneisses rich in young palingenic pegmatites and granites. There are two parallel, ore-bearing layers. The lower layer is a magnetite-limestone bed with forsterite, chondrodite, serpentine, diopside, tremolite, talc, and chlorite. Most of it is too poor in magnetite to be mined. The upper layer is a good magnetite ore with pyroxene and hornblende together with some garnet. Biotite, quartz, hypersthene, cummingtonite, almandite, and cordierite also occur. The poor ores in the lower layer have relatively coarse magnetite grains and are often banded. The richer ores in the upper layer are more fine-grained and more homogeneous. The leptite gneisses are in part grey, in part red. The grey leptite gneisses are oligoclase-quartz rocks with minerals such as cordierite, sillimanite, and almandite. Sometimes andalusite and cummingtonite are also present. The red leptites have no alumina minerals but are rich in microcline. The grey gneisses seem to be magnesia-metasomatic alteration products of leptite. The alteration is older than the formation of the veined gneisses which have caused the chaotic mixture of minerals in these gneisses. The magnesia-rich minerals in the carbonate rocks have also been formed in connection with magnesia-metasomatic alterations and later palingenic processes. The ore layers undulate gently due to the plastic condition of the rocks during the palingenic processes. The red leptite gneiss sometimes passes into a fine-grained palingenic granite and the grey leptite gneiss locally into inhomogeneous, porphyritic young granite.

The region around the Falun sulphide ores was mapped in 1914–1916 by P. Geijer (1917). Later, H. J. Koark (1960) revised this map and subdivided the leptites into grey, grey-pink, and red types. The grey leptites include even-grained stratified types and types with phenocrysts of feldspar. Some grey types are rich in biotite, others in sericite. The grey-pink and the red leptites are divided into even-grained types and quartz-feldspar porphyritic types. Furthermore, agglomeratic leptites and amphibolites have been found. Limestones and dolomites occur only in a few places. The large sulphidic ore bodies of the Falun mine as well as the small sulphide ores of the Skyttgruvan and Näverberget mines occur in anthophyllite- and cordierite-bearing quartzites, occasionally with andalusite and almandite also.

According to Geijer, these ore quartzites as well as the cordierite-bearing mica-schists displaying transitional rocks between the quartzites and the normal leptites are magnesia-metasomatic alteration products formed around pre-existing limestone-dolomite bodies.

In the Falun mine occurs a large, rounded, central compact ore body essentially composed of pyrite, together with inferior quantities of chalcopyrite, pyrrhotite, sphalerite, silver-bearing galena and, locally, even magnetite. In some parts of this ore there are remnants of dolomite, often changed to ophicalcite, as well as remnants of limestone. The dominant skarn minerals are here tremolite and actinolite. Elsewhere there are remnants of ore quartzite, the main skarn minerals being cummingtonite or anthophyllite. It has even been possible to draw the boundary between the original carbonate body and the original leptite, now altered to ore quartzite.

The Falun ore body extends as a narrowing lobe to the southeast and is surrounded by a sköl zone up to 30 m wide. This sköl consists of biotite, chlorite, and talc in varying proportions together with amphiboles such as anthophyllite, gedrite, cummingtonite or common hornblende as well as cordierite or almandite. *Sköl* is a term originally used in Falun for such zones but also for faults.

Towards the southwest, almost unaltered rocks (leptites and carbonate rocks) appear in the immediate vicinity of the sköls. In other directions they are surrounded by ore quartzites which pass outwards into cordierite mica schists. The ore quartzites are intersected by fissures along which alterations to sköls and concentrations of chalcopyrite occur. In the sköl marking the boundary with the large compact ores, rich copper ores were mined in former times. The Falun deposit was then mainly a copper mine also producing some gold.

Even in the ore quartzites themselves there are and have been here and there relatively large areas with chalcopyrite and some pyrite, forming spots and veins. Some gold has also been found in the quartzites together with the rare lead-selenium-bismuth-mineral weibullite. In the ore quartzites small skarn-dolomite bodies with chalcopyrite, pyrite, sphalerite, and galena have been found, but these are insignificant in comparison with the compact central ore body. They have been formed where small carbonate bodies existed outside the large carbonate body of the central, compact ore.

Amphibolite and quartz porphyry appear in composite dikes, the amphibolite occurring as border zones to the porphyry. There are also separate dikes of amphibolite. The composite dikes are closely similar to the hälleflinta-greenstone dikes found by the author in the Sirsjöberg mines (see page 32). The author is therefore convinced that these dikes, even i Falun, belong to the volcanic period. The dikes in Falun have been broken into pieces, displaced in relation to each other. The sulphide-forming processes are even younger than these dikes, the hornblende in them often being replaced by grünerite. The dikes were also strongly deformed and broken before the magnesia-metasomatism started.

After having studied the Falun sulphide ores and most other ores of the same type in Central Sweden, Geijer (1917) came to the conclusion that the ore material and to some extent the gangue were derived from the synorogenic Svecofennian granites and that this material left the granite magmas as gaseous solutions and subsequently soaked the leptite complex.

A few years earlier P. Eskola (1913), in a monograph on the Orijärvi district in southwestern Finland in another part of the same geological province, presented evidence of a remarkable increase of magnesium in corresponding rocks around the sulphide ores in the Orijärvi mines. The alteration was found to be related to a body of synorogenic Svecofennian granites.

Recent discussions about the source problems will be presented later on.

The sulphide ores of the Falun type have been found especially in a region extending from Falun in the north to the Ljusnarsberg and Riddarhyttan regions in the south (Geijer 1917, Magnusson 1948). Here and there iron ores have been impregnated with sulphides, and the same alterations as around the sulphide ores of the Falun type have taken place in connection with these impregnations. The description of the ores in the Stollberg-Svartberg zone in Väster-Silvberg (Hjelmqvist 1944) and the ores in Ljusnarsberg (Magnusson 1940) are good examples.

The Lövåsen mine (Magnusson 1953) recently described by N. Pilava-Podgurski (1957) and situated southeast of Falun, displays a small but geologically very interesting deposit. A limestone-dolomite body intercalated with thin leptite layers contains skarn-iron ores with varying but often relatively large amounts of quartz. These iron ores locally show good banding indicating a sedimentary origin. The skarn minerals formed by reactions between the ore layers, the carbonates, and the leptites were hornblende, pyroxene, and garnet. The iron ores and the carbonate rocks then became impregnated with sulphides and fluorite. The magnesia-metasomatic solutions followed the leptite layers which became more or less altered to quartzites. The sulphides included sphalerite, galena, chalcopyrite, pyrrhotite, pyrite, and arsenopyrite. Of these sulphides sphalerite, galena, and arsenopyrite became fixed chiefly in the carbonates and the remaining ones in the iron ores and their skarn masses. In connection with the sulphide invasion new skarn minerals such as diopside, actinolite, a coarse-grained garnet rich in grossularite, epidote, and wollastonite appeared. In the leptite surrounding the ore-complex almandite and biotite were developed. The best zinc-lead ores were concentrated in a local fold in the iron ore-carbonate-leptite complex. It is quite clear that the skarn-iron ores in Lövåsen are essentially older than the invasion of the sulphide minerals.

In the Garpenberg sulphide mines (Magnusson 1953) there are two important ore zones, one with chalcopyrite in quartzites which are magnesia-metasomatic alteration products of leptites, the other with complex sphalerite-galena-chalcopyrite ores appearing in dolomitic limestone, ophicalcite and a skarn containing tremolite, humite minerals, talc, serpentine, and abundant fluorite. In this sulphide-bearing zone the leptite has as a rule been altered to mica-schists and mica-quartzites, in which cordierite, gedrite, cummingtonite, almandite or staurolite appear frequently and andalusite and gahnite more rarely. The complex zinc-lead-copper ores appear also in these mica-schists rich in biotite, and between the different ore bodies there is a net work of mica sköls with smaller concentrations of sulphides. It seems clear to the present author that the sköl zones acted as channels for the magnesia-metasomatic solutions. In the mica schists there is also an ore body consisting mainly of pyrite and pyrrhotite. Where the tectonic movements along the schistosity zones have been most intense, abundant rounded pieces of the surrounding rocks occur in the almost compact sulphide body, the main minerals of the latter being sphalerite and chalcopyrite. The Garpenberg ores have locally been altered by weathering into soft ores with carbonates, sulphates, limonite, and kaolinite.

The leptite zone in which the Garpenberg sulphide ores are situated is limited towards the northwest by a large intrusion of synorogenic Svecofennian granite, which has followed the stratification of the leptite complex. At a short distance from the contact stretches a horizon with several small deposits of iron ore (Geijer 1944). These are all skarn iron ores as a rule comparatively rich in minerals containing much magnesia such as pure diopside, tremolite, humite minerals, and serpentine. In two of these deposits Geijer has found ludvigite-pseudomorphs and in one of them a fluoborite. The leptite often contains thin layers of garnet and epidote skarn together with a green-skarn rich in iron.

In one of the deposits of this zone, the Ryllshyttan ores (Geijer 1944, Magnusson 1953) southwest of Garpenberg, a central rich zinc ore with subordinate amounts of galena and chalcopyrite was surrounded by diopside-garnet skarn with concentrations of magnetite ore. The zinc ore is, according to the present author, distinctly younger than the iron ores and their skarn masses. It was deposited in the central carbonate body that remained after the alteration of the iron ores to skarn iron ores similar to the ones in the Garpenberg region outside the manganiferous iron ores. In the zinc ores remnants of limestone and dolomite occur here and there. The gangue of the rich zinc ores is mainly quartz and fluorite. Metasomatic alterations have been observed in the older, iron ore skarn masses, new minerals being tremolite, humite minerals, phlogopite, etc., and in the leptites locally altered to ore quartzites cordierite and almandite. Several amphibolite dikes have proved to be younger than the skarn iron ores but older than the sulphide ores and the metasomatic alterations associated with them.

The Intrånget iron ores (Magnusson 1944) are situated in a leptite fragment intersected by diorite and gabbro and together with these rocks enclosed in the large synorogenic granite mass northwest of Garpenberg. The main ores are skarn-iron ores with remnants of quartz-banded ores and dolomitic limestone. Between the concentrated ores there are often quartz-banded ores with variable amounts of skarn. The larger ores appear in the limestones and dolomites in which the sedimentation of ore material has been most intense. In connection with the folding a rearrangement of the ore material into ore bodies with irregular forms took place. Intense magnesia-metasomatic alterations gave rise to magnesium skarn (tremolite and anthophyllite) mixed with the older reaction skarn (pyroxene, actinolite, and garnet). At the same time the leptites became largely altered to quartzites with cordierite, almandite, etc., and the iron ores here and there were impregnated with sulphides (pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena). At the contacts of the diorites and gabbros there has occurred a later invasion of pyrrhotite and pyrite. All this happened before the whole complex was enclosed in the granite.

The Smältarmossen skarn iron ores (Magnusson 1944) are situated northeast of the Garpenberg sulphide ores. The main skarn minerals are pyroxene, garnet, and epidote. Ore and skarn are richly impregnated with pyrrhotite and subordinate pyrite, often in relatively large compact concentrations. The content of sulphur has often been 2–3 %.

The sulphide impregnations in the Ryllshyttan, Intrånget and Smältarmossen iron ore deposits were naturally intimately connected with the formation of the central sulphide ores in Garpenberg. The same is also true of the sphalerite-galena impregnations in the northern part of the nearly 4 km long zone with the Långvik-Holmgruvan-Haggruvan manganiferous iron ores (Lindroth 1944), belonging to the highest etage in the leptite complex. All iron ores of this zone appear in the same comparatively thin, banded serie which has been followed by investigations in the mines and diamond drilling between. The amount of manganese varies from 0.5–1 % up to 6–10 %. The percentage of iron also shows great variations. The ores are in part skarn iron ores, in part carbonate iron ores, and there are all transitions between them. On an average the percentage of iron has been 37 % and of manganese about 3 %. The width of the ore layer average 3 m.

In Långvik in the northernmost part of the horizon the ores are poor in iron and consist of fine-grained magnetite in the carbonate mass, which is a limestone rich in iron, manganese, and magnesia. The extremely small magnetite grains remember of the magnetite in knebelite in the better preserved parts of the Ställberg ores and of the small hematite grains in the ferruginous quartz at Långban, Stripa, etc. There is also, along the boundaries with the leptites, a garnet rich in manganese. In the Holmgruvan mine there have been, according to G. T. Lindroth, skarn-iron ores rich in manganese, carbonate iron ores rich in manganese and skarn-, and carbonate-iron ores poor in manganese. The skarn minerals have been knebelite and dannemorite with garnet and hornblende near the leptites. These ores have been particularly rich in galena and sphalerite, which have occurred in fissures in the ore and skarn or as a fine impregnation in these. Sometimes the amount of lead has been as high as 3 % and of zinc 1.5 %. In the ores rich in manganese the percentage of this metal has been between 5 and 11 %.

The Haggruvan mines, recently mapped by the author (Magnusson, unpublished investigation), are located in the southernmost part of the continuous ore layer here bent to a double fold. The westernmost part of it has been assimilated and removed by the synorogenic granite. Small remnants of the ores remain, however. The iron in the Haggruvan mines is on average 33 % and of manganese 2.5 %. Both metals show great variations above and below these concentrations. The percentages of iron and manganese do not vary sympathetically. The ores show all transitions from limestone-dolomite layers very poor in iron and manganese over magnetite-banded carbonate ores with a varying percentage of manganese to more concentrated ores. The rich skarn iron ores with knebelite and more subordinate dannemorite usually display well-defined, compact bodies like the knebelite skarns in the Tuna-Hästberg manganiferous iron ores. The content of silica must have been greater in the original ore sediments, where skarn ores rather than carbonate ores now occur. Outside the ores a pale skarn consisting of garnet, pyroxene, and tremolite has been found in the Haggruvan mines. The garnet seems to be essentially grossularite, the pyroxene diopside. Between the manganiferous ores and the leptites a skarn of garnet rich in spessartite, dark hornblende, and biotite occurs in the usual way.

West of the Haggruvan ores the manganiferous iron ore layer can be followed as a large number of remnants in the synorogenic Svecofennian granites of the Pålsbenning mines and between these mines and the Jönvik mines. The ore remnants in the latter mines have been strongly recrystallised. They are now coarse-grained and rich in sulphides.

The Rocks and Iron Ores in the Riddarhyttan, Fagersta and Norberg Regions

(Geijer 1944)

The magnesia-metasomatic alterations have their largest extension in the zone Riddarhyttan-Fagersta-Norberg.

In the Riddarhyttan field (Geijer 1923) potash leptite is the main rock type but has been altered to cordierite-mica schist over large areas. This magnesia-metasomatic alteration has, at several places, reached the iron ore horizons, altered them more or less and impregnated them with sulphides such as pyrite, pyrrhotite, chalcopyrite, and cobaltite. Geijer (1923) divided the ores into several types. These include most frequently quartz-banded, generally rather lean, specular hematite ores as long and regular zones alternating with potash leptite. These ores also contain some skarn minerals, particularly diopside and ordinary garnet. Locally, rhodonite and yellow garnet have also been found. Quartz-banded magnetite ores of the same general character appear in the potash leptite and quartz-banded ores, the iron content occurring partly as magnetite and partly as specular hematite interstratified in bands of plagioclase leptites.

In the potash leptites there are also manganiferous skarn-iron ores in the Rödgruvan-Höjdgruvan horizon, which should be considered as the highest stratigraphic etage in the Riddarhyttan region. The Höjdgruvan ores appear in limestone and dolomite. The skarn minerals are actinolite, hornblende, diopside, garnet, and biotite. The garnet is usually combined with dark hornblende and biotite and appears at boundaries between the ores and leptites. In the Rödgruvan ores the carbonate rocks have been totally replaced by skarn. The skarn minerals are here dannemorite, red-brown garnet, and biotite. The amount of manganese in Rödgruvan and Höjdgruvan have been between 1 and 2 %.

Skarn iron ores poor in manganese appear at several places in carbonate rocks. The skarn silicates in these ores are amphiboles (mostly actinolite), garnet, and pyroxene. Closely related to these ores are some small deposits of chalcopyrite, pyrite, and cobaltite in the same kind of skarn and occurrences of cerite, törnebohmite, orthite and other cerium minerals in the actinolite gangue. It may be added that cerite with some törnebohmite and orthite has also been found in a tremolite or actinolite skarn in dolomitic limestone and törnebohmite with orthite in an anthophyllite-bearing quartzite belonging to the products of the magnesia-metasomatic alterations. The significance of the cerium occurrences of the Bastnäs type will be discussed later on.

The ore in the Myrback mines is a quartzose, striped but not regularly quartz-banded magnetite ore, often with bands of biotite and almandite or of a quartz-fluorite rock. It is often rich in sulphides such as pyrite, chalcopyrite, pyrrhotite, and cobaltite. The sulphides are distinctly younger than the magnetite. The country-rock is the even-grained potash leptite, but near the ore bodies this rock changes to a mica schist or to quartzitic rocks often with large spots of almandite. Geijer first thought that these ores, as a whole, were formed in connection with the magnesia-metasomatic alterations, which are widespread in this region. The present author has, however, found remnants of quartz-banded ores in the Myrback ores, and Geijer and the author now agree that these ores are quartz-banded ores that were changed by magnesia-metasomatism and at the same time became impregnated with the sulphides mentioned above.

The rocks around the Källfallet ore have been more intensely altered to cordierite-anthophyllite-quartzites. These grade into cordierite-mica schists. The ore bodies contain some intermixture of the silicates mentioned and at times also of quartz. As the alterations of the surrounding leptites are almost exactly the same as those of the most common sulphide ores of Central Sweden, it was natural for Geijer in 1923 to conclude that these iron ores were formed at the same time as the sulphide ores of the Falun type. It seems, however, now quite clear that the mentioned iron ores are older than the magnesia-metasomatic alterations and have been transformed by them.

In Persgruvan mine the same alteration has affected a skarn iron ore with actinolite and some pyroxene and garnet in limestone and dolomite. Much of this mixture has been transformed into talc-anthophyllite ores. As Persgruvan and Källfallsgruvan appear on the same horizon it seems obvious to the author that the Källfall ores have once been of the same type as the

Persgruvan but have been later more strongly altered to iron ores rich in magnesia. We can also draw a close parallel with the alteration of the ores of the Persberg-Storgruvan type with garnet and pyroxene to ores of the Alabama type with talc and anthophyllite.

The Bastnäs field has, in the southeast, the usual potash leptite and in the northwest mainly cordierite and andalusite mica-schists. At the boundary between the leptites and the schists there is a horizon with quartz-banded iron ores containing layers of leptite. To the southeast the ore is a scaly hematite with quartz and some actinolite. Magnetite is the main ore mineral towards the schists in the northwest and is there accompanied by some anthophyllite. The leptite layers have been here altered to biotite schists. Immediately northwest of these magnetite ores there are skarn masses of actinolite, sometimes alternating with quartz layers of the same character as in the quartz-banded ores. In this skarn cerite and the other cerium minerals mentioned above have been found locally together with chalcopyrite, molybdenite, bismuthinite, and linnéite. Sometimes bornite and chalcocite are present, too.

In the part of the Bastnäs field described now there existed, as Geijer has pointed out, a layered complex of quartz-banded iron ores with layers of leptite, ore quartz and dolomite before the magnesia-metasomatic alterations. The material for cerite and the other minerals named above has thus been transported together with the magnesia-metasomatic solutions.

The many small iron ores in the Högfors-Hultebo region are a direct northerly continuation of the Riddarhyttan region. They are partly quartz-banded ores, partly skarn ores. The quartz-banded ores have magnetite and hematite in varying proportions. In one mine there was also a manganese-silicate-banded variant. In the skarn-iron ores a more or less magnesia-rich skarn, sometimes of the Källfall type, is dominating. The main mineral is anthophyllite sometimes in association with ophicalcite. The leptite has been altered on a large scale to mica schists and quartzites of the same magnesia-metasomatic types as in the Riddarhyttan region. Cerite has been found even here and is related to magnesia-metasomatic alterations of the quartz-banded ores.

The original quartz-banded iron ores and the manganiferous skarn iron ores in the Höjdgruvan and Rödgruvan mines are situated in a syncline that can be followed from Lake Lien to the Bastnäs field. On both sides of this syncline there are anticlines. On the southern side of the southern anticline, quartz-banded iron ores appear in the Stripa field. The northern anticline has skarn-carbonate ores, naturally on both sides more or less altered by magnesia-metasomatic solutions, as in Källfallet and Persgruvan. These ores belong to the lowest etage in the general stratigraphy. North of the anticline there is a new syncline with quartz-banded ores in the Gräsberg field.

Between the Riddarhyttan region and including the Högfors-Hultebo region on the one side and the Fagersta region on the other the leptite complex has been intersected by young palingenic granites and pegmatites in such a way that there is no room for larger ore deposits between them.

Around Fagersta (Geijer 1944) the leptite complex contains several iron ore deposits, most of which are very small. They vary from pure quartz-banded ores and skarn-bearing varieties of these to skarn iron ores with or without quartz, banded or more massive. Together with the main ore types mentioned, which are poor in manganese, there are also manganiferous, knebelite-bearing skarn-carbonate ores. A remarkable feature is that these iron ores appear in thin limestone-dolomite layers, whereas the large carbonate bodies totally lack iron ores. This had not been the case if the ore material had come metasomatically from the synorogenic granites. The whole series of ores in this region gives the impression of sediments more or less metamorphosed, as Geijer has expressed it.

Of special interest are the Rudgruvan ores. These are skarn-banded, relatively fine-grained magnetite ores, which are more or less quartziferous. The skarn consists of actinolite and hornblende.

In agglomeratic leptites north of the Rudgruvan mines a great many small rounded pebbles of magnetite and magnetite ores have been found by the author.

In the Hedkärra field, south of Fagersta, manganiferous carbonate-iron ores with knebelite-dannemorite skarn appear in three parallel narrow synclines. In the two anticlines between them quartz-iron ores occur together with varying amounts of skarn minerals (garnet, hornblende, actinolite, and pyroxene) poor in manganese.

North of Fagersta the manganiferous iron ores appear in the east. Towards the west follow quartz-banded ores, as in the Stortäkt mines. West of these the zone with skarn-banded iron ores with some quartz appears. We thus have the usual stratigraphy characterized by the etage with manganiferous iron ores at the top of the ore-bearing complex, then the etage with quartz-banded iron ores and under these the etages with skarn-iron ores poor in quartz.

Magnesia-metasomatic alterations have been observed locally in the iron ore-bearing zone at Fagersta described above. East of this zone more intense alterations of the same kind are common. Pilava Podgurski has here found cordierite-bearing mica schists brecciating leptites with about equal contents of potassium and sodium. He has also found that in connection with the magnesia-metasomatic alterations in this brecciation zone the alkali-intermediate leptites have been altered into extremely sodic types in the same way as the present author found along the sköl zone in the Nordmark mines in the Filipstad region (Magnusson 1929). We have here two good examples of secondary soda leptites.

In the zone at Västanfors quartz-banded iron ores dominated when the skarn-forming processes started. Where limestones and dolomites had been deposited contemporaneously with the quartz-banded ores, skarn masses were developed. Where magnesia-metasomatism operated, the skarn-forming processes became intensified, the leptites being altered to mica schists and quartzites with cordierite or almandite. Accordingly the skarn masses vary from garnet-pyroxene-actinolite skarn to anthophyllite skarn. In the carbonate masses ophicalcite has often been found as completely isolated grains of olivine or humite minerals, which have been more or less changed to serpentine. The author had the opportunity of studying Bäckgruvan mine before it was abandoned. Here quartz-banded scaly hematite ores sometimes altered to quartz-banded magnetite ores have occured. The quartz in these ores was sometimes ferruginous. Side by side with these ores there were skarn-magnetite ores in limestone-dolomite layers. The skarn varied from green pyroxene skarn with garnet to diopside-tremolite skarn. The leptite was altered to mica schist.

In the Bäckgruvan mine as well as in the Nordstjärnegruvan mine the ores have been locally impregnated with sulphides such as chalcopyrite, bornite, pyrite, and molybdenite. The amount of molybdenite was especially high in Nordstjärnegruvan, and it seems quite clear that this mineral has been formed by material received from the pegmatites here cutting the ores and belonging to the products of the late Svecofennian palingenesis. The pegmatites have also caused feldspar impregnations in the mica schists and ought therefore to be younger than the magnesia-metasomatic alterations, as Geijer has pointed out. Pegmatites rich in molybdenite are common in this region, even outside the ore-bearing zones. Both Geijer and the present author have found that pegmatites belonging to the young palingenic granites have been responsible for impregnations of bornite and chalcocite in the iron ores at several places in Central Sweden (Geijer 1924). For this reason the bornite in the Västanfors zone may have come from such pegmatites.

In 1936 Geijer published his description of the Norberg region. Here 0.08 mm is the normal upper limit for the size of the grains in the groundmass of the leptites. The original textures observed include phenocrysts of quartz and feldspar as well as stratification. As a rule stratification and porphyritic texture are not found together though exceptions occur.

From a chemical point of view the following main groups can be distinguished: 1. soda leptites nearly exclusively made up of almost pure albite and quartz; 2. potash leptites with microcline being the leading feldspar though not as dominant as the albite of the first group, and also with quartz in "granitic" amounts; 3. "plagioclase-potash leptites" corresponding to dacites and quartz-latites; and 4. "hornblende-bearing plagioclase leptites" showing andesitic composition and constituting a group of little quantitative importance.

The soda leptite consists of quartz and albite phenocrysts in a groundmass of the same minerals. The size of the quartz phenocrysts is between 0.5 and 2.5 mm. Usually they are granulated but sometimes the original bipyramidal form is perceptible, often with corrosion indentations. The phenocrysts of albite have often got the tabular form preserved. Some mica (biotite and muscovite) also appears in the groundmass, which is fairly inhomogeneous, the grain size varying between 0.03 and 0.08 mm. This rock is reminiscent of the extremely sodic leptite rich in large grains of quartz and albite in the Persberg district, the Filipstad region. This is, according to the present author, the youngest leptite in the lower division of the Persberg district.

In the Norberg region the soda leptites rich in phenocrysts appear together with and have in part been replaced by cordierite-bearing mica schists. The origin of the soda leptites will be discussed later on.

The potash leptites in Norberg have been divided into quartz-porphyritic varieties with even-grained groundmasses and stratified types. In the former phenocrysts of microcline sometimes enclosing albite appear. The quartz phenocrysts are often remarkably well-preserved. In other cases even the plagioclase phenocrysts have got their original character preserved. The microcline phenocrysts are, on the contrary, usually granulated in the same way as the recrystallized groundmass. Geijer has come to the conclusion that these rocks have to be interpreted as lavas over large areas, which should be especially the case where the phenocrysts are rather uniformly distributed in the even-grained groundmasses.

The stratified potash leptites without phenocrysts are sedimentary volcanic rocks. Their chemical composition is the same as in the porphyritic types mentioned above, likewise the mineralogical composition. They must represent tuff material deposited directly in water or later, after transport. The stratification is most frequently marked by thin layers of quartz-banded iron ore and skarn layers or by the distribution of minerals such as hematite and epidote, more seldom by varying proportions of quartz and feldspar. Agglomeratic leptites are rare.

The grey plagioclase-potash leptites have a lower percentage of quartz than the potash leptites described above, further a higher content of oligoclase than of microcline and a high content of biotite. Phenocrysts of oligoclase are common, as well as a marked parallel orientation of the mica flakes. In some small areas the plagioclase-potash leptites have a coarse agglomeratic texture. Sometimes they also contain inferior quantities of hornblende. These rocks have probably been originally dacites or quartz-latites.

The term "hornblende-bearing plagioclase leptites"are used for dark, grey-green rocks rich in hornblende and without any appreciable amount of microcline. Phenocrysts of tabular plagioclase are common. The groundmass consists of plagioclase, blue-green hornblende, some quartz, titanite, magnetite, and apatite. Originally these rocks have been andesites.

The cordierite-mica schists consist of quartz, biotite, a nearly colourless mica with small axial angle, and cordierite. Biotite predominates in the dark mica schists and the colourless mica in the light schists. Cordierite often appears as poikilitic ovoids. Other minerals worth mentioning are andalusite, anthophyllite or gedrite, and tourmaline. As a transitional rock between the mica schists and the leptites appears a variety of the latter rich in flakes of mica mutually parallel and frequently appearing in marked zones together with quartz and tourmaline.

As pointed out by Geijer it is a peculiar feature that the soda leptites in the Norberg region so often occur together with cordierite mica schists. This relationship is particularly clear in a zone from Malmkärra in the southwest over Lake Noren to Kallmora and Långgruvan in the northeast. The problem is to decide whether the potash leptites, which are so abundant in the iron ore-bearing leptite complex, have been altered to soda leptites or if these leptites were sodic from the beginning. Geijer favours the latter explanation.

Large areas of the soda leptites lack iron ores, and it is possible that they originally displayed more coarse-grained tuffs with varying grain dimensions. It is possible that these tuffs were less resistant to magnesia-metasomatic solutions than the denser volcanic material. Soda leptites, however, appear around the Malmkärra deposit in the southwest and the Kallmorberg and Långgruvan deposits in the northeast, at both of the latter localities together with cordierite-mica schists. The author has come to the conclusion that both types of soda leptites exist in the Norberg region – the primary soda leptites in the large uniform areas lacking iron ores and the secondary soda leptites at places where the iron-ore bearing potash leptites have been subjected to magnesia-metasomatism.

As consulting geologist to mining companies in the Norberg region the author had good opportunities over a period of several years to study there the magnesia-metasomatic alterations. These alterations are much more extensive than have been shown on the maps. Around Storgruvan and Prostgruvan, for example, and in the tunnel from these mines to the Mimer shaft the rocks have been more or less altered to mica schists with cordierite. Along the northwest boundary of the Mimer ores the same schists occur together with soda leptites. The mica schists north of Storgruvan and Prostgruvan continue to the northeast as strongly schistose leptites. Between the Getback and Östanmossa skarn-iron ores the leptite has been altered to mica schist with cordierite, and these schists can be followed into the quartz-banded Norrberg ores. North of the Kallmorberg ores the schists pass into broad sköls with mica, talc, and cordierite. At several other places in the ore-bearing complex, schistosity zones have acted as channels for the magnesia-metasomatic solutions.

Where the magnesia-metasomatic alterations were most extensive, the mica schists pass into quartzites with such minerals as almandite, gedrite, and biotite. These quartzites appear together with sulphide concentrations, especially in the Kallmorberg and Häste fields. The copper ores have consisted of chalcopyrite, bornite, and chalcocite together with fluorite. The silver ores largely consist of galena and sphalerite. In the Malmkärra field in the southwesternmost part of the Norberg region rich concentrations of pyrite, chalcopyrite, and molybdenite occur locally. In the Bondgruvan deposit, where the quartz-banded ores are locally altered metasomatically along their boundaries, chalcopyrite, chalcocite, and molybdenite are present together with fluorite.

The skarn-iron ores appearing in dolomites and limestones often contain skarn minerals richer in magnesia than is usual in reaction skarns and include pure diopside, tremolite, humite minerals, and ophicalcite. Associated with these are cerium and boron minerals, which here, as in Riddarhyttan, belong to the most intense magnesia-metasomatic alterations and have nothing to do with the original iron ore formation.

The iron ores belong to three types: manganiferous iron ores, quartz-banded iron ores, and skarn-iron ores poor in manganese. These are contained in three of the four ore etages that the author has tried to trace in Central Sweden.

The manganiferous iron ores represented by the Kolningberg and Klackberg ores occur in dolomites. They consist mainly of fine-grained magnetite mixed with a carbonate rich in manganese and iron. Silica amounts to only a few percent and occurs in skarn silicates, such as knebelite and dannemorite. The manganese-iron carbonate and admixed dolomite give the ores a basic character. The manganese content generally amounts to 4 or 5 %. A skarn essentially consisting of dark hornblende, biotite and garnet occurs as a reaction zone between ore and leptite. The latter skarn surrounds the ore-bearing dolomite bodies and sometimes alternates with these bodies as narrow layers with kernels or isolated remnants of leptite. A characteristic feature in certain ore bodies is the frequent occurrence of graphite, especially on glide planes. An interesting problem is if the graphite represents organic material or if it has been formed from carbon in the carbonates. Geijer seems to favour the latter explanation.

In the Bålsjöberg field dolomite appears in some mines side by side with the quartz-banded ores. Further a carbonate rock rich in manganese and containing layers of silicates rich in manganese (rhodonite, schefferite, and manganophyllite) has been observed.

In the Häste field there also occur quartz-banded iron ores and skarn-iron ores side by side. Adjoining the quartz-banded ores layers of manganese silicates (rhodonite, schefferite, and manganophyllite) and also braunite have been found at some places.

In Assessorskan mine hematite together with manganese silicates (rhodonite, yellow garnet and yellow pyroxene) have been found in a zone with small quartz-banded ores. Rhodonite also appears on fissures.

It is very interesting to find here skarn of the Långban type and also braunite so far from the Långban mines. The skarn also here occurs together with quartz-iron ores.

The ore minerals in the quartz-banded ores are crystalline hematite or magnetite. In most ore bodies the hematite has a dominant position, the magnetite being restricted to peripheral parts of the deposits. Ore bodies consisting entirely or predominantly of magnetite are rare. Examples are found in that part of the Norrberg field that lies near the contact with the synorogenic Svecofennian granite which has intruded the ores. There is no doubt that the character of the iron mineral is determined by metamorphism and magnesia-metasomatism, magnetite developing at the expense of hematite in both cases.

The chief impurity is silica in the form of quartz, sometimes coloured reddish by tiny flakes of hematite. The banding is regular and the separation fairly good: the ore bands do not contain more than a subordinate amount of quartz, whereas the quartz bands may carry a little hematite or magnetite finely distributed. The thickness of the banding varies. Most of the ores show quartz bands less than 3 mm thick, but important parts may exhibit quartz bands of 5 to 10 mm or more throughout. The ore bands generally are not much thicker than those of quartz.

Skarn silicates are fairly common. Andradite is most wide-spread. The appearance of this mineral often illustrates its character of a reaction product between hematite and quartz. Presumably it has been formed on expense of thin limestone layers. Actinolite is also rather common and may entirely take the places of the quartz bands. The actinolite may have originated by reactions involving consumption of dolomite layers. The quartz-banded ores are bed-shaped throughout and have often been strongly deformed. They frequently alternate with leptite layers.

Where limestone and dolomite have been deposited together with quartz-banded iron ore, large skarn masses have originated by reactions between the carbonate rocks and the ore, fragments of the latter often remaining in the skarn. There are especially good opportunities to study these phenomena in the Kallmorberg mines (Magnusson 1958). Here possibilities also exist for studying how a well-stratified series with layers of quartz-banded ores with hematite and limestone-dolomite layers pass by reaction into massive skarn-iron ore with magnetite as the only oxide mineral.

Magnesia-metasomatic solutions have intensified the skarn-forming processes in this field. About this problem in Kallmorberg Geijer (1961) has written a paper entitled "The distribution of halogens in skarn amphiboles in Central Sweden". Geijer here points out that the regional heating by diffusion responsible for the formation of reaction skarns cannot have caused the great transformations in the ore bodies with fluorine-rich actinolite-skarn often only some few meters distant from the contacts undisturbed by reactions. It seems clear that not only some substances contained in these ore-bodies, as fluorine, were contributed by the emanations of the magnesia-metasomatism, but that these emanations furnished also the heat necessary for the reaction, presumably in addition a quantity of water considerably above that normally contained in the rocks. It is possible and in the opinion of P. Geijer even probable that also some iron was contributed in this way, but this possibility does not affect the conclusion that rearrangment of a sedimentary deposit was here the main factor in giving the deposit its present aspects.

Moreover Geijer added that the present author's description of the Ljusnarsberg region (Magnusson 1940) pointed out the possibility that reaction skarn formation and magnesia-metasomatism may sometimes have coalesced into one process. However, Geijer's investigations concerning the halogens in skarn amphiboles clearly show that fluorine was added during the magnesia-metasomatism in considerably greater quantities than has been previously assumed.

There could, according to the present author, also have been some fluorine in the original ore sediments, as the material for these sediments ought to originate from magmatic emanations such as fumarole gases and thermal springs.

In the Bondgruvan mine the quartz-banded iron ore, as stated previously (Magnusson 1958), is locally altered to talc-anthophyllite ores with remnants of quartz-banded ores. The leptite has been changed to quartzite containing anthophyllite (gedrite), cordierite, and sometimes even almandite. Between the ores and this quartzite a mica sköl several meters thick has been formed. It is quite clear that the alterations now recorded have been caused by magnesia-metasomatism. In the Norrberg field strong alterations of the same kind have affected the quartz-banded ores in the vicinity of the shaft. Weaker magnesia-metasomatic alterations took place along the vertical or nearly vertical dislocation and schistosity zones which are common in the ores of the Norberg region. Along these zones the leptites have been more or less changed to rocks rich in quartz and mica. Locally the alterations have been more intense and have given origin to quartz-rich mica schists, often with cordierite, and even to quartzites with minerals such as cordierite, anthophyllite, and almandite. Here as well as in the altered parts of the Norrberg and Bondgruvan deposits, sulphides, mostly copper minerals but locally galena and sphalerite, have been concentrated. Both copper and silver were mined in small concentrations of this sort in the Norberg region.

The ore mineral of the skarn-iron ores is invariably magnetite, mostly developed as aggregates the grains of which have a more or less octahedral habit. However, locally the magnetite of the largest deposit of this type in the region, Åsgruvan, and of part of another, Östanmossa, sometimes exhibits a lamellar texture, undoubtedly indicating that it is pseudomorphic after original hematite. In general, the distribution of magnetite in the skarn is more or less irregular. Locally, however, the author has traced an original stratification. At least a little skarn is always present in the ores, and the boundaries of the workable ore bodies are mostly quite vaguely defined.

The commonest skarn minerals are light green diopside and actinolite. Andradiate also occurs, sometimes abundantly, but is not so closely associated with the magnetite. As in the Storgruvan ores in Persberg (Magnusson 1925) andradite and magnetite seem to replace each other mutually. Hornblende and epidote appear at the leptite boundaries. Other skarn silicates of importance are tremolite and minerals of the humite group (including norbergite). As is often the case in skarn deposits, actinolite is frequently seen to replace the diopside. Humite minerals do not, as a rule, occur in the more common skarn types but, unaccompanied by other silicates, rather in dolomite there forming ophicalcite, or associated with tremolite. To this paragenesis belong also the numerous cerium compounds (cerite, orthite including magnesia varieties, törnebohmite, and bastnäsite) that are found locally in a number of skarn deposits, sometimes in considerable quantities. A special form of skarn ore is represented by Tallgruvan mine, where boron minerals (ludvigite and fluoborite) accompany magnetite and humite minerals.

The geological significance of the cerium and boron mineral occurrences in the Riddarhyttan and Norberg regions has recently been reconsidered by Geijer (1963). He points out that "all the Riddarhyttan and Norberg occurrences are within one continuous belt of the folded leptite complex, bounded on both sides by intrusive granites. Is it possible then", Geijer asks, "to draw from this distribution any geological information beyond the obvious one that special conditions favourable for the forming of local concentrations of cerium minerals have characterized the zone in question?" In the opinion of Geijer this seems to be the case, and the answer concerns the relations between the synorogenic intrusions of the earlier Svecofennian granites and the magnesia-metasomatic activity. No doubt these two processes have essentially been at work contemporaneously.

In the discussions between Geijer and the present author the Malmkärra ore deposit has played a great role. This mine seems to rank next to Bastnäs in regard to the quantity of cerium minerals present. According to Geijer a bed of dolomite and limestone is, along its footwall, replaced by magnetite ore with amphibole skarn (actinolite and tremolite) and with much orthite in the form of scattered grains of microscopic size. Towards the hanging wall this ore grades into a much narrower, probably discontinuous band with cerite, magnesium-orthite, törnebohmite, tremolite, and chondrodite.

The problem Geijer and the present author have most intensely discussed is whether it is necessary to assume that the material for the magnetite in the skarn-iron ores in the Malmkärra mine was metasomatically injected at the same time as the skarn and cerium minerals were formed. There is also, as the author (Magnusson 1953) has pointed out, the possibility that primeval sedimentary iron ores existed but subsequent metasomatic alterations were so intense that no original structures remain. The deposits in Central Sweden we can discuss in this way are few and unimportant and cannot affect the opinion of the author that the iron material, even in such cases, has been taken from sedimentary iron ores and transformed by intense magnesia-metasomatism.

In two abandoned mines Långgruvan and Lövsveden the author found (Magnusson 1953) that iron material has been taken from poor, quartz-banded iron ores and transported into carbonate rocks in the immediate vicinity in connection with magnesia-metasomatism. Accordingly it is not necessary to assume that the iron has come from the granites. The magnesia-metasomatic solutions could have taken the iron from neighbouring sedimentary ores.

In the discussions having lasted since 1925 between P. Geijer and the present author the essential point has been how much of the skarn- and limestone-dolomite-iron ores have been sediments from the beginning and how many deposits could have been developed by contact metasomatism, the iron material then coming from the synorogenic Svecofennian granites. In 1948 we (Geijer and Magnusson) presented a joint paper about the geological history of the iron ores of Central Sweden to the Geological Congress in London.

From this paper the following has been quoted.

”To turn now to our own interpretation of the various ore types: 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 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. There are, in the least metamorphic deposits, striking similarities to the development of the strongly red-pigmented quartz bands of the Lake Superior jaspilites. The character of the original iron mineral is not established with certainty. Siderite seems improbable, 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.

The skarn and limestone ores present a much more complicated problem – or rather, set of problems. The association with limestone or dolomite, the shape of the ore bodies – at least when not well stratified – and the mineralogical composition are features that seem to indicate an origin by contact replacement (pyrometasomatism) for at least the vast majority of these deposits. Yet this group, however homogeneous it may appear even from a geological point of view, has proved to be quite inhomogeneous in origin. It is convenient to follow three different lines of advance in its interpretation, each starting from a special sub-type, and see where they lead.

When speaking of the quartz-banded ores, we mentioned the local development of andradite skarn as layers or concretions. It is evident that this garnet forms a reaction product between the hematite layers, quartz layers, and interstratified layers of limestone. Similarly, in more or less clearly stratified skarn ores, one can trace an origin from a similar bedded deposit which originally differed from the variety of quartz-banded ore just alluded to only by its greater quantity of limestone or dolomite layers. This greater proportion of carbonates has increased the quantity of reaction skarn resulting from the metamorphism. In this type, apparently, a sedimentary origin is indicated.

In the manganiferous limestone ores or basic skarn ores, again, a parallel metamorphic history may be traced. These ores, even in their present metamorphic stage, still contain manganiferous and ferrous carbonates mixed with the predominant magnetite, and there are strong reasons for believing that they were originally carbonatic throughout, with only a moderate quantity of quartz gangue. The rather common occurrence of graphite in these ores is, for good reasons, held to have resulted from the thermal dissociation of iron-manganese carbonates. The skarn silicates mixed with the ore are interpreted as reaction products between carbonate ore, quartz, and dolomite. Characteristic is the development of a zone of manganiferous skarn between an ore body mixed with dolomite and its siliceous wall rock (hälleflinta or leptite). Thus again we meet the typical 'reaction skarns'. As to the original ore-depositing process it is not possible to state with certainty to what extent sedimentation together with the associated dolomite, or 'shallow' replacement of this rock, have contributed, but it seems probable that both processes have been active.

It is evident from the close association of manganiferous and non-manganiferous types, that the same interpretation must apply also to a large number of deposits of the latter type.

One characteristic variety of non-manganiferous skarn ores presents an entirely different picture. This is the type with highly magnesian skarn (mostly humite minerals, forsterite or serpentine) and that only in moderate quantities. This type, which is related to the dolomite or limestone in a way very clearly indicating replacement, provides, in this region, the only unquestionable evidence of iron ores that have resulted from contact metasomatism. For many other types, with skarn of diopside, tremolite, etc., such an origin is 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 (ludwigite, fluoborite, szaibelyite).

From a genetic point of view, therefore, one may distinguish between two kinds of skarn ores, those with reaction skarn, and those with primary skarn. The former, probably a quite decided majority of the deposits, originated as sediments or through replacement at comparatively shallow depths, during the accumulation of the leptite series. The metamorphism indicated by the reaction skarns is, for very strong reasons, believed to have taken place during the deformation of the leptite series and the intrusion of the first granite group. Many cases are known where it can be shown clearly that the skarn-forming reactions preceded the regional magnesia metasomatism which was allied to the granite intrusion. Thus changes meaning an increase of magnesium relative to calcium occurred in the skarn, for instance replacement of hedenbergitic diopside by tremolite or anthophyllite, the iron set free forming a new generation of magnetite. Since the plainly pyrometasomatic type of skarn ore is also genetically connected with the first granite group, the development of skarn may be regarded, in all its phases, as the result of processes connected with the folding of the leptite series and the intrusion of the first group of granites: first, reaction skarns were formed; later, the skarn-bearing deposits were in many cases 'worked over' by solutions that added magnesia (and occasionally some iron), and in places limestones or dolomites were replaced by pyrometosomatic deposits, the skarn of which is to be designated as primary. With such a complicated history, it is hardly surprising that for many individual deposits it has not proved possible to establish the exact part played in their development by the various processes. One has to be satisfied with the knowledge that these processes have been at work in the region, and that in very many cases one can be fairly sure of their relative importance."

Even when this paper was presented at the Geological Congress in London in 1948 it was quite clear to the present author that pyrometasomatic deposits with what Geijer called primary skarn, if they existed, were very small and unimportant. With primary skarn Geijer meant that the iron material had appeared simultaneously with the formation of the skarn minerals. Since 1948 the author has had several opportunities to study the iron ores in the Riddarhyttan and Norberg regions and has come to the conclusion that the skarn minerals named by Geijer as typical for primary skarns all have been developed by magnesia-metasomatic alterations of the old iron ores and that the enrichment of boron and cerium minerals is due to the most intense alterations of this type. My opinion is (Magnusson 1965 b) that the skarn minerals rich in boron and cerium may be called pyrometasomatic but not the iron ores in which they play only subordinate roles.

Recently (1962) Geijer published a paper with the title "On the association of magnesium and sulphide ores in metasomatic mineralization". Regarding the source problem he states that "it is necessary – assuming a magmatic derivation – to conclude that this concentration of the material occurred considerably below the depth zone where deposition took place". According to Geijer it occurs in Central Sweden only in exceptional cases that the localization of a deposit can be conclusively shown to be dependent upon a special intrusion. And even then the question remains, whether the emanations were derived wholly from this individual magmatic body or from a larger unit. Reasons have been given for the belief that the bulk of the emanations may have been concentrated at a depth below the one represented by the present erosion surface, but this does not exclude the possibility that emanations of a similar nature may also have been given off by the granites during their final emplacement.

Geijer also claims that "any hypothesis that thus counts with processes 'in the unknown depth' is apt to encounter criticism. But this is not meant to imply that a mysterious agent has been at work. It seems reasonable to assume that at these depths two factors favourable for the concentration and fractionation of volatile compounds may have been available in greater amounts than is generally the case higher up, in the intrusion zones: continuous masses at or near magmatic temperatures, and time."

The present author, in his text-book on ore geology (Malmgeologi, 1953) has claimed that the magnesia-metasomatic alterations and the sulphide ores seldom occur at the granite contacts. This indicates that the emanations having caused these alterations came from greater depths. In other words: they have been emitted from the large magma masses from which the synorogenic Svecofennian granites or, to put it more exactly, the solutions and melts that have given origin to these, have come. The magnesia-metasomatic solutions have, according to the author, been driven in front of the magmatic intrusions. They are not residual solutions coming from the crystallizing granites. The reaction skarns in the iron ores were formed when the supply of heat from this front was great enough to make it possible for such reactions to take place. The magnesia-metasomatism occurred afterwards and made the recrystallized ores richer in magnesia. This process is also responsible for the mica sköls that often appear at the contacts with the hälleflintas and leptites and has in many places given birth to minerals such as cordierite and gedrite in the neighbouring volcanic rocks. In the Persberg Odal field the author could identify a hiatus between the reaction skarn and the metasomatic alterations of this. In other mines the magnesia-metasomatism was very close in time with the formation of the reaction skarn, as the present author has pointed out in his description of the iron ores in the Ljusnarsberg region (Magnusson 1940). In the Riddarhyttan and Norberg regions the magnesia-metasomatic alterations are so wide spread and so intense that it is often difficult to identify the reaction skarns, especially in the skarn-iron ores.

In 1954 the present author expressed his belief that the reaction skarns "must have been formed through reactions in the solid state. Small amounts of water have naturally been present here and there". Later experimental work (Hedvall 1958) has shown that the minerals in question, andradite and diopside, could not have been produced through reactions in the solid state at the probable P and T conditions. On the other hand both minerals were formed in the presence of water vapor. It was at the initiative of the author that Hedvall carried out his experiments, and it seems reasonable to assume that the water vapour necessary was derived from water in the original sediment.

As to the stratigraphy of the Norberg region, the skarn iron ores of the Åsgruvan-Östanmossa type characterize a lower etage and the quartz-banded iron ores a higher etage in the complex with iron ores poor in manganese. The upper leptite division contains the Kolningberg and Klackberg ores rich in manganese. Above them we have the dacitic and andesitic rocks as intercalations in the potash leptites. Above them there follows a quartzite belonging to a sedimentary series which the author has called the Larsbo series. This series has been mapped in detail by S. Hjelmqvist, who also published a description of it in 1938.

The rocks belonging to this series occur in several isolated areas surrounded by synorogenic Svecofennian granites. Small remnants appear here and there in these granites. The lowest parts of the sedimentary complex usually consist of mica quartzites locally passing into pure quartzites with subordinate feldspar, usually albite, more seldom microcline and some mica. Geijer (1967) found in such a quartzite in the Norberg district a 5–15 cm thick layer of magnetite together with quartz, sericite, apatite, orthite, and zircon. The grains of the latter mineral are well-rounded. We have here an enrichment of heavy minerals in ancient sand.

The mica quartzites often contain minerals such as cordierite, andalusite, and sillimanite. Tourmaline is common. The micas include muscovite and biotite in varying proportions. The texture in thin section is granoblastic.

All transitions exist between mica quartzites and mica schists, the essential minerals in the latter being quartz, muscovite, biotite, and some oligoclase with 15–20 % An. There are also small amounts of garnet, sillimanite, tourmaline, magnetite, and a good deal of apatite. Locally, the mica schists also contain cordierite, and in more coarse-grained types individuals of this mineral are sometimes as big as a clenched fist. In the southeastern part of the syncline of the Larsbo series andalusite-bearing mica schists with a fine banding occur. These pass into coarse-grained mica gneisses the texture of which is granoblastic, however, with irregular grain contours. The mineralogical composition is quartz, microcline, biotite, muscovite, andalusite, tourmaline, zircon, and magnetite. Sillimanite is sometimes present together with cordierite and/or andalusite.

In the mica quartzites intercalations of arkosic greywackes occur at some places. These are rather coarse-grained rocks consisting of fragments of quartz and feldspar as well as fragments of older rocks and a variable amount of mica. The colour of the greywackes is light grey. Microscopically the greywackes of the Larsbo series display a granoblastic texture with large, granulated, rounded quartz grains and a mica-rich groundmass which consists of quartz, microcline, oligoclase, muscovite, and biotite. Small amounts of apatite, rutile, epidote, and magnetite have been found. Conglomerates have been observed at a few localities only.

In the central parts of the Larsbo syncline sedimentary oligoclase gneisses occupy large areas. In the northwest these schistose gneisses contain muscovite as an essential mineral together with biotite, quartz, and oligoclase. The oligoclase has 20–30 % An. The size of the grains in the more fine-grained rocks is 0.1–0.6 mm, and 0.2–1.5 mm in the more coarse-grained varieties. Sillimanite sometimes is present, and such minerals as tourmaline, apatite, zircon, and magnetite occur in small amounts. Graphite occurs often as isolated grains or has been concentrated into thin layers.

In these gneisses there occurs often a certain amount of sulphides which are responsible for the rusty weathering surfaces of the oligoclase-gneisses. The observed sulphides are pyrrhotite with subordinate pyrite and chalcopyrite. Together with the sulphides there is also a certain amount of magnetite and graphite. In some places the amount of graphite was sufficient to permit mining.

In the southeast, occur even-grained oligoclase-gneisses showing smaller grain size and good stratification. Usually muscovite is lacking; biotite being the only mica mineral present. The stratification depends upon the varying amounts of quartz and mica. Fine-grained, quartz-rich, mica-poor layers alternate with layers of mica schists showing coarser grain size. The oligoclase is basic, with 25–30 % An. Microcline is rare and occurs only in small amounts.

In the oligoclase-gneisses there are more basic intercalations which Hjelmqvist has explained as dacitic and andesitic tuff layers. These have the same granoblastic structure as the oligoclase-gneisses but consist of andesine

(30–35 % An), quartz, and red brown biotite. More basic rocks called greenstones appear also in the oligoclase-gneisses. They consist of hornblende and andesine together with some quartz, biotite, and ore minerals (magnetite, pyrite, and pyrrhotite).

The rapid fluctuations that are characteristic for the Larsbo series clearly indicate deposition under topographic conditions different to those in existence when the Grythyttan series was deposited. The latter must have been formed in tectonically stable areas during periods of subsidence without folding. The Larsbo series on the contrary was formed in connection with folding (early Svecofennian) in a mountainous region. The author has therefore come to the conclusion that the Larsbo series should have been deposited somewhat later than the Grythyttan series.

The slates and greywackes of the Grythyttan series appear as an upper sedimentary etage above the volcanic iron ore-bearing etages and always with the etage with iron ores rich in manganese or iron and manganese ores of the Långban type nearest beneath. The Larsbo series appear in a rounded area above and in contact with all four etages including different types of iron ore. There must be a sharp discordance between the Larsbo series and the iron ore-bearing etages.

The Rocks and Iron Ores of Northern Uppland

(Geijer 1944, Magnusson 1940 a, Lindroth 1916, Sund 1957)

In northern Uppland the synorogenic Svecofennian granites are the dominant rocks, the supracrustal rocks occurring in isolated areas within these. Sediments of the same type as the rocks in the Larsbo series have been found at Barknåre on the coast north of Dannemora. Here, according to B. Sund (1957), a syncline opens to the east, and its central part consists of quartzite containing feldspar and variable amounts of mica. In the western part of this structure the quartzite displays a light-coloured rock composed of rounded quartz grains in a sericitic matrix containing some feldspar. The percentage of feldspar increases to the east. Beneath the quartzite there are tuffitic-argillitic, grey to greyblack and very fine-grained sediments. The mineral composition is essentially quartz, plagioclase (oligoclase or andesine), and mica, both biotite and muscovite. A weak impregnation of sulphides is rather common. In the lowermost layers of these sediments there have been found volcanic agglomerates and conglomerates.

Around Harg volcanic agglomerates as well as conglomerates and tuffitic-argillitic sediments have been found (Beyer 1954). The largest area with such rocks is situated south of Harg and has been followed together with dacites to Bladåker in the south.

Leptites and hälleflintas are, however, the main supracrustal rocks, most of them being alkali-intermediate types. Potash-rich and soda-extreme types appear more locally. Metadacitic and metaandesitic rocks of the same types as in the Norberg region occur in the uppermost part of the volcanic complex. The metadacite south of Harg consists of oligoclase, hornblende, biotite, and some quartz. Accessory minerals are apatite, epidote, titanite, and ore minerals. In the leptite-hälleflinta complex there are as usual limestones, dolomites and iron ores.

The only important iron ores in Northern Uppland are the manganiferous ores in Dannemora. The hälleflintas in the Dannemora field are rich in potassium and belong to the upper etage of the leptite-hälleflinta series. A common type of hälleflinta is a porphyry rich in phenocrysts of quartz and sometimes with an agglomeratic appearance due to the presence of abundant fragments. In some cases the content of quartz phenocrysts is so high that the groundmass is very subordinate. The hälleflinta has then a good clastic structure. Together with phenocrysts of quartz there are also phenocrysts of microcline and sometimes albite or perthite and aggregates of magnetite. Through intermediate types these hälleflintas are combined with volcanic breccias with angular or rounded fragments of hälleflintas. All these types of hälleflinta should be characterized as clastic rocks formed by sorting of volcanic tuff material. Geijer has often found disconformities in these volcanic strata. Among the hälleflintas free from phenocrysts the "banded hälleflintas" are well-known. They consist of silliceous layers with different colours or such layers alternating with carbonate layers.

The manganiferous magnetite iron ores appear in a large limestone-dolomite body which locally even outside the ores contain a few percentages of iron and manganese carbonates together with the magnesium and calcium carbonates.

The fine-grained (0.04–0.1 mm) magnetite in the Dannemora ores usually appears in carbonates or silicates, or both. The carbonates have varying percentages of calcium, magnesium, iron, and manganese. Dannemorite is the dominant skarn mineral. More subordinate are pyroxene, actinolite, garnet, knebelite, and in some types serpentine. Locally knebelite is the dominant mineral. The skarn ores sometimes grade into skarn masses poor in magnetite. G. T. Lindroth (pers. comm.) has found 2.95 % Mn in a collection of separated magnetite grains from a carbonate-magnetite ore from Dannemora.

In the southern part of the field are some intrusions of synorogenic granite. In the vicinity of these intrusions, concentrations of sphalerite, pyrite, pyrrholite, and galena have been formed and also poor impregnations of the same minerals in carbonate rocks and iron ores.

The ores are intersected by hälleflinta dikes with phenocrysts of quartz and albite, or albite alone. Other types are keratophyric with phenocrysts of albite in a groundmass of albite and very small amounts of quartz. More basic dikes (greenstone porphyries) consist of phenocrysts of plagioclase (about 15 % An) in a groundmass of plagioclase and secondary minerals such as actinolite, epidote, and biotite. All these dikes are younger than the ores.

Potash leptites dominate also in the Vattholma district, south of Dannemora. Here quartz-banded magnetite ores, often with some hematite or skarn minerals, are usual. The skarn-banded ores often pass into skarn-magnetite ores with more irregular distributions of magnetite and of the different skarn minerals. It is quite clear that we have had here originally quartz-banded hematite ores deposited together with varying amounts of limestone and dolomite. These ores were later to a large extent metamorphosed into magnetite ores with skarn. In sveral ores the amount of manganese has been about 1 % or more. This ought to be a transition zone between the upper leptite-hälleflinta etage with iron ores rich in manganese and the etage with quartz-banded iron ores poor in manganese.

The Brunna and Salsta mines have been the largest in the Vattholma district. The Strömhag ores differ from all other ores in the district in having high percents of barite in both the magnetite and the hematite ores.

In the Ramhäll field (Lindroth 1916) northeast of Vattholma and south of Dannemora two ore types occur side by side in a 1500 m long and 50 m broad zone with an east-westerly direction. The manganiferous limestone-banded magnetite ore has economic value. It is dolomitic and contains manganese carbonate. Silicates, especially garnet, appear as reaction skarn minerals towards the leptites. The manganese content varies between 0.5 and 2.5 %. The surrounding leptite is according to Lindroth (1916) a sodic one, the only exception from the rule implying that ores rich in manganese are always associated with potash leptites. North of the limestone ores rich in manganese and parallel with them occurs a zone of quartz-banded hematite ores. The surrounding leptite is here a stratified potash one locally containing small layers of limestone and dolomite and sometimes of quartz. The Ramhäll ores thus belong to the transitional zone between the two upper etages. Small quartz-banded hematite ores also occur north of Dannemora, and in the Börsta mines west of Harg and near the sedimentary rocks there have been mined extremely quartz-rich magnetite ores alternating with leptite as well as hematite ores with quartz and actinolite. These ores are very similar to some in the Vattholma region. Nearly all other iron ores in northeastern Uppland belong to the lowest etage with skarn iron ores poor in manganese and poor in or free from quartz. The larger skarn-iron ores include Rörberg and Vigelsbo NNE of Dannemora. In Rörberg the magnetite occurs in a garnet-pyroxene skarn and in Vigelsbo in a pyroxene-actinolite skarn. Among the skarn-ore fields in this large region the Herräng field is the most interesting one.

The author has made a detailed map (1:800) over this field and published a short description (Magnusson 1940 a) of the ores and rocks (with a map in scale 1:2 400).

The main rocks are leptites and grey or red synorogenic Svecofennian granites. The leptites outside the granites contain bodies of iron ore, skarn, limestone, and dolomite in varying proportions. In the transitional zone between granite and leptite, the leptite as well as the iron ore-bearing bodies just mentioned have been intruded by veins of granite, and in the granites leptite, iron ore, skarn, and carbonates form both large and small fragments, patches and spots. In the granites there are also found fragments of greenstone, the corresponding rocks in some places occurring as relatively large masses outside the granites. They then appear as gabbros and diorites. The red granite rich in microcline is distinctly younger than the grey one, which is an oligoclase granite of the Uppsala type. Both these rocks have been intruded by a very large number of greenstone dikes and by a few porphyry dikes.

When the granites appeared, the front zone was made up of leptites with variform bodies of iron ore, skarn, and carbonate rocks. The present shapes of these bodies outside the granites appear to be essentially unchanged. The strong tectonic deformation indicated by the shape of the ore-bearing bodies should thus have occurred prior to the appearance of the granites. For several reasons it appears probable that the dip of the leptite formation in this area was already high before the granites were emplaced.

The grey granite, which predominates in the mapped area, displays no sharp intersecting contacts. The boundaries between grey granite and leptite are as a rule indistinct, and the massive granites slowly grade into leptites veined with granite or containing disseminations of granitic material. The granites themselves are often found to contain profuse quantities of large and small patches of leptite, sometimes, however, even angular fragments. A thorough investigation discloses that the granite has not caused any very considerable dislocation of the fragments of leptite, iron ore, skarn or limestone-dolomite, and the stratigraphy found in the leptite complex can be traced into the front zone of the granites with the aid of the fragments.

The above-mentioned observations in the field show that the granites must have come into place by intrusion. The magma was comparatively fluid and chiefly made room for itself by dissolving material. It has, indeed, eaten itself into the older leptite formation, thereby replacing it. However, the fact that the granite was really a magmatic one has been proved by the presence of sharp-edged and in part rotated fragments of iron ore, greenstone, or leptite, which are often completely embedded in a variety of granite containing diffuse patches and spots of the same material. Scattered pieces of leptite or greenstone are often encountered quite unexpectedly in ore-spotted granite.

The red granite, mainly concentrated to the eastern parts of the field, occurs, generally speaking, in the same manner as the grey variety but is quantitatively subordinate. It has thus not influenced the development and appearance of the area to the same extent as the grey granite.

If we accept a process of assimilation like the one assumed by the author to have taken place during the intrusion of the magmas of the Herräng granites, it has also to be accepted that the assimilated material became very rapidly dispersed in the large granite masses adjoining the Herräng field towards the south. The fact that the assimilated material has influenced the Herräng granites is quite obvious. The Herräng leptites are extreme sodic, and the Herräng granites are decidedly richer in sodium than the great majority of synorogenic Svecofennian granites in Uppland.

The central parts of the large granite areas surrounding the Herräng field are poor in fragments. Sometimes fragments are entirely lacking, and the granites are then very homogeneous. The writer is, therefore, inclined to look upon the intrusion of the granites in the manner outlined above as a contact phenomenon.

When the granites intruded the leptites, partly dissolving them, the iron ores had already the character of skarn-iron ores, occurring together with limestone and dolomite in the normal way. There were also subordinate quantities of quartz-iron ores, partly quartz-banded, and leptite iron ores. In the latter, the ore material was directly interbedded with leptite, in the quartz-iron ores with quartz. The predominant skarns consisted of andradite, pyroxene (intermediate between diopside and hedenbergite), and small quantities of actinolite.

The intruding magmas of the synorogenic granites brought about great changes in the mineralogical composition. In the carbonate rocks remaining from the older skarn formation younger skarns were formed, consisting mainly of garnet rich in grossularite. While the older garnet does not hold more than 3 % Al_2O_3, the younger garnet contains 5–10 % Al_2O_3. Together with this garnet there are quartz, calcite, pyroxene, hornblende, and epidote. The younger pyroxenes are generally richer in hedenbergite than the older ones. At one place where late Svecofennian palingenic granites and pegmatites appear in contact with the carbonate rocks, the author has found minor quantities of vesuvianate, wollastonite, and scapolite.

In the older iron-ore skarns, the synorogenic granites have developed new minerals and mineral associations. These may replace the older ones or occur quite extensively together with them. The commonest of the new minerals is hornblende, the product of an alteration of pyroxene and actinolite. Part of the pyroxenes were first transformed into types rich in hedenbergite. In addition there have also been formed garnet richer in Al_2O_3. The garnet has then to a high degree been replaced by epidote. To a great extent new biotite, too, was formed simultaneously with this late skarn. In areas of leptites penetrated by granite veins the alterations described above have been intensified, and to the minerals mentioned have to be added feldspar and increased quantities of quartz.

Where the ores occur as fragments, patches, and streaks in the granite it is, of course, especially the contents of quartz and feldspar that have increased in them, the younger skarn minerals occurring in a chaotic mixture together with the older skarn minerals in ore and granite. Parts of the granite containing many fragments of ore and skarn have been enriched in hornblende, epidote, and magnetite. This mineral association is thus the final phase in the process of alteration brought about by the granites. The intensity of this alteration steadily increases when passing from the areas of the mica-streaked leptite over the granite-veined leptites to granitic areas showing more or less complete assimilation of iron ore and skarn.

In connection with the invasion of granite, the skarns and the ores became richly impregnated with sulphides. In the ores least influenced by the granite, the content of sulphur may be as low as 0.010 %. In the fragments enclosed in the granites the content of sulphur was often 2–5 %. The sulphides consist of pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. Pyrite and pyrrhotite are spread throughout the whole field, whereas chalcopyrite, sphalerite, and galena have been concentrated almost exclusively to the fragments of ore and skarn in the granite. The quantities of metals, especially zinc, enriched in the ore fragments are by no means insignificant. The heavy metals (Cu, Zn, and Pb) have been concentrated to the front part of the granite masses and have thus been removed from those granitic solutions that have afterwards continued outwards from the granites. The iron found in pyrite and pyrrhotite outside the granites was probably taken mainly from the magnetite of the iron ores. The fluorine of the granite has to a great extent been concentrated as fluorite in the fragments of ore and skarn but has also entered into hornblende and biotite. Scheelite and molybdenite have been observed in small quantities in the vicinity of late Svecofennian palingenic granite.

The author's studies in the Herräng field and sourrounding parts of Northern Uppland made him brood on the problem of the origin of the synorogenic Svecofennian granites. It was quite clear that these granites had taken the place of the leptite-hälleflinta series with its intercalations of carbonate rocks and iron ores, sometimes also of the clastic sediments deposited upon this series. But how did it happen? That was the real problem. When the expanding granite advanced from the south and from the bottom of the crust, a very inhomogeneous supracrustal complex consisting of volcanic rocks, lavas and tuffs, limestones, and dolomites, iron ores, and clastic sediments existed in northern Uppland. These rocks and also intrusive gabbros and diorites must have diasappeared as such when the granites took their place. The material must have been taken up by the granites and spread out by diffusion. The granites ought to have been real melts to make such a homogeneization process possible. In the front-zone in the Herräng field we can study how the leptite disappears, how the limestones and dolomites first became altered to skarn before material was assimilated, and how the iron ores have left only hornblende and epidote as remnants.

The granite magma in the front zone must have been very liquid, otherwise it could not have spread as the field observations suggest. To explain what has happened in the front-zone we can speak of metasomatic processes, ion migrations and such things. The central parts of the granites to the south must, however, have congealed from melts.

If we look at events in the front zone from a place inside the better preserved supracrustal rocks we can, if we like, speak of a granitization. If we place ourselves inside the granite we can speak of assimilation. However, not all material has been assimilated. The sulphides have been driven out before the advancing granites. In the Herräng field they have found places of refuge in the larger remnants of iron ores and usually in the higher parts of them. If the granites had advanced further to the north they would certainly have been expelled from these places, too. On the contrary the iron oxides remained in the melt and became taken up in the silicates, especially hornblende and epidote. Magnesium seems to have been driven out of the front zone causing magnesia-metasomatic alterations, in the Herräng field concentrations of biotite, chlorite, anthophyllite, and quartz. Cordierite has not been found in Herräng.

The author will here recall the explanation given by P. Geijer (1962) concerning the origin of the magnesia-metasomatism. If there had been more dolomites in the Herräng field, the magnesia-metasomatic alterations would certainly have been more intense. The author believes that the stronger magnesia-metasomatic alterations in the west, where the sulphide ores of the Falun type are concentrated, have been caused by solutions driven out from front zones rich in dolomites at depth.

In the Söderby-Karl region a zone of dolomite bodies with skarn-iron ores poor in manganese and characterized by magnesia-rich minerals has been mined. The skarn minerals are tremolite, members of the humite group partly in ophicalcite, serpentine, and chlorite. Sometimes pure diopside is also present. In one mine, Geijer (1944) has found the magnesium-borate szajbelyite and ludwigite, in another mine abundant ludwigite, brucite, and spinel. It is quite clear that these minerals are products of magnesia-metasomatic alterations.

The Rocks and Iron Ores in the Hofors-Torsåker Region

(GEIJER 1944, LINDROTH 1944, and LUNDEGÅRDH 1967)

In the central part of the Hofors region around the Vingesbacke mine and between this mine and the Nyäng mine, the ore-bearing leptite series has, over large areas, been soaked by granitic solutions as in the Herräng field (see above). As in this field it seems probable that the essential tectonic features are older than the intrusion of the synorogenic Svecofennian granites. Large parts of the leptites, ores, skarns, and carbonate rocks have been assimilated by the granitic solutions. An intense exchange of material has taken place in the broad front zone of the advancing granites. It is usually very difficult to draw boundaries between the granites, the leptites, the iron ores, and the carbonate rocks as diffuse transitional zones occur almost everywhere. Where the skarn-iron ores poor in manganese are well preserved, the dominant skarn minerals are pyroxene and garnet, sometimes with some actinolite. They are thus of the Persberg-Storgruvan type. In the front zone of the granites, however, these minerals have been altered to hornblende and epidote. Biotite and chlorite have also been found frequently as alteration products. The rocks, which must be defined as granites, are rich in hornblende and epidote in the assimilation areas. These minerals are distributed in the granites in a very irregular way. The ore remnants usually have very diffuse boundary zones with the granites. Magnetite is often irregularly distributed as spots in the granites and has as a rule been associated with hornblende, epidote, biotite, and chlorite in more or less granitized leptites. Limestones and dolomites, free from iron ores in the beginning, contain skarn minerals such as diopside and grossularite, frequently with a good parallel arrangement following the original banding stratification of the carbonates. These minerals were also replaced later, in the vicinity of the iron ores, by hornblende and epidote. This process has taken place especially where granite offshoots and dikes have penetrated the carbonate rocks. Greenstone dikes have also been more or less assimilated by the granite melts and solutions resulting in the development of hornblende and epidote as scattered grains in the granite.

Of special interest is the fact that in this region, as in the Herräng field, sulphides have been concentrated in the larger skarn ore remnants in the granites. It is particularly here that pyrite and pyrrhotite occur. In the Vingesbacke ores, which are wholly surrounded by granite, these minerals have been especially concentrated at the top of the large ore body beginning at about 250 m level. On this level the ore body is elongated and narrow but widens downwards, being 3 000 m² on the 230 m level, 12 000 m² on the 290 m level and 10 000 m² on the 350 m level before terminating on the 410 m level against a basic granite rich in remnants of leptite and skarn-schlieren. Small limestone-dolomite layers have also been found here. The minable ores are usually surrounded by skarn masses with small magnetite concentrations and sometimes also impregnated with pyrrhotite and pyrite as well as, in a few cases, sphalerite and galena in small quantities.

The iron ores between Vingesbacke and Nyäng are essentially skarn-iron ores poor in manganese, with the same skarn minerals as in the Vingesbacke ores and attacked by the advancing granites as described previously. A large number of mines have been opened here on remnants of skarn-iron ore horizons isolated from each other by granite. Most of these mines are very small, the largest being Stollgruvan and Storgruvan. In addition to the skarn-iron ores poor in manganese there were also a few mines with manganiferous iron ores characterized especially by knebelite and dannemorite. The largest of these ores were those of the Penninge mines in the vicinity of Vingesbacke. In the mine dumps B. Asklund (1934), who has made thorough investigations here, found hedenbergite skarn with rhodonite and actinolite, actinolite-pyroxene skarn, a garnet-knebelite skarn with mica and a dannemorite-knebelite-calcite skarn, a chlorite skarn with biotite, hornblende skarn, magnetite ore with dannemorite-knebelite skarn, and magnetite ore with knebelite and carbonate.

From the Penninge ores the horizon with manganiferous iron ores can be followed through several small mines to Gamla Beskow mine, ENE of Nyäng. The Linderås mines northwest of the Penninge mines are also manganiferous and are probably situated on the same stratigraphic etage above the skarn iron ores poor in manganese.

In the Nyäng mine there are two types of iron ore in the same limestone-dolomite body: a striped magnetite-carbonate ore and a pyroxene-skarn iron ore with andradite. Solutions from the granites have caused exchange of material giving rise to minerals such as hornblende, epidote, biotite, and chlorite, but the alterations in this direction are here very weak. In the pure limestones and dolomites which occur together with the often lens-shaped or more irregular ore bodies, the author has found a good deal of grossularite and quartz.

The iron ore-bearing leptite-zone of the Nyäng and Vingesbacke fields can be followed several km towards the east but is here attacked by the advancing synorogenic Svecofennian granites in an even more intense way. Only small ore remnants have been preserved here and there in the same way as between Nyäng and Vingesbacke. Therefore great interest was aroused when the Vingesbacke ores (nearly 5 million tons), were shown by magnetic investigations to begin at about the 250 m level.

Southwest of the Nyäng mine there are two parallel limestone-dolomite horizons, the one with skarn-or carbonate-iron ores poor in manganese and the other with manganiferous iron ores. The largest of the former, the Storstrecket ores, are usually well banded due to parallel orientation of the magnetite grains in the carbonate rocks. Richer ore beds about one meter wide have been known to occur. Skarn minerals (garnet, pyroxene, and hornblende) have appeared only locally and essentially along leptite boundaries. About 0.4 % Mn has been reported. Northwest of the Storstrecket ores there is another ore, the Afze ore, of the same type but with an essentially higher percentage of manganese, up to 5.24 %.

It is, according to H. Löwenhielm, quite clear that most of the manganese in these ores has been taken up by the magnetites. In the Sjöström mine a magnetite ore of this type with 10–13 % Mn was mined in 1942–1943. Magnetite from the Sjöström ore was analysed by A. Bygdén, who found it to contain about 13 % Mn. Unfortunately, only a few magnetites from Central Sweden have been analysed for manganese. There are in several places, for instance in the Grythytte field, ores without minerals characteristic of manganiferous iron ores and which nevertheless show high percentages of manganese. Perhaps most of the manganese in such cases has entered the magnetites.

Another interesting feature concerns the sulphides. In the ore-bearing complex between Nyäng and Vingesbacke, where intrusions of granite magma have been most intense, there has often occurred a significant impregnation of pyrite and pyrrhotite, less frequently sphalerite and galena. In Storstrecket, however, and in the other ores southwest of Nyäng, the sulphide impregnations consist of sphalerite, galena, and some chalcopyrite. There have also been observed magnesia-metasomatic alterations of the leptites to quartzites and mica schists with cordierite and gedrite.

In his description of the new petrological map of the Gävleborg County, P. H. Lundegårdh (1967) has published observations concerning the ore and skarn minerals in the dumps at the old mines south of Tjärnäs and Torsåker. This region is situated south of the intense granite assimilation zone described previously around Vingesbacke as well as west and east of this mine. The iron-ore bearing zones here stretch southwest to northeast and have been intruded by synorogenic granite magma having solidified to massifs orientated in the same direction. Nearly all iron ores in this large region are skarn-iron ores poor in manganese, only a few mine dumps containing minerals indicating a noticeable percentage of manganese.

The ordinary skarn minerals are pyroxene (variable proportions of diopside and hedenbergite), actinolite, hornblende, a garnet more or less rich in andradite, and often epidote. The dominant ores have thus been of the Persberg-Storgruvan type. Magnesium-rich minerals have been found in some ores as subordinate constituents and include tremolite, ophicalcite, serpentine, and humite minerals.

Most interesting is the impregnation with sphalerite and galena in the iron ores in the northern part of the area south of Tjärnäs and Torsåker. This mineralisation is a continuation of the one met with southwest of the Nyäng mine. In the region north of Tjärnäs and Torsåker it consists of pyrite and pyrrhotite being fixed in the remnants of iron ores enclosed in the granites. The temperature was there evidently too high to permit the formation of sphalerite and galena. These sulphides have therefore been driven in front of the granite into the relatively well preserved iron ores in the zone from Storstrecket and Afze ores in the northwest to the Prästhyttan ores in the southeast. In several occurrences around Prästhyttan there have been found comparatively good concentrations of sphalerite and galena and subordinate chalcopyrite, pyrite, and pyrrhotite in limestone and ophicalcite. They have, however, been too small to permit mining.

In the region of Hästbo and Bodås (Lindroth 1944), south of the sphalerite and galena mineralisations, impregnations with pyrite and subordinate pyrrhotite are found again and increase in intensity towards Bodås mines. The iron ores in this region appear in leptites, which have been more or less altered into mica schists here and there grading into quartzites. The parallel structures in these rocks are indicated by biotite and chlorite as well as by schlieren and impregnations of pyrite and subordinate pyrrhotite, sometimes also some chalcopyrite. The magnetite is usually accompanied by hornblende and epidote, which are alteration products of pyroxene and garnet.

The largest ores in this region are those at Bodås, which have been very irregularly mineralised with the sulphides mentioned above. These occur partly along cross-cutting shear fissures, partly as finely distributed grains in the ore mass between the fissures. The dominant skarn minerals are chlorite, hornblende, and epidote. Remnants of pyroxene and garnet have been found at several places. The iron content was about 35 % and the content of sulphur about 2 %, varying between more than 5 % to less than 1 %.

East of the iron ores in Bodås the leptites in contact with the late Svecofennian palingenic granites have become strongly recrystillized and cut by granite and pegmatite veins orientated parallel with the banding in the leptites.

Young palingenic granites appear also west and north of the Bodås ores, and it seems most probable that the pyrite-pyrrhotite-chalcopyrite impregnations of the Hästbo-Bodås area are closely connected with the emplacement of the palingenic granites.

The Herräng field (Magnusson 1940 a) as well as the Hofors-Torsåker region offer both excellent possibilities for studying what happened when the synorogenic Svecofennian granites attacked the leptite complex with its limestones, dolomites, and skarn-iron ores. The author is quite convinced that it was magmas formed at great depth that started the attacks. Later these magmas expanded in all directions assimilating most of the supracrustal material and driving some of this material in front of them. Sulphides in particular were driven out and have found places of refuge in the iron ore remnants and in remnants of carbonate rocks. If the processes originating the synorogenic granites had not been stopped by an upheaval of the section displayed by the present surface of the crust to cooler levels, the sulphides would have been driven out of these remnants also.

The iron ores have contrary to the sulphides in part been assimilated, and in the front zone their iron was captured in hornblende and epidote. Towards the interior of the granites the amount of these minerals diminishes. A good deal of the calcium of the skarn minerals and the carbonate rocks has been assimilated, too, and occurs now in the same minerals. Magnesium entered the micas and also minerals such as anthophyllite, cummingtonite, chlorite, and talc. These actions of magnesia-metasomatism took place before the front of the advancing granite. Perhaps we have here the explanation of magnesia-metasomatic alterations in general. What we can study in Herräng and in the Hofors-Torsåker region on a small scale is perhaps the same as both Geijer and the present author think has happened at great depth, implying the ejection of emanations having originated at higher levels the sulphide ores of the Falun type as well as the magnesia-rich skarns and sköls of the skarn-iron ores. At great depth, where the magnesia- and silica-rich solutions arose, there must have occurred a large amount of magnesia and especially of dolomite. The most intense formation of sulphide ores accompanied by magnesia-metasomatic alterations has been found in a zone from the Falun region to Guldsmedshyttan. This zone is not related to the granite contacts, but in the better preserved leptite regions it is seen to stretch at some distance from the granites. In regions where granites dominate and the leptite complex occurs as narrow zones between them or as remnants within them, only scattered impregnations of sulphides have been found. The sulphide concentrations mined in old times or being mined nowadays are all situated in better preserved regions at a considerable distance from the granites. The latter have driven the sulphides before them in the front zones and also upwards from greater depths.

The Rocks and Iron Ores in Södermanland and Närke

(MAGNUSSON 1944)

Around Lake Mälaren and south of this region, greywackes and slates occupy deep synclines. This sediment series has been called the Mälar series. Like the Larsbo series it shows rapid fluctuations in the size of clastic sediments. The Larsbo series is to be considered an outlier of the Mälar series but is richer in quartzites than the latter.

The sediments of the Mälar series, the volcanic rocks of the hälleflinta-leptite complex beneath it and the synorogenic granites intrusive in the supracrustal rocks have all been altered more or less into veined gneisses. Together with these alterations new, palingenic granites and pegmatites have arisen.

The iron ore occurrences of the Kantorp mines (Magnusson 1936) are situated inside the veined gneisses south of Lake Mälaren.

In 1929 the author started investigations in these mines. The dominant ores are the pegmatite-iron ores of the Kantorp type. These were originally quartz-banded ores of the same type as has been described from the ore-bearing region of Central Sweden, but they have later been richly impregnated with feldspar and mica, the quartz having been driven out and enriched in other parts of the ore masses. In these parts even magnesia has been enriched. Such ores are the quartz-anthophyllite ores of Kantorp. Where limestones, dolomites and larger skarn masses were present, new skarn minerals have been formed by reactions between this material and the pegmatite solutions. These ores therefore show a chaotic mixture of older and later minerals and have been called skarn-pegmatite ores.

It was quite clear from the very beginning of my investigations in Kantorp that the alterations of the quartz-banded iron ores were caused by the same processes as altered the surrounding rocks: the leptites and sediments, to coarse-grained veined gneisses. I therefore started to investigate and map the Kantorp region, and in 1932 I expressed the opinion that the iron ores of Kantorp and the surrounding rocks originally had the same appearance as the corresponding ores and rocks in the best preserved parts of the ore-bearing region of Central Sweden. It was also considered that they had undergone the same alterations as these ores and rocks in connection with the first Svecofennian folding and the intrusion of the synorogenic granites, before the late Svecofennian alteration which gave the whole ore-bearing complex its present coarse, inhomogeneous texture.

As early as in 1907 P. J. Holmquist suggested that the Stockholm granites were associated with the pegmatitization in the Stockholm region. The author came to the same conclusion in 1932 and expressed the opinion that new regional investigations of the veined gneisses in the county of Sörmland should prove that younger granites of the Fellingsbro and Stockholm groups have played a great role in this region and that their co-operation in the processes giving the veined gneisses have been essential. This does not mean that all the pegmatites appearing in the gneisses should have come from the young granites. On the contrary the material coming from them ought to have been subordinate in comparison with the material mobilized in the older rocks themselves. This has been made quite clear by the fact that the young granites are always rich in microcline whereas in the largest part of the complex white pegmatites rich in plagioclase dominate.

In describing the bedrock of the Kantorp region the author (1936) expressed his opinion as follows:

"The alteration of the Kantorp rocks to veined gneisses was caused by a regional sinking, by which large parts of Central Sweden came into the deep crustal zones where the palingenic processes are predominant. This sinking was caused either by orogenic or by epeirogenic movements. Several geologists assume them to be orogenic but I think epeirogenic movements to be more probable. We have not found in the non-gneissic region surrounding the area of the veined gneisses such tectonic features that could be expected if the sinking was caused by an intense folding. What we can state is that the parallel structures are always very steep (80–90°) except in local folds of the layers where the axes usually dip gently (20–30°). The steep dips of the parallel structures were caused by a strong tangential pressure, not by a new folding. I therefore think that the foldings are much older and that the pressure only caused a compression of the complex in one direction and a stretching out in the other. The rock bodies existing before the alteration into veined gneisses were thus deformed and more elongated.

The deformation was in some degree plastic in detail. We sometimes find, for instance, the greenstone dikes curved and bent. Small S-shaped curves are found here and there, but these studies of details do not force us to assume more intensive folding of the whole complex of veined gneisses.

The alteration to veined gneisses was caused by the high temperature in connection with the compressional forces and by emanations and solutions from deeper zones of the earth's crust, where the palingenic processes were stronger.

The veined gneisses are characterized by an inhomogeneous structure with coarser pegmatite veins. Here and there appear small gneissic but homogeneous fragments of the original rocks, which have escaped the stronger alteration. In the transition zones between the veined gneisses and the central part of the ore-bearing region in Central Sweden, where normal leptites, graywackes and slates are the characteristic rocks, one can follow the alteration and see the pegmatitic parts develop as small spots or strings, which become more and more numerous. In the veined gneisses the pegmatitic veins dominate the rocks. The whole rocks are usually recrystallized and pegmatitic. We can therefore also call the alteration process a pegmatitization. Among the homogeneous fragments in the veined gneisses of the Kantorp district we have leptites, slates, old granites, quartz-banded iron ores, skarn iron ores, and limestones. Among them the slates always seem to be the most easily pegmatitized. Also the leptites are much more easily altered than the old granites which from the very beginning were relatively coarse-grained. Among the leptites the types rich in CaO are altered in a greater degree than those poor in CaO and the banded types more than the more massive ones.

The alteration process is to be considered as a metamorphic differentiation. The most soluble or fusible constituents have been segregated in the form of more or less irregular spots and veins and bands. That these spots and veins and bands received pegmatitic structure depended upon the emanations and solutions that must have soaked through the whole complex at the beginning of the alteration process. We have excellent proofs for this opinion in the chemical alterations that can be proved. Microscopical investigations and comparative studies of nineteen analyses from the district have shown that both the slates, the leptites, and even the old granites have been altered in such a way that an enrichment of the stablest constituents and a reduction of the most soluble substances have taken place. We find a reduction of silica, alkalies and calcium and increase of aluminium, iron and magnesium. As this alteration also has occurred in the slates, the increase of the last-named elements can not be explained by assuming transport of material from the slates. In my opinion it is necessary to assume granitic emanations and solutions soaking their way through the strongly schistose leptite-slate-old granite complex with its iron ores, limestones and dolomites.

The veins which can be regarded as metamorphic differentiates from the rocks themselves show transitions to more independent, larger, intrusive pegmatites, and from the latter to the younger granites of the district. The pegmatitic veins of the rocks themselves vary according to the original chemical composition. The intrusive pegmatites are more independent of the composition of the surrounding rocks and are richer in quartz and microcline. The same tendency is still more pronounced in the younger granites, which often appear as central bodies in the pegmatitized areas. The granitic emanations and solutions causing the metasomatic alterations have always preceded the pegmatite intrusions and these preceded the younger granites. With the intrusions of these granites the pegmatitization finished.

The tangential pressure continued also after the alteration process was essentially ended and caused undulose extinction in the quartz grains of all rocks of the district, the veined gneisses, the more or less independent pegmatites as well as the younger granites. This gives us new proofs that the pegmatites and the granites originated during the pegmatitization process of the region. The pegmatites and the younger granites are concentrated segregation products. The main mass has come from deeper parts of the earth crust. Partly, however, they may have come from the rocks now accessible for our investigations. It is, in fact, often difficult to determine whether we have before us larger segregations in situ or intrusions."

When mapping the Kantorp region, the author classed all supracrustal rocks rich in feldspar as leptite, this being the custom at that time among Swedish geologists. However, it was quite clear that not all feldspar-rich rocks were volcanic rocks of the same kind as in the central part of the ore-bearing region of Central Sweden, that is metamorphosed hälleflintas and leptites. In his paper (p. 13) the author pointed out that supracrustal gneisses with plagioclase rich in anorthite (up to 70 %) have a wide distribution in the western part of the Sörmland gneisses and that in the Kantorp region these are at least as common as genuine volcanic leptite-gneisses. The author also pointed out that the "anorthite-rich leptites" of the Kantorp region were very similar to the rocks in the Larsbo series found by him when leading the mapping of the map-sheet Smedjebacken. It was clear already at that time that this series was rich in greywacke and quartzitic layers.

During his mapping in 1932, the author has defined as sediment-gneisses (mainly altered slates) rocks with a high content of minerals such as cordierite, almandite, andalusite, and sillimanite even in more homogeneous remnants. These rocks always have a large amount of biotite. The boundaries between "slate gneisses" and "leptite gneisses" were of course very difficult to draw. The author therefore pointed out in his paper that he has possibly underestimated the amount of "sediment-gneisses" and that perhaps the "leptite-gneisses with plagioclase rich in anorthite" were also genuine sediments. A noteworthy difference between the leptite-gneisses rich in anorthite and the slate gneisses is that the latter are poor in plagioclase and rich in microcline. There are, however, of course also transitional types between them. Owing to the presence of large quantities of pegmatite, the separation of the different types mentioned above has been difficult in the Kantorp region. This was another reason why the author used the term "leptite" in a wider sense than in the regions outside the veined gneisses. I regret that, in discussions about the origin of the veined gneisses, many geologists thought I only meant genuine volcanic leptites and that these quartz-feldspar rocks have given origin to gneisses rich in cordierite and other femic minerals.

In the veined gneisses of the Kantorp region the microcline is perthitic in an irregular way and often encloses rounded quartz grains. The plagioclase individuals have often been more or less altered to sericite and largely replaced by myrmekite. The quartz individuals have usually been divided into several smaller grains and have rounded contours against the feldspars. The cordierite individuals have frequently been replaced by andalusite and biotite and appear as large, in part poikiloblastic, rounded grains. Also andalusites are often poikiloblasts, too. Almandite is a common mineral in the slate-gneisses in Sörmland and occurs often together with cordierite. Sillimanite appears as thin needles or as bundles of needles. These needles intersect the quartz, feldspar, and cordierite grains but never the andalusite and biotite. It is noteworthy that the two latter minerals always appear together. The biotites are usually red brown and to some extent occur as poikiloblasts. The accessory minerals include apatite, magnetite, pyrite, zircon, and rutile in varying proportions but always in small amounts. In the vicinity of the iron ores, however, the amount of magnetite and often also of hematite has increased significantly by exchange of material.

The boundary relations between the minerals described above and especially the perthitization of the microcline and the myrmekitisation of the plagioclase have been intimately connected with the alteration to veined gneisses and indicate intense rearrangements even in detail.

The synorogenic Svecofennian granite-gneisses seldom show such well-preserved remnants as those contained in the supracrustal gneisses, and they have only occasionally been so strongly pegmatitized as these. The main minerals are quartz, microcline, plagioclase, and biotite. The proportion of plagioclase to microcline is very variable. Most of the synorogenic granites are intermediate. However there are all transitions to plagioclase-granites with very little or no microcline. Extreme microcline-granites are very uncommon. In some plagioclase-granites hornblende appears together with biotite or as the only dark mineral.

Even the best preserved synorogenic granites in the veined gneisses have been changed into coarse-grained gneisses with relatively even-grained granoblastic texture. Often, however, fairly good idiomorphy may olso be displayed by the plagioclase individuals, particularly in the more basic types. The quartz grains have always been subdivided into irregular areas, and as a rule show undulatory extinction. The quartz aggregates often show rounded boundaries towards the feldspars. The microcline is often perthitic. The plagioclase is usually an oligoclase, but variations have been found from oligoclase-albite to acid andesine. More basic plagioclase has not been found by the author in the Kantorp region. Towards the microcline individuals there are often myrmekite rims. Accessory minerals include magnetite, apatite, titanite, and zircon.

In synorogenic gneiss-granites displaying stronger pegmatitization the rounded contours of the quartz aggregates have become more pronounced towards the feldspar, the amount of myrmekite higher, and the plagioclase often dissolved in part so as to appear as ragged remnants in microcline.

It is necessary to assume an exchange of material between the synorogenic granites on the one hand and the slates and greywackes on the other. This is indicated by the common occurrence of minerals such as cordierite, almandite, andalusite, and sillimanite near the boundaries of the synorogenic gneiss-granites and also otherwhere in a less regular manner. Similarly, I have found an exchange of material between the volcanic quartz-feldspar rocks changed to gneisses and adjoining greywacke gneisses.

The intrusive pegmatites differ from the pegmatitic veins and schlieren characterizing the veined gneisses in displaying greater mobility in both the supracrustal rocks and the synorogenic gneiss-granites. They are usually poor in dark minerals except where the pegmatites have taken material from the surrounding rocks. In such cases almandite, cordierite, andalusite, and sillimanite can thus be found in them. At several places the intrusive pegmatites contain such minerals even when they lack in the surrounding rocks. These minerals ought then to have been transported a comparatively long way. Their presence connects the intrusive pegmatites very nearly to the veined gneisses. Structurally they differ very little from the gneisses disregarded from the fact that they are more coarse-grained. The boundary relations between the quartz and feldspar minerals are just the same as in the surrounding gneisses. The mafic minerals also appear in the same way. The intrusive pegmatites are thus even texturally very closely connected with the veined gneisses.

What has been said about the intrusive pegmatites is also valid for the rocks mapped as younger granites by the author in the Kantorp region. Here clear and sharp boundaries frequently show in an excellent way that they are the yongest rocks in the veined gneiss complex. Most of the boundary relations between the minerals found by microscopical investigations in the veined gneisses and the intrusive pegmatites have also been found in the younger granites, which consist essentially of quartz, microcline, plagioclase, and biotite. Locally, these rocks also contain small amounts of minerals such as almandite, cordierite, and sillimanite, usually concentrated in spots. Accessory minerals are magnetite, apatite, zircon, and fluorite. The microcline often appears as large approximately rectangular individuals (often Carlsbad twins). Petrographically, it is in reality only the character of their microcline and their more massive appearance that distinguish them from other quartz-feldspar rocks in the Kantorp region.

After having tried to explain (Sundius 1935) the veined gneisses containing garnet, andalusite, cordierite, and sillimanite as products of magmatic differentiation *in situ,* N. Sundius changed his mind. In 1947 he declared that the veined gneisses of Sörmland should all originate from femic (mafic) leptites of volcanic origin, that their aluminous minerals have been developed by late-magmatic metasomatism connected with the appearance of pegmatites, that the pegmatites have come from the synorogenic granites; and that the pegmatites have no connection with the younger granites. To these opinions I have (Magnusson 1948) objected that the synorogenic granites outside the veined gneisses are never accompanied by pegmatites, that the synorogenic granites have been altered in the same way but not so strongly as the supracrustal rocks, and that there is an intimate connection between the pegmatitic spots and veins of the veined gneisses and the more independent and intrusive pegmatite masses. Besides, there are all transitions between these and the younger granites of the Stockholm-Fellingsbro group.

In 1936 and 1937 H. G. Backlund published his well-known papers "Der Magmaaufstieg in Faltengebirgen" and „Die Umgrenzung der Svekofenniden". In these papers Backlund expressed his opinion that the Svecofennian granites and gneisses are granitization products *in situ* originating mainly from sediments. In the discussion starting after the issuing of these papers, the author (Magnusson 1937 and 1938) emphasized that the veined gneisses could not be coordinated with the synorogenic granites. Certain granites have, however, appeared as products of the alteration process that resulted in the formation of the veined gneisses. These granites show only small variations. They are in fact nearly always red or grey porphyritic granites (Fellingsbro granite) rich in quartz and microcline and showing all transitions to even-grained, medium- or fine-grained granites (Stockholm granite). The granite group older than these granites and not combined with veined gneisses are all differentiated including gabbros, diorites, tonalites, granodiorites, and granites proper. The young granites appearing together with veined gneisses tended more and more, as they left the region of these gneisses, towards an eutectic composition.

Between these eutectic granites and the concentrations of granitic material inside the veined gneisses there are all transitions. As two diagrams published in 1938 illustrate, the granite concentrations inside the veined gneisses have highly varying compositions. Mostly the amounts of potassium are high, as well as the amounts of alumina and femic oxides. Two conclusions may be drawn from these facts. The first is that these granites have not released themselves from the supracrustal material they have soaked and from which they have taken a good deal of their material. The second is that the high potassium concentrations in several of the analyses indicate a stronger enrichment of potassium than of soda. We are thus justified in speaking of potassium metasomatism.

The corresponding granites outside the veined gneisses have, as the diagrams show, lower amounts of alumina and femic oxides and about the same amounts of potassium and sodium. The compositions thus very nearly approximate the eutectic composition.

On a map published in 1938 the author tried to illustrate the distribution of the veined gneisses and the late Svecofennian granites and pegmatites. The central part of the veined gneisses is surrounded by a zone rich in pegmatites and granites. Outwards from the central area these pegmatite and granite concentrations become more and more sharply defined as dikes and stocks. From the zone mentioned a broad belt starting in the region between Örebro and Västerås stretches in a northerly direction via Ludvika and Grängesberg to Falun, and from Falun in an easterly direction to Öregrund and Gräsö. In this belt rounded massifs of granites of nearly eutectic composition occupy large areas. They are always accompanied by a great many pegmatite dikes.

Where concentrations of pegmatite dikes occur without visible connection to massifs of such granites, it seems to be quite obvious that such massifs should exist under the pegmatites. Furthermore, these massifs ought to display diapirs and, as there are all transitions between these granites and the granite concentrations in the veined gneisses, I think it is clear that the diapirs belong to the roof of the veined gneisses and that the granite material in them and in the pegmatites surrounding them must have come from the zone of the veined gneisses.

According to the opinion expressed by the author in the discussions with Backlund in 1937, 1938, and earlier, granitic material should have passed through the zone of the veined gneisses. This zone has acted as a filter, and in the roof of this zone the granitic material streaming upwards has become more and more eutectic in composition. At the same time more mafic material was left behind.

Perhaps the explanation in my paper on the Kantorp region was somewhat diffuse, and it has often been misunderstood. What I tried to explain was that in the section represented by the present earth surface there has occurred a decreace of silica, alkalies, and calcium and an increase of aluminium, iron, and magnesium, and that the former elements were to a great extent driven out, following the granitic solutions and emanations upwards. As a result of this upward stream of a certain amount of the most soluble material, an enrichment of the stablest constituents in the gneisses took place. Even these have, however, been movable, though on a smaller scale. There must have been an exchange of material at the boundaries of the different supracrustal rocks, i. e. between genuine volcanic alcaline leptites without or with very little mafic material, greywackes rich in anorthite and usually with a significant amount of mafic material, and slates with large quantities of mafic material. Otherwise it is impossible to understand the irregular appearance of cordierite, for example together with zones of biotite in the volcanic rocks proper.

The pegmatitic material impregnating the quartz-banded iron ores in the Kantorp mines often contains sillimanite and cordierite together with a large amount of biotite. The remnants of the quartz-banded ores indicate that these ores were originally jaspilites. There must therefore have been a considerable transport of material into the ores. As mentioned before, the quartz has been largely driven out of the ores impregnated with pegmatite material. In the cordierite- and anthophyllite-gneisses of these mines the distribution of the minerals has become very irregular. There are streaks and spots rich in cordierite and others rich in anthophyllite. We have here an example of extensive rearrangement of the material inside the veined gneisses during the formation of these.

Since 1938 I have had opportunities to study several other iron ores situated within the veined gneisses and within the zone rich in pegmatites surrounding these gneisses. I found the same impregnations with feldspar and mica, and the same formation of new skarn-associations in limestones and dolomites occurring together with the iron ores. The carbonate rocks not associated with iron ores and situated within the veined gneisses have been more or less altered to marbles rich in schlieren, veins, and irregular spots of silicate minerals such as diopside, tremolite, forsterite, spinel, and serpentine. These minerals should have been formed by migrating emanations and solutions driven in front of the pegmatites and granites. Such "schlieren-marbles" called Kolmård marble appear in Sweden only in the veined gneisses.

These observations in the mines and in the limestone quarries confirm the view that metasomatic alterations through emanations and solutions were essential for the formation of the veined gneisses in Central Sweden and that there has been a transport of material on a large scale through the filter of the veined gneisses.

In the Kantorp region the original leptites were dominant among the supracrustal rocks, and true sediments displayed subordinate elements. When the author continued his investigations into the region between Kantorp and the Baltic, he soon found that the sediments belonging to the Mälar series were the dominant rocks and that most of the so-called garnet gneisses were originally greywackes and slates. The mineral constituents of these veined gneisses are quartz, plagioclase (An_{15}–An_{30}), perthitic microcline, and biotite in varying proportions together with the characteristic aluminous minerals almandite, cordierite, sillimanite, and, though more seldom, andalusite. In these rocks graphite is rather generally present, especially as sparse impregnations in association with iron sulphides.

The author has found that the layers owing to metamorphic differentiation are more sharply limited than they were in the original sediments. The biotite has to a great extent accumulated in one layer and the light minerals in another. Due to recrystallization the quartz and feldspar have increased in grain size, and the veins have became pegmatitic and irregular. Studying the layers, the author has also noted that the aluminous minerals referred to in the foregoing text are very irregularly distributed in the layers. In many cases the almandite has assembled to small spots at various places in the layers. The same irregular distribution often characterizes the other minerals rich in alumina. The quartz and feldspar have often assembled to true veins in the layers, or they cut the bedding. Finally, the microcline has been concentrated together with quartz and subordinate plagioclase in schlieren and veins varying from very thin lens-shaped bodies to thick intrusive dikes grading into pegmatites and granites.

The author has gained a strong impression that the irregularities described above are the result of a disintegration process having taken place at high temperatures in connection with migrations of emanations and solutions.

In the Stav mines northwest of Kantorp there have been found quartz-banded iron ores and skarn-iron ores in limestones and dolomites. Pegmatite material has, as in the Kantorp mines, penetrated the ores and the carbonate rocks here and there and has caused great irregularities and the formation of many new minerals. The pegmatites are often sillimanite-bearing. The usual skarn minerals are pyroxene, actinolite, hornblende, and garnet. The ore minerals are magnetite and more subordinate hematite. The original banding has sometimes been preserved in the quartz-iron ores, sometimes also in the carbonate and skarn ores. In the carbonate rocks serpentine, olivine, humite minerals, and spinel have been found. Some ores are rich in manganese and contain garnet rich in spessartite as well as rhodonite and manganese carbonates. According to P. J. Holmquist (1907) a good deal of the manganese has gone into the magnetite. G. T. Lindroth (pers. comm.) has found 1.41 % Mn in a collection of separated magnetite grains from an ore from the Stav mines.

Together with the skarn minerals mentioned before anthophyllite and cummingtonite have been found at several places. The leptite has often been altered to anthophyllite-schists. The distribution of the different skarn minerals has frequently been very irregular especially in the vicinity of the pegmatites.

Near the shaft big masses of pegmatite have entered the ore-bearing complex and taken up material from the iron ores. Magnetite then appears as scattered grains, spots, and schlieren. The skarn minerals in the pegmatites are hornblende, epidote, and biotite occurring in the same way as the magnetites.

The different ore types in the Stav mines have become mixed in a chaotic manner, depending upon the presence of large carbonate bodies and pegmatites.

The ore-bearing zone can be followed from the Kantorp and Stav mines towards the northwest to Lake Hjälmaren. All iron ores in this zone are quartz-banded and combined with skarn-iron ores in limestones and dolomites. The most interesting are the ores in the Askö mines, where the original quartz-banded iron ores and the skarn-iron ores in limestone and dolomite have been intersected by large pegmatite masses. A mixture of ore and abundant pegmatite has also been mined. New minerals such as garnet, hornblende, epidote, and biotite have been formed in connection with the pegmatite invasion. Only small remnants of the original ores occur. The author was able to follow the extraction of the ores during several years. Some days there was relatively good ore in the walls, other days only pegmatite was visible.

In the iron ore zone southwest of Mariefred the ores in the Skottvång and Älgsjöbacken mines were originally quartz-banded and combined with skarn-iron ores in limestone and dolomite. Both magnetite and hematite have occurred. The ores and the surrounding leptites have been invaded by large pegmatite masses. At places where the ore and skarn minerals have become scattered in the pegmatites, their constituent minerals have often grown very large. Magnetite, pyroxene, hornblende, and garnet individuals up to several cm or sometimes even dm in diameter have been found in the dumps.

Bredsjönäs mines, in the same zone, has displayed manganese iron ores as irregular concentrations in large limestone-dolomite bodies. The content of MnO has been between 5 % and 0.5 %. Coarse-grained carbonate ores and skarn ores, pyroxene skarn ores poor in manganese, and knebelite-skarn ores rich in manganese have been present. Almandite-biotite-sköls occur along contacts with leptite. In connection with the pegmatite invasion many new minerals have been formed: pyroxene, hornblende, garnet, epidote, biotite, dannemorite, and knebelite near contacts with the ores, and scapolite, wollastonite, spinel, and zoisite close to carbonate rocks.

The ores in the Järna mines SSW of Södertälje were originally skarn iron ores which have been rich in quartz and feldspar in varying proportions due to the pegmatite invasion. The skarn minerals include pyroxene, hornblende, and garnet. The pyroxene is dark and rich in hedenbergite. The hornblende is black, high in iron and alkalies. The garnets vary between andradite and almandite. Much iron has been taken from the ores to form these new, iron-rich minerals.

Northeast of Nyköping several mines have been opened on skarn- and carbonate-iron ores rich in manganese. The magnetite in these ores is accompanied by knebelite, dannemorite, a garnet rich in spessartite, hornblende, pyroxene, and carbonate in varying proportions. The contents of garnet, hornblende, pyroxene, and biotite increase towards the pegmatites and the leptitic gneisses. Where the pegmatites have penetrated the ores, the latter have become very inhomogeneous and often very coarse-grained.

Nearer Nyköping city a few iron ores, which have been quartz-banded hematite-magnetite ores, occur side by side with skarn-banded magnetite ores. From the fine-grained ores there are all transitions to coarse-grained pegmatite-invaded ores. The banding has disappeared in the predominantly coarse-grained ores, and many new minerals have been formed.

WSW of Oxelösund, near the Baltic, layers of skarn minerals rich in manganese occur near ordinary skarn-iron ores. A. Erdmann called these layers eulysites (Palmgren 1921). They consist of the same skarn minerals as the manganiferous skarn iron ores described previously (Ställberg, Kolningberg, Klackberg etc.). The minerals of the eulysites are essentially knebelite together with pyroxene rich in manganese and garnet rich in spessartite. Along the boundaries occur dannemorite, iron-anthophyllite, and garnet rich in spessartite. Some geologists have tried to explain these skarn layers as intrusive rocks. In my opinion they were originally sediments which have altered to skarn in the same way as the manganiferous skarn-iron ores named above. The difference is only the low content of magnetite in the eulysites. The skarn mined had 6–12 % Mn and 24–33 % Fe. The content of phosphorus was about 0.2 %.

The presence of manganiferous iron ores and quartz-banded iron ores together with limestones and dolomites in the leptite zones now described from the Södermanland county indicates that the leptite formation here belongs to the upper part of the ore-bearing leptite complex, which appears as anticlinal ridges between synclines filled with greywackes and slates more or less altered to veined gneisses.

In the southeastern part of the Stockholm archipelago (the Skärgårdzone) at the eastern boundary of the greywacke-slate syncline of the Mälar series occur on the island of Utö comparatively large, well-preserved quartz-banded hematite iron ores in which the quartz usually is of the ferruginous type with a grey red colour. The ores mined appear in the central part of a complex consisting of alternating layers of more or less dolomitic limestone and a rock that has been called hälleflinta by P. J. Holmquist (1910), who led the mapping of this region on account of the Geological Congress in Stockholm 1910. According to him these banded hälleflintas were metatuffites in part similar to hornfels, metatuffites banded with thin layers of carbonates, and tuffites more intimately mixed with calcareous mud.

Pilava Podgurski, who published a geological survey of the Utö iron ore deposit, in 1957 came to the conclusion that the rocks here had been developed by sedimentation of eroded matter and of carbonate rocks. He found a high frequency of intermediate stages between the two groups of rocks, *viz.* quartz and feldspar with carbonate. Even products of volcanic activity should according to him possibly be included in the rock series now considered. The occurrence of feldspar in quartz-banded ores indicates, according to Pilava Podgurski, that mechanical sedimentation has taken place simultaneously with the precipitation of iron, silicic acid, and carbonates as chemical sediments.

Six diamond drill cores give evidence of interbedding of quartz-banded hematite ores with ferruginous quartz, carbonate layers, and hälleflinta layers having originally been tuffites or sandstone layers with or without carbonate material.

Owing to tectonic deformation with nearly vertical folding axes, the ore and hälleflinta layers became more or less divided into pieces surrounded by the incompetent plastic carbonate rocks. By reactions between these rocks and ore as well as ferruginous quartz and hälleflinta an often intense formation of skarn minerals occurred in connection with the regional metamorphism, which also altered some hematite into magnetite, especially close to or in skarn. Remnants of hematite ores and ferruginous quartz are often found enclosed in skarn and skarn ores with magnetite. The common skarn minerals have been pyroxene, actinolite, and hornblende. Garnet, epidote, and tremolite are also met with.

In the hälleflintas Pilava Podgurski has found biotite, chlorite, and graphite. He thinks that the biotite and chlorite originates from clay. The present author has in the dump heap only found sköl zones of biotite and chlorite formed in the usual way.

In the carbonate layers northwest of the iron ores occur fahlband impregnations consisting of sphalerite, galena, and pyrrhotite in varying proportions. In connection with the sulphide invasion the limestones and dolomites became more or less altered to skarn consisting of diopside, tremolite, and scapolite. In addition to the sulphides mentioned above chalcopyrite, pyrite, cuprite, arsenopyrite, and bornite have been found. The latter occur near or sometimes in the iron ores, in which biotite and chlorite and some hornblende were also formed.

Northwest of the complex with interbedded hälleflintas and carbonates sediments of the Mälar series appear. These have here been strongly altered to veined gneisses, and it seems probable to the author that the sulphide material was driven out of these greywacke-slate-sediments in connection with their palingenic alteration to veined gneisses.

As S. Gavelin (Gavelin-Lundegårdh 1960) has pointed out, most rocks southeast of the limestone-dolomite-hälleflinta complex classed as leptites by P. J. Holmquist (1910) are greywackes and conglomerates. Towards the southeast the supracrustal complex with comparatively well-preserved rocks is bounded by the synorogenic Svecofennian granites. The supracrustal rocks have been followed from Utö over Ornö, Nämndö and Runmarö and a large number of smaller islands. On Ornö and Runmarö there are sulphide impregnations, but no iron ores have been found north of Utö.

The Utö region belongs to the outer zone of the palingenic processes characterized by an abundance of cross-cutting pegmatites. These are considered to represent material that has passed through the inner zone of the veined gneisses at depth, removing and assimilating material from these rocks. This outer zone, the i n t r u s i o n z o n e, can be followed from Utö *via* Nyköping to Åmmeberg. In the pegmatites of the outer zone west of Nyköping we find minerals such as tourmaline, beryl, orthite, and apatite, sometimes even topaz and here and there uraniferous minerals. In the iron ores cut by the pegmatites mentioned the same minerals also appear. Moreover the leptites nearby the pegmatites have frequently been altered to mica schists in which the same minerals are once again enriched.

In the intrusion zone outside the central area of the veined gneisses there are also sulphide impregnations clearly connected with the pegmatites and the mica-schists. In this zone situated south, southwest, and southeast of the central area pyrite, pyrite-chalcopyrite, pyrrhotite, chalcopyrite-cobaltite, and sphalerite-galena deposits have been found. These occurrences should either be interpreted as new formations caused by the processes that developed the veined gneisses, or older occurrences removed and strongly altered by these processes. In the central zone of the veined gneisses there exist no sulphide occurrences worth mentioning, only sparse impregnations. In the intrusion zone in the roof of the veined gneisses, on the other hand, concentrations to real occurrences have taken place. The enrichment has occurred in the relatively well-preserved parts of the very irregular (from the metamorphic point of view) outer zone. Often we can observe a zoning of the sulphide minerals against local migmatite fronts. Finally, the iron ores of this zone have usually become more or less impregnated with various sulphide minerals.

In other words, the author's opinion is that in connection with the formation of the veined gneisses metals have been driven out from the sediments and from older sulphide ores and concentrated outside the migmatite front in the intrusion zone. In this way, zinc, lead, and other metals have been deposited, especially where the migmatite front is relatively sharp, as in the Åmmeberg field and in the northern part of Utö in the southern Stockholm archipelago.

The sulphide impregnations of the Utö region have already been described.

In the Åmmeberg Field (Johansson 1910, Magnusson 1948, Magnusson 1953 and 1960, Henriques 1964) the veined gneisses are situated to the south of the ore-bearing zone. Taken as a whole the area of the veined gneisses here seems to be of a rather monotonous character but is very heterogeneous when regarded in detail, with irregular bands and veins of 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.

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

The central ore-bearing zone in Åmmeberg presents a very great diversity of rock types. The dominant 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 intercalated in the banded leptites. Even in the leptites themselves there is usually a certain amount of calcite and dolomite present as thin layers or evenly distributed solitary grains. The amount of these carbonates was originally considerably greater, most of the carbonates having been replaced by skarn minerals such as diopside, garnet, hornblende and, in the vicinity of the migmatite front, also wollastonite and vesuvianite by reactions with the intruding granitic solutions and with the surrounding minerals. The secondary minerals mentioned are in the skarn-bearing zones mixed with quartz, microcline, andesine, or labradorite and zoisite, or epidote as an alteration product of plagioclase.

Intercalated with the limestone and skarn layers of the banded leptites are also more gneissic rocks rich in biotite and with a low amount of cordierite, andalusite, and sillimanite. These rocks were undoubtedly originally sediments rich in alumina. The banded leptites with their high content of feldspar were from the beginning 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 have been here and there concentrated in layers 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 developed by the same process.

The intensity of the sulphide precipitation and the skarn-forming processes increases considerably in the southern part of the central belt against the migmatite front, and it is only here that ores occur rich enough in zinc and lead to permit mining.

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 high 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 occurs the main zinc and lead ore layer. It begins with a skarn layer essentially composed of pyroxene with some garnet, hornblende, 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. Wollastonite and vesuvianite, too, have been found locally in the ore.

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

The ore mined at present appears on a large scale as one or two distinct layers. In detail there are, however, many irregularities, 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 the pyrrhotite-bearing skarn zone in the south is also broader than usual. It seems 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 to intrude at various places 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 the ores as well as the skarn. The sulphide- and skarn-forming solutions and the pegmatites have come from the migmatite front originated by the palingenic processes that altered the rocks in the south to veined gneisses. An alteration in the same direction can also be observed here and there in the central belt, especially in the more gneissic rocks rich in biotite, but the alteration is here much weaker.

The stronger migmatitization in the central belt has locally stopped against the limestone-banded and calcareous 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 migmatic 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.

The author has thus given the same explanation for the Åmmeberg ores as for the sulphide ores on the Utö island.

According to Å. Henriques, who has made thorough investigations in the Åmmeberg field, it is not quite clear that the present author is right in his opinion about the origin of the sulphide ores of the Åmmeberg type.

His investigations, published in 1964, have according to him shown that ”no infallible interpretation of the genesis of the ores is possible: most factors could be used equally well for epigenetic or syngenetic theories of ore formation. Nor has a postulation and discussion of different modes of ore formation provided unambiguous proof as to the genesis. A possibly subjective weighing-up of the implications of circumstantial evidence discussed suggests, however, that in all probability the ores were syngenetically formed from ore material originating from submarine emanating hydrothermal solutions.

None of the factors which can be connected with the ore formation oppose such an interpretation. In fact, most of the observations suggest that the ore has been formed in this way. The structures which are characteristic of the ore zone agree consistently better with a syngenetic than with an epigenetic ore formation. This applies, amongst other things, to the constantly identical stratigraphic position of the Main Ore Layer, despite the presence of a wide zone of similar presumptive host rocks (skarnbanded leptite) directly adjoining the Main Ore Layer, and the fact that no pre-ore tectonization seems to have contributed to the localization of the ores. Other indications of a syngenetic formation include the fine layering of the ores which can be followed for considerable distances, often through several ore bodies and the absence of 'jumping' of the mineralization from one band to another. The structures which suggest that there has been a slumping of already mineralized layers also provide signs of a supracrustal ore formation. The same applies to the absence of wall rock alterations and channelways for ore solutions and the low temperature of formation of the ores according to the often observed low iron content of the sphalerites.

The usually low admixture of epiclastic minerals in the ores does not exclude the possibility of a chemical sedimentary formation, but points more towards a formation connected with the magmatic activity which was going on while the ore zone (the grey leptite) was being formed.

Continued investigations of this 'one of the most mysterious of ore deposits' will provide more evidence which will either support or oppose the syngenetic interpretation."

The present author will not deny the possibility of a syngenetic origin for the Åmmeberg sulphide ores but considers the problems concerning these ores as details in the much more greater problem of sulphide impregnations which appear here and there in the intrusion zone from the southern Stockholm archipelago (Utö deposits) to the iron ore region northwest of the Åmmeberg ores.

Northwest of Åmmeberg there is a zone with manganiferous iron ore extending from the Västerby to the Åmme mines (Magnusson 1944). The original impregnation of the knebelite with very fine-grained magnetite which certainly once characterized these ores like the well-preserved manganiferous ores in Ställberg and Norberg has disappeared in connection with the strong recrystallization having affected the whole region northwest of Åmmeberg. The ores mined have been coarse-grained and the magnetite has displayed a compact mass between the well crystallized knebelite grains. In addition to knebelite the skarn consists of pyroxene, dannemorite, garnet, hornblende, and biotite. The three last-named minerals have occurred near the leptite boundaries and also in the central parts of the ores, which have then had a much more variable composition than corresponding ores in better preserved regions.

These ores and the leptite northeast of them have been richly though irregularly impregnated with sulphides, particularly sphalerite and galena.

Northeast of the zone with manganiferous iron ore runs a parallel zone, the Åmmestorp-Lövfalla zone with -skarn-iron ores poor in manganese. These are magnetite ores with pyroxene as the dominant skarn mineral though more or less altered to hornblende. Sometimes hornblende predominates. At the leptite boundaries biotite appears together with hornblende. A diffuse banding has locally been found. Quartz appears here and there in the ores. The iron ores in this zone are richly impregnated with sulphides, especially pyrrhotite and pyrite but also chalcopyrite. Cobaltite has been found locally.

Between the zone with manganiferous iron ores and the zone with skarn-iron ores poor in manganese is the Vena field situated. It shows sulphide impregnations along schistosity planes in the leptite. These impregnations have been mined. They consist of cobaltite, smaltite, and chalcopyrite with some pyrrhotite as well as sphalerite, galena, arsenopyrite, and also some bismuth minerals. These impregnations in the iron ores and in the leptites indicate that Åmmeberg is a detail in the much larger problem concerning the sulphide impregnations in the outer intrusion zone south of the veined gneisses.

The Blackfärd and Lindhult ores east of Åmmeberg are also pyroxene-hornblende ores richly impregnated with sulphides, in Blackfärd pyrite and pyrrhotite, in Lindhult mainly sphalerite together with pyrite, pyrrhotite, galena, and arsenopyrite. In the latter ores there are also quartz-banded iron ore types. The Håkantorp ores are rich in magnesium with coarse-grained tremolite skarn containing serpentine, spinel, actinolite, talc, and biotite in varying proportions. The surrounding leptites are rich in mica and contain cordierite and anthophyllite.

The Tybble ores have been rich in grey or greyblue quartz containing fine-grained magnetite and showing a diffuse banding. These ores have biotite as the main skarn mineral. There are, however, all transitions between them and skarn-iron ores with hornblende as the main skarn mineral. The ores are rich in tourmaline and orthite, minerals which also appear in the intrusive pegmatites.

The Doverstorp ores (Asklund in Tegengren 1924, Magnusson 1944) are partly quartz-iron ores with complete transitions between hematite and magnetite ores. To the northeast there is a limestone-dolomite layer with serpentine, humite minerals, tremolite, and pyroxene but lacking iron ores.

In the central part of the zone there are carbonate rocks with stripes and spots of serpentine, olivine, humite minerals, diopside, spinel, tremolite, and phlogopite. There is also a coarse-grained pyroxene-skarn lacking magnetite but containing garnet rich in grossularite and skarn-iron ores with pyroxene, garnet, actinolite, hornblende, often also cummingtonite, anthophyllite, hypersthene, cordierite, muscovite, and quartz. Sometimes the content of quartz is high. The leptite has often been altered to cordierite-anthophyllite-bearing, sometimes quartzitic types. At the boundaries the leptites have been altered to garnet-bearing mica sköls.

We have in this region both magnesia-metasomatic alterations and alterations from the Gothian granites in the west.

The pyroxene-skarn-iron ores in the Glan mines appear as layers in a thick limestone-dolomite body in which layers of a serpentine-bearing carbonate-magnetite ore have been mined. In the skarn ores garnet, hornblende, and mica were also constituents. The surrounding leptite, intersected with pegmatite veins, is rich in mica. At the boundary mica sköls with red garnet and hornblende have existed.

In the Doverstorp field there occur parallel to the iron ore zone described previously several zones impregnated with sulphides. The sulphide-impregnated rock is a dark grey leptite rich in quartz. Pyrite is the dominant sulphide appearing in isolated grains and as veins. On fissures appear pyrrhotite and subordinate pyrite, sometimes also chalcopyrite, sphalerite, and galena.

The ore zones in the Ervalla mines to the north of Örebro, which have sometimes been more than 20 m thick, have been composed of ore layers a few cm thick and alternating with poorer leptite layers. Pyrrhotite and pyrite are the main ore minerals, but impregnation zones of chalcopyrite, sphalerite, and galena have also occurred. Thin skarn layers with remnants of limestone are especially interesting because the skarn minerals have been pyroxene, garnet, epidote, and vesuvianite. The Ervalla impregnations are reminiscent of the Åmmeberg ores, as the author could confirm when he visited the mines before they were abandoned.

In Dylta, south of Ervalla, pyrite-rich fahlbands have been mined. They were of the same type as the Ervalla ores.

The Tunaberg copper-cobalt ores southwest of Nyköping have been concentrated to a limestone in a region rich in palingenic granites and pegmatites. Granitic material has been mixed with the limestone giving a pyroxene skarn with feldspar, quartz, scapolite, orthite, titanite, cobaltite, and chalcopyrite.

Between Åmmeberg and Tunaberg there are several small fahlbands with sphalerite, galena, and pyrrhotite. Outside this zone there occur other fahlbands with pyrite and pyrrhotite. These as well as the more irregular and scattered sulphide impregnations around and between them resemble the sulphide fahlbands and more scattered impregnations in the Åmmeberg field and in the iron ores in the Åmmeberg region and between these. The author therefore came to the conclusion that the development of the fahlbands in the Åmmeberg field were details in the regional sulphide migrations in the intrusion zone south of the veined gneisses.

If the fahlbands of the Åmmeberg type have been syngenetically formed from ore material originating from submarine exhalative solutions, it is, according to the author, necessary to postulate two types of sulphide occurrences in the intrusion zone – that at Åmmeberg and the more widespread type of impregnation which has affected the iron ores and the supracrustal rocks between them. These impregnations must have been connected with the late Svecofennian palingenic processes, and these processes ought also to have affected the fahlbands in Åmmeberg and altered them. The skarn layers appearing together with the fahlbands cannot have originated together with the original exhalative sediments. The skarn must, in this case, be younger, and as wollastonite and vesuvianite are characteristic for the Åmmeberg skarn layers, the author is convinced that at least the skarn-forming processes were connected with the young palingenic processes which gave us the veined gneisses and the pegmatites and palingenic granites in the intrusion zone south of them.

The author has found in the better preserved regions in Central Sweden that the development of wollastonite and vesuvianite have always been connected with the late Svecofennian palingenic processes. The skarn minerals in the iron ores have, however, been formed in connection with the intrusion of the synorogenic granites but have later been altered more or less as a consequence of the palingenic processes and have simultaneously become impregnated with sulphides in front of the migmatites.

The Lekeberg Region

(MAGNUSSON 1935 and 1944)

Most of the iron ores in the Lekeberg region are poor in manganese. Only a few manganiferous skarn and carbonate iron ores are known. The iron ores poor in manganese include quartz-iron ores with only little skarn, quartz-rich skarn-iron ores as well as skarn- and carbonate-iron ores lacking quartz. Often these types poor in manganese appear side by side in the same mines. At several places skarn-bearing quartz-iron ores appear in or close to large carbonate bodies. In the carbonate rocks there frequently appear skarn masses without magnetite but usually with large individuals of garnet.

Both the quartz-iron ores and the quartziferous skarn-iron ores are sometimes hematite ores, sometimes magnetite ores, or transitional types between these. It is astonishing to find so many hematite ores in a region where the leptites have been so strongly metamorphosed. There is no doubt that the magnetite is a recrystallization product of the hematite. The author has also found hematite preserved in the carbonate ores and skarn-iron ores poor in quartz.

The ores are often more or less distinctly banded. The banding sometimes characterizes the whole ore body. Sometimes it appears as a residual structure in subordinate parts of the ore layers, the remaining parts of these showing a more irregular structure. The banding is best preserved in the quartz-iron ores. Even in the carbonate iron ores the banding is sometimes well-preserved, however. Sometimes the iron ore layers alternate with skarn layers or with leptite layers.

Quartziferous hematite and magnetite ores lacking larger masses of skarn appear in the Lekeberg region, often close to carbonate rocks, and indicate that the older alteration in connection with the intrusion of the synorogenic granites was very weak. Thus the ores and rocks, i. e. hälleflintas and fine-grained transitional types between hälleflinta and leptite, were well-preserved before intrusion of the late Svecofennian palingenic granites. It is therefore often difficult in this region to distinguish between older and younger skarn, that is between skarn minerals formed in connection with the intrusion of the synorogenic Svecofennian granites and such developed as a consequence of the young palingenic processes. The author has found that a remarkable amount of the older skarn has been preserved, though in recrystallized form, in the skarn-iron ores. These are, however, subordinate in comparison with the quartz-iron ores. Palingenic processes and intrusions of young palingenic granites are, however, no doubt responsible for the great coarse-grained skarn bodies present here and there in the carbonate rocks associated with the quartziferous and carbonate iron ores. They are also responsible for the development of the great sköl skarns which appear in or in contact with the quartz-iron ores, the leptites here being changed to mica schists. The garnet skarn has sometimes been so strongly developed that the quartz-iron ores nearly disappear in it. White quartz and red feldspar are typical for this skarn, and subordinate epidote, hornblende, and pyroxene occur together with the garnet.

The formation of sköl skarn has transformed the quartz-iron ores to skarn-iron ores at several places. Most of the quartziferous skarn iron ores in the Lekeberg region have originated in this way. In the Kronoberg mines, such ores dominate and have been called "sköl-ores". They are characterized by the presence of abundant mica, particularly biotite but also muscovite, chlorite, and talc. In addition there occur minerals such as garnet, epidote, actinolite, and hornblende, sometimes in such quantities that it is necessary to assume that limestone and dolomite have been present in the original series of sediments. Where the formation of sköls grew very intense, minerals rich in magnesium, such as cummingtonite, hypersthene, and cordierite, formed. Boundary sköls appeared also simultaneously with the older skarn formation. The great importance these sköls have got in the Lekeberg region depends on the late Svecofennian pegmatite intrusions and the alteration of leptites to mica schists. The latter are often rich in garnet. Orthite and tourmaline appear as isolated grains or as aggregates in which some apatite may also occur.

The limestone has often been altered to ophicalcite, and in carbonate rocks and ores serpentine, humite minerals, spinel, phlogopite, and chlorite frequently appear. In many iron ores and carbonate rocks larger or smaller sulphide impregnations have been found. Pyrite, pyrrhotite, chalcopyrite, bornite, and galena are all present but at only a few places have they been sufficiently concentrated to permit mining (Hässelkulla copper ores and Garphyttan silver ores). Most of the sulphide impregnations seem to be connected with the pegmatites and the formation of the young garnet skarn. Observations in the Hässelkulla and Klara mines are largely responsible for this conclusion.

In the manganiferous iron ores in this region we never find fine-grained magnetite in the knebelites. This mineral is usually free from magnetite, which in stead occurs as a cement between the knebelite grains. At the same time a mixture of minerals has appeared which in the better preserved regions characterizes the boundary zones but is here forced into the interior of the ores. Reaction zones have also been formed at the boundaries between different minerals. Dannemorite, for instance, occurs between knebelite and manganese-hedenbergite in the manganiferous iron ores. Actinolite needles occur around the magnetite grains in the sköl iron ores. Pseudomorphic alterations of older minerals such as cordierite, plagioclase, and hornblende are common in the sköl ores as are also alterations along fissures and cleavages in the minerals. The simple mineral compositions which are characteristic of the older reaction skarns in well-preserved regions have thus, in the Lekeberg region, been replaced in detail by varying mineral combinations showing increased grain size and developed by the palingenic processes. At first the palingenic granites and pegmatites have caused a heating and a recrystallization. Later, the pegmatites themselves have caused mineralogical alterations (garnet skarn, sulphide impregnations). Still later, circulating solutions have caused new minerals to develop in the ores and in the carbonate rocks along the boundaries towards the leptites (formation of sköl skarn). There are, in the Lekeberg region, no distinct boundaries between these three types of formation of new minerals. Elsewhere one of them dominates over the other two.

In the Klara mines the ores appeared as irregular concentrations in limestone and skarn. In the ore-bearing complex there are a great many pegmatite and granite dikes. The ores have contained both magnetite and hematite together with some quartz and thin skarn zones close to the carbonate rocks. Sometimes, however, the skarn forms large masses. It is coarse-grained and contains garnet and epidote accompanied by some hornblende and pyroxene. Abundant quartz and feldspar have appeared in connection with the late Svecofennian granite and pegmatite intrusions. The latter are also responsible for the pyrite and chalcopyrite in both ore and skarn.

The iron ores in the Hässelkulla mines were coarse-grained quartziferous magnetite ores. These occurred as irregular aggregates in a garnet skarn with subordinate hornblende, pyroxene, calcite, quartz, feldspar, and larger and smaller remnants of limestone often rich in garnet. Ore, skarn, and limestone have been cut by pegmatite and granite dikes. Ores and skarns have been the same as in the Klara mine. The banding has, however, been destroyed as a result of the intense skarn formation.

In the Hässelkulla copper ores pyrite, chalcopyrite, and bornite have impregnated iron ores, garnet skarn, and limestone. The same sulphides have also been formed in the pegmatite dikes. Near the pegmatite vesuvianite, wollastonite, and scapolite have been found.

In the S a n n a mines there were two parallel layers – one a quartziferous magnetite ore rich in sulphides, especially pyrite and pyrrhotite, another a dolomitic limestone rich in manganese. Between these a thin zone of hematite has stretched.

In the Kronoberg field the most interesting ores are the sköl ores. These are rich in biotite and magnetite, sometimes with remnants of hematite. They are quartz-bearing to quartz-rich ores often with good banding preserved. Together with quartz and biotite large contents of actinolite and hornblende as well as subordinate garnet, epidote, pyroxene, cordierite, tremolite, hypersthene, cummingtonite, talc, and chlorite have sometimes been found. Remnants of carbonate rocks have also been observed together with these skarn minerals. In some mines the skarn mentioned has dominated over the sköl skarn, which often contains remnants of garnet-pyroxene skarn. In this field an original reaction skarn was subjected to magnesia-metasomatic alteration, and afterwards sköl skarn was formed as a consequence of the palingenic processes. Very great mineralogical variations have resulted from the evolution thus sketched.

The Kärrgruvan mines in the Guldsmedsboda field have all had sköl ores rich in quartz, sometimes magnetite ores, sometimes hematite ores with more or less magnetite. Layers rich in mica alternate with layers of purer ore and quartz. Fine-grained hematite occurs in such a way in the quartz as to leave no doubt that the original material was ferruginous quartz. Leptite layers have also been found interbedding the ores. Locally there appear high contents of tourmaline, orthite, apatite and zircon. Dikes and veins of pegmatite and aplite are abundant in the ores and the surrounding rocks as well. Granite material has also been introduced as solutions at various places.

The description of the iron ores in the Lekeberg region given above indicates that these received their present character as a consequence of the intrusion of the late Svecofennian palingenic granites of the Stockholm-Fellingsbro type and associated pegmatites and aplites. Between the Lekeberg region and the Nora region there is a girdle especially rich in such palingenic granites and pegmatites. On the northern side of this girdle the Dalkarlsberg, Pershytte, and Striberg fields are situated. As described prevously alterations of the palingenic type disappear northwards in these fields.

In the Mälar region from Stockholm *via* Västerås to Köping, the late Svecofennian palingenic granites of the Stockholm-Fellingsbro type are very intimately connected with veined gneisses. North of the zone from Västerås to Örebro the same granites appear as rounded massifs with abundant apophyses of pegmatite and aplite. The material for these massifs ought to have come from zones of veined gneisses at depth. Where accumulations of pegmatites and aplites appear outside the massifs, they ought to exist at depth but near the present surface of the crust. In the massifs, which are reminiscent of diapirs, the material for the palingenic granites must have streamed upwards. It ought to have been developed in a zone of veined gneisses with abundant quartz and feldspar material. Such massifs have been previously described in this book from the Ljusnarsberg and other regions in Central Sweden.

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