SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:o 424.

ÅRSBOK 33 (1939) N:o 4.

GEOLOGY AND ORES

OF

THE MALÅNÄS DISTRICT

VÄSTERBOTTEN, SWEDEN

BY

SVEN GAVELIN

WITH 38 PLATES

Pris 5.00 kr.

STOCKHOLM 1939

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

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Svensk resumé:
Malånäsets geologi och malmer.

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KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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Errata

in Geology and Ores of the Malånäs District

by *Sven Gavelin.*

Page 43. Line 2, below Analysis No. 8: angite-type read augite-type.
Page 52. Fig. 6 A: Figure 20 read 23.
Figure 10 in the lower right hand corner read 20.
Page 63. Summary, second passage, line 5: point 39 read point 40.
Page 68. Line 7, below Analysis No. 10: (*37*) read (*38*).
Page 75. Foot-note 1, line 2: *75* read *30*.
Page 80. Foot-note 1, line 3: (*33*) read (*34*).
Page 93. Line 6: alteration read alternation.
Page 93. Fourth passage, line 6: *35* read *36*.
Page 180. Second passage, line 3: *2* read *3*.

391136. S. G. U. Ser C nr 424. Gavelin.

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PREFACE.

In 1920 the Geological Survey of Sweden started extensive geological mapping and ore prospecting in the Skellefte District, preliminary work having been carried out still earlier by Chief Director A. Gavelin who made some general investigations during 1916—1919. From the very beginning the Malånäs District was assigned primary importance owing to the ore indications already known of in that district.

The present paper is intended to give a general survey of the results obtained as the work progressed, which results have but in recent years become so extensive that they may be presented in a detailed survey. Due to the geological work having been carried out mainly with a view to finding and investigating ores, this paper will chiefly deal with such problems as are connected with the ores, their origin and distribution. Certain questions of special petrographical and mineralogical interest, which require additional special investigations that they may be solved, have in many cases necessarily been left in abeyance for the time being.

My own field investigations were carried out during the years 1933 to 1937, in which latter year they were practically completed. Additional geophysical investigations and diamond drilling were carried out in 1938. To a certain extent this paper refers also to older material belonging to the Geological Survey of Sweden, this being particularly true of the ores that have been subjected to no renewed investigations since 1932. As regards the Bjurträsk ores, Norrliden, and, to a certain extent, Bjurliden, my account is mainly founded on material furnished by Alvar Högbom, J. Eklund, and A. Barkenberg. The main topographical features, watercourses, outlines of swamps and outcrops, etc., in the geological map, are mainly based on a general map of the area originally prepared by Alvar Högbom. When the mapping was started there already existed a large geophysical material and, at least for certain parts of the area, maps of outcrops, and finally there existed a large number of observations of schistosities, collected by W. Larsson.

The investigation was made on the initiative of Chief Director A. Gavelin who gave me the task of carrying out the geological treatment of the results in the district, who in many ways facilitated my investigations, and whose great personal interest and rich regional experience proved excellent stimulants in my work.

A considerable part of the laboratory research was carried out at the Mineralogical Institute of the University of Stockholm. My esteemed teacher, Professor P. Quensel, who first acquainted me with petrographical methods, was kind enough to place the equipment of his institution at my disposal. My sincere thanks are also due to him for all his assistance both in my present work and previously, when he has always contributed with valuable suggestions and productive discussions.

Dr. N. H. Magnusson under whose guidance I worked several summers, was the first to introduce me to geological working methods in the field and always displayed great interest in my work, tendering valuable advice and suggestions with reference to geological problems both of a general nature and of a more specific ore-geological kind, for all of which I beg to express my great gratitude.

I am greatly indebted to my colleagues at the Geological Survey of Sweden, Dr. Alvar Högbom and J. Eklund, for the excellent manner in which they acquainted me with the main features of the geology of the district and the geological experience that had already been gained. Thanks to their thorough knowledge of the general geological features of the Skellefte District, they have greatly facilitated my work. Discussions on various matters with my other colleagues and with Professor P. Geijer, Dr. H. von Eckermann, and Professor H. Backlund, have proved of great value.

Grants received from the C. F. Liljevalch foundation made it possible for me to study the principles of ore-microscopic methods under the guidance of Professor P. Ramdohr at the Mineralogical Institute of the University of Berlin. The microscopic examination of the ores from the Skellefte District was then started. Guided by Professor Ramdohr and aided by his vast knowledge of the geological problems, I was able to study the various aspects of microscopic methods as well as various questions of a general kind, for all of which I am greatly indebted to him.

Professor G. Aminoff most kindly placed the equipment of the Mineralogical Department of the National Museum of Natural History at my disposal for the two Debey photograms taken, and most readily advised me on mineralogical questions of special kinds.

I have further derived great benefit from my collaboration and discussions, in the field as well as in the laboratory, with my friends at Bolidens Gruv A.B., Dr. E. Dahlström, E. Grip, and O. Ödman.

Certain parts of the translation have been made by Dr. T. Nilsson, the main part, however, having been made by Mr. B. Norbelie, who has also revised the whole manuscript and assisted in reading the proofs, in doing which he has displayed great interest.

Stockholm, Geological Survey, April 1939.

Sven Gavelin.

I. Introduction.

The Skellefte District is the ore district latest discovered in Sweden. A. G. Högbom introduced the name and has discussed the rocks of the area in several publications (*44*, *45*, *46*, *47*). During the last few years a number of papers have been published on various problems in the district. Alvar Högbom (*42*) recently published a map of the rocks in the area together with a description in which he gives an exhaustive summary of the literature previously published and also makes a survey of the historical evolution in the district. Those who desire to study the more regional or special literature that does not refer to the questions discussed in this work, are referred to the List of References in A. Högbom's work (*42*). As A. Högbom's description also covers the area here called the Malånäs District, I have endeavoured as far as possible to make the compass of this treatise suitable that it may be directly linked up with his description and complete it. Nevertheless, it has of course not been possible to avoid certain repetitions.

According to the above-mentioned authors the rocks of the district belong to the earliest archaean formation, the Svionian rocks. The same interpretation is found in the new map of Fennoscandia (*26* a). Professor Backlund (*1*) has recently asserted, mainly on the basis of general tectonic considerations, that the rocks belong to the formation next in order, the Karelides. This question, however, has no bearing upon the problems discussed in this paper, nor is any light thrown upon it by the results obtained.

The Malånäs District is situated in the parish of Norsjö, south of the Skellefte River. Its exact location is apparent from fig. 1. The bedrock is very extensively covered with glacial drifts, sand, and swamps, but within certain areas the outcrops are quite abundant. The result is that in certain parts a very detailed map can be produced whereas in others there is no possibility of mapping the details of the geological features. In order that the details may not be lost and with a view to producing a conception of the main features of the district, the scale of the map has been selected so that the details can be denoted. To make the difference between well known and badly known areas distinctly visible, the covered areas have not been printed in colour, the boundaries of the various rocks merely being denoted (see the map, Pl. 38).

The problems associated with the ores of the Malånäs District, the history of their discovery, and the prospecting activity have been discussed by

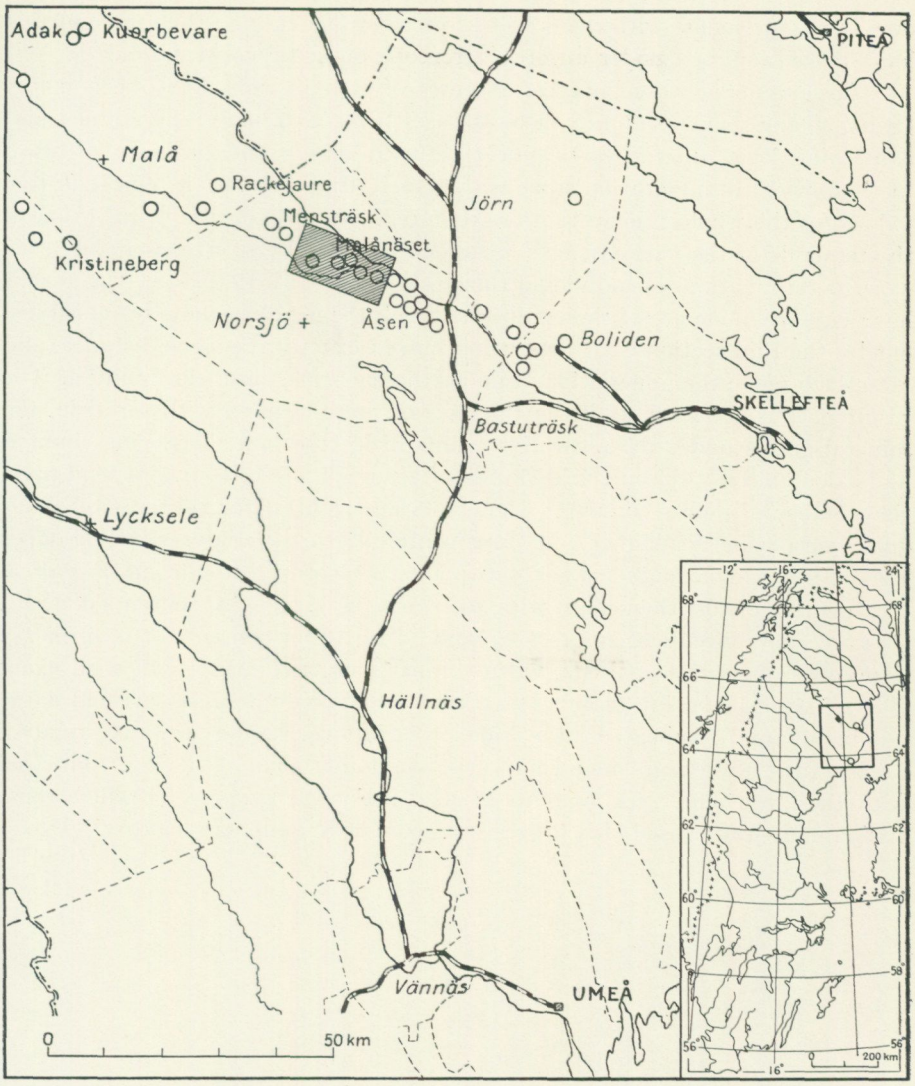


Fig. 1. Map showing location and extension of the mapped area (= Pl. 38).

J. Eklund (*11, 13*), A. Gavelin (*23, 24, 25, 26*), Alvar Högbom (*39, 40, 42, 43*), H. E. Johansson (*49*), H. Lundberg (*54*). The general geology of the district has been discussed by Eklund (*10, 12*) and Alvar Högbom (*39, 41, 42*).

The determinations of the optical properties of the minerals have generally been made on a universal stage of Leitz' construction. The refraction has been checked by the immersion method, refraction liquids being used whose indices were determined in a total-refractometer. Double refraction was determined with the Berek compensator, the thickness of the thin section being determined either by comparative measurements in adjoining quartz grains or by

direct measurements with the ocular screw micrometer. The opaque minerals have been examined under an ore-microscope of Leitz' construction.

A large number of volumetric analyses of thin sections have been made. Owing to the rocks examined in most cases being extremely fine-grained and containing large quantities of finely diffused micas, the ordinary Rosiwal method with an integration-stage is extremely time-wasting, if representative values for the whole thin section are required. In addition the distribution of the minerals of the various rocks examined is generally so irregular that very exact determinations of individual thin sections are of little value. The author has therefore made use of the "point method", the measurements being carried out by the thin section each time being moved exactly the same distance, and after each move the mineral found under the hair-cross has been counted. The result is thus the same as if the thin section were covered with a reticle, the mineral grains under the respective points of intersection then being counted and calculated in per cent. The degree of accuracy will of course depend upon the number of points counted. The errors are greatest for contents of about 50 %, decreasing for higher and lower contents. In the analyses in this paper I have generally counted about 500 points. According to the mathematical treatment one must then count with an error of $\pm$ 2.25 % for contents of 50 %, $\pm$ 1.8 % for contents of 20 or 80 %, and $\pm$ 1.3 % for contents of 10 or 90 %. A number of control analyses, when comparisons were made both with exact determinations on integration-stage and with point analyses with a large number of points, indicated rather smaller variations. In the cases investigated, for instance, there were found no variations larger than $\pm$ 1.5 %, compared with the ideal values, for contents of 40 %. For the purpose for which these analyses are to be used this degree of accuracy is quite satisfactory.

II. General Survey of the Rocks.

In his description accompanying the map of the Skellefte District, Alvar Högbom (*42*, pp. 9—10) presents the following classification of the pre-Cambrian rocks, the specification below also showing the general chronological sequence from older rocks to younger ones, starting at the bottom:

Younger Archaean:	Youngest Archaean granites
	Younger supercrustal formation, the Vargfors formation (conglomerates, arkose, sandstone, phyllite)
	— — — *Unconformity* — — — — — — —
Older Archaean:	Younger Archaean granites, the Revsund granite series
	Older greenstone dikes
	Older Archaean granites, gneiss-granites, the Jörn granite series
	Older supercrustal formation
	The porphyry-porphyrite series in Arvidsjaur and adjacent districts
	The phyllite series with effusive greenstones
	The leptite-hälleflinta series (more or less recrystallized volcanic rocks, ranging in composition from quartz-porphyries to basalts)

The present paper will deal only with rocks belonging to the lower part of the older supercrustal formation, i. e. the phyllite and the leptite-hälleflinta series. Towards the south the investigation was extended as far as the large granite massive belonging to the younger Archaean granites, which constitutes the boundary of the supercrustal rocks of the Skellefte District in the south; on the north the area studied is bounded by the southern edge of the largest area of the Vargfors rocks.

The chemical composition and the structure of the volcanics vary quite considerably. Quartzporphyries, lavas as well as their pyroclastic derivates, are of great importance. The latter may be developed as typical agglomerates or volcanic breccias, or as even-grained, massive or stratified tuffs and tuffites.

With the decrease of silica, types of rock are encountered which may be looked upon as quartzkeratophyres or keratophyres. However, homogeneous lavas of true keratophyric composition are very rare within the mapped

area, if they occur at all. On the other hand, this type of rock is abundant as fragments in the volcanic breccias and a great part of the dense tuffs in the western sections of the area are intermingled with keratophyric material.

Greenstones of andesitic to basaltic composition are fairly abundant. Metamorphism, however, often renders it difficult to tell lavas from tuffs, although very well developed agglomerates occasionally are found also in this group. Spilitic types, constituting gradations to the keratophyres, are also encountered in the north-western part of the investigated area.

The purely sedimentary part consists very largely of graphite-bearing phyllites. Grey, graphite-free phyllites and arkose are encountered, though less frequently, and in isolated cases even with conglomeratic development.

In the previously published general surveys of the rocks of the Skellefte District, the terms leptite and hälleflinta, borrowed from Bergslagen (the ore district in Central Sweden), have been used to denote the more or less recrystallized volcanic rocks. Within the southern and more intensely metamorphosed parts of the present area there occur bedded or homogeneous rocks of quartzporphyry composition, which in many respects greatly resemble some of the Bergslagen leptites. Towards the north the metamorphism decreases, primary structures and textures are better preserved, and certain analogies to the hälleflintas of Bergslagen are encountered, although the rock in this case generally is more femic than in Bergslagen.

In his description of the upper series of the older supercrustal formation, the Arvidsjaur porphyries, Grip (*31*) has consistently used the names of the original lava rocks, for these rocks are so slightly metamorphosed and form such distinct types that such a nomenclature can be adopted without difficulty. Within the best preserved parts of the Malånäs area, however, there are rocks that are identical to those described by Grip, both with regard to structure and in certain cases also as regards their chemical composition. Under these circumstances it may be desirable also here to use a nomenclature that is easily correlated with the nomenclature employed for the upper supercrustal series.

When drawing the map certain difficulties were often encountered in effecting a consistent and in all respects uniform classification of chemically different types of rock. During the mapping work in the field it is of course first of all the structural characteristics that catch the eye, while the chemical variations or similarities may be far more difficult to discern. The difficulties are of course most pronounced within the even-grained, dense rocks, where a megascopic estimation of the mineral components present may be very precarious. Microscopic examinations of these types of rocks disclose considerable variations even within quite small areas and in the strike of the rock beds. When the rocks are extremely fine-grained even microscopic examinations may fail to give a clear idea of the mineral composition (cf. e. g. p. 32).

It is thus often impossible to draw a definite boundary line between even-grained rocks of a quartzporphyry composition and those of a keratophyric composition as well as between keratophyres and rocks that might best be

termed spilitic greenstones. These difficulties are especially conspicuous in the north-western parts of the mapped area, where the rocks to a large extent are of tuffitic origin. In these cases we can do no more than attempt to delimit such areas where either keratophyre or quartzporphyry definitely predominate. It has then proved most practical to reserve the name of quartzporphyry for rocks of true quartzporphyric (granitic) composition, and they are also readily recognized as such. On the other hand the dense rocks of tuffitic origin which are neither quartzporphyries, typical keratophyres, nor andesites (cf. p. 33), have had to be grouped with the keratophyres and the quartzkeratophyres, at least on the map. Among the rocks denoted on the map as "dense tuffs, mainly of intermediate composition" we may thus also find quartzporphyric members but on the whole these areas are more intermediate than those characterized as quartzporphyries. The reason for dividing e. g. the chemically very homogeneous quartzporphyries into a large number of subdivisions, while the keratophyric rocks, often displaying rather decided chemical variations in their composition, have been grouped under one heading, is that in the former case the different rocks form very characteristic types which are readily recognizable as well-defined beds when mapping the area. In the latter case the various types of development display a more irregular distribution and consequently they cannot be used when drawing the map. The somewhat heterogeneous method of classifying the rocks adopted for the map is thus intended as far as possible to indicate the data on which the combinations of the rock beds are extensively founded.

There is another circumstance that must not be disregarded. When classifying the volcanic rocks according to certain main types no attention has been paid to the degree of the metamorphism to which the rocks in question have been subjected. It is thus a question of great importance whether or not the calcite, very abundant in the low-grade areas (cf. the special description of the different rocks), should be included in the original composition of the rock itself. The metamorphism being high-grade, CaO occurs in hornblende and intermediate plagioclase. This means that in such cases spilitic and even certain keratophyric types in high-grade metamorphic areas correspond to rocks of practically andesitic character (see further Chapters V, 5 and VI, 1).

III. Stratigraphy.

An exhaustive analysis of the mutual stratigraphic relations of the various rock-types in the present area is hardly possible. The reason is that the tectonics have often produced results that are very irregular and in many cases difficult to interpret, and it may thus often be questionable if the recurrence of certain rock-types in a cross-section means new stratigraphic horizons or if they constitute folded parts of the same horizon. In earlier surveys the opinion has been stressed that the phyllite series generally superpose the volcanites, and this opinion is confirmed in several cases also within the present

area. It seems undeniable, however, that the volcanic action has continued also after the formation of phyllites had commenced. This is borne out for instance by the occurrence of phyllite fragments in volcanic breccias (cf. the special description on p. 36). Furthermore, at least part of the phyllite beds at Skäggträskberget (see map, Pl. 38) are undoubtedly interstratified layers in the volcanics.

In the eastern part of Skäggträskberget we find the only well exposed area with an unquestionably continuous series of strata within the mapped area, viz.:

Graphite-phyllite

Volcanic breccia with black, phyllitic groundmass	1—5 m
Volcanic breccias interbedded with light, dense, partly stratified tuffs	50 m
Fine-grained quartzporphyry, in the upper part enclosing occasional dense fragments	250 m

The figures show the approximate thickness of the individual beds reduced for a dip of 30°. The thickness of the quartzporphyry bed is calculated only to the place where the outcrops disappear but it is most probably very much greater. Above the phyllite we again find volcanic breccias and light, dense tuffs interstratified with thin layers of black phyllite, though these latter in places may represent a repetition of folded and broken parts of underlying phyllite layers. The inner, thickest phyllite bed, however, is in all probability the uppermost part of this series of strata. It is on all sides surrounded by light, dense tuffs, which would thus appear to underlie the phyllite. It consequently seems most probable that the thick phyllite bed is underlain by a series of rocks interbedded with thin phyllite layers, which series in turn is underlain by quartzporphyric lavas. A. Högbom (*42*, p. 10) has also maintained that such interstratified beds undoubtedly do occur.

Turning now to the phyllite beds between the thick bed west of the village of Bjurträsket and the Bjurträsk ores, it would not appear unreasonable to explain them in a similar manner. These phyllites interchange with bedded tuffitic rocks of average quartzporphyry composition. The section across the rock beds from the Bjurträsk ore to the village of Bjurträsket gives a good idea of the variations in the rocks in this part of the investigated area from the quartzporphyry to the thick phyllite bed. At the Bjurträsk ore the porphyry lies on a beautifully developed quartzporphyry agglomerate with interstratified beds of greenstone. On the quartzporphyry we then find acid agglomerates with greenstones. Upwards, the agglomerates are converted into banded tuffs; thin phyllite horizons then appear until at last the uppermost, thick phyllite bed is reached. It is a remarkable fact, however, that immediately below this phyllite horizon there again appears a homogeneous quartzporphyry bed of exactly the same character as that at the Bjurträsk ore.

The greenstones of andesitic or basaltic composition, often quite abundant, cannot be located to any stratigraphic horizon, and in the present area it is

not even possible to find any tendency towards enrichment of the greenstone beds within anyone part of the formation. The map may possibly give the impression that the zone containing the thin phyllite beds north of the village of Bjurträsket is poorer in greenstone than the lower parts. This, however, may depend very much upon the fact that the rocks are not at all so well exposed within those zones as elsewhere. Very little of the thick phyllite bed in the south appears within the mapped area and it has consequently not been very closely examined, but the visible parts do not seem to contain any greenstones. In neighbouring areas, however, greenstones are abundant within the corresponding stratigraphic horizon (cf. A. Högbom, *42*, p. 22). In the lower parts of the volcanic series the distribution of greenstones is also irregular. Greenstones thus appear near and around the Bjurträsk ore chiefly in the agglomeratic rocks, but west of Norrliden and at the Bjurfors ores we find greenstones and quartzporphyry lavas directly interchanging with each other.

A certain irregularity in the regional distribution of the andesitic greenstones can be established, however, and will at once be seen on the map. These greenstones are thus plentiful in the eastern and central parts of the area; in the westernmost parts, on the other hand, they are very rare and within large areas they are entirely lacking. In the latter area, however, tuffites and volcanic breccias with abundant keratophyric material are quantitatively very important, whereas keratophyres seem to be entirely absent in the eastern parts. These differences thus illustrate two different types of volcanic development.

It will be seen from the above that it is impossible on the basis of the field observations to carry out a detailed stratigraphic classification of the different rock-types. It is merely possible to distinguish between a lower series consisting only of volcanics of quartzporphyry to andesite or possibly basalt composition, a transitional division largely consisting of tuffs and tuffites, the upper part of which is interstratified with graphite-phyllites, and finally the uppermost, mainly sedimentary beds, the graphite-phyllite series.

IV. Tectonic Features.

The supercrustal rocks of the area are greatly upraised and never occur in their original position. The general impression conveyed by the tectonic features is that the foldings are very comprehensive and that their characteristic is that of a true orogenesis.

However, the possibilities of making an exhaustive tectonic analysis in this area of the mutual relationship of the rocks and of those processes that have led to the present development are rather limited. In many cases it is possible only to touch upon certain features, which, however, for the present can be assigned value only as local phenomena. Other questions of a more regional importance must be left in abeyance until it is possible to overlook larger

parts of the greatly folded, supercrustal series when it might be possible to obtain a solution of the tectonic problems in a wider connection.

There are many reasons for the above-mentioned difficulties. First of all the extremely irregular distribution of outcrops should be mentioned, as it makes the tectonic observation material most heterogeneous and usually quite incomplete. This disadvantage, however, is partly compensated by extensive geophysic investigations, often making it possible also in areas heavily covered to follow certain rock layers in detail.

Furthermore, however, the composition of the rocks themselves causes certain difficulties in the interpretation of tectonic conditions in general. It has already been pointed out that the phyllite series generally superposes the volcanic rocks, but that it is impossible either in the lower or upper parts of the rock series to determine a detailed stratigraphic sequence. The variations of rocks within a certain area thus do not always assist in determining what is up or down in the group of beds. The reaction of the different rocks to the deforming forces also contributes to making the tectonic conditions more complicated and difficult to interpret. Thus the generally massive greenstones, for instance, seem to be very much less plastic, more competent, than the stratified rocks and the quartzporphyries rich in biotite and sericite. The graphite-phyllites are exceptional in this respect, in all stages of the deformation being without comparison the most mobile rock. The result is that the glidings preferably take place along the phyllite beds, thus often making it impossible definitely to decide whether or not a phyllite bed actually has an autochtonic position in relation to the surrounding rocks. In many cases the wedging out of a phyllite bed in the strike presumably means that it has simply been pressed out mechanically and need not necessarily have any bearing on the original stratification. On the other hand, phyllite may be pressed in along fractures in other rocks, and these fractures being fairly large, the phyllite tectonite also becomes quite important. On the map of the surroundings of Skäggträskberget, Pl. 38, one can see some conspicuous phyllite beds of this kind.

A direct observation of the great plasticity of the graphite phyllite has been made in the western part of the area, i. e. within the quartzporphyry bed in the northern part of Kaffeheden. Phyllite has been observed there as fissure-filling in quartzporphyry. The phyllite, not especially rich in graphite, however, forms up to 2 cm wide fissure-fillings, mainly vertical, and rather appears to brecciate the porphyry. The quartzporphyry bed actually borders stratified tuffites containing beds of phyllite of the same type as the phyllite in the fissures. The locality, however, where the fissures are found, is surrounded by rocks containing homogeneous quartzporphyry exposed within a radius of at least 35 metres, which makes it probable that the phyllite actually has been moved a considerable distance.

The inhomogeneity of the folded material mentioned above often makes the minor tectonic features very irregular, and it does not always really mirror the main tectonic features. Special care should be exercised in areas where phyllite occurs in greater quantities and together with other, more competent

rocks. Within the mapped area we can distinguish certain main parts each with its characteristic features, which, however, do not always portray the mutual relationship of the major tectonic features. A. Högbom (*42*, p. 17) has also commented upon this lack of agreement between the tectonic details and the major tectonic features, in the tectonic survey in his description. On the other hand, there are also areas where the minor structures directly mirror the major features. In order to demonstrate the relation between the structural details and the major tectonic features, the exposed areas on both sides of the line Bjurliden — the Bjurträsk ores — Snåttermyran and also at Skäggträskberget should first be examined.

The first-mentioned area can be subdivided into two main sections, each of which presents an individual tectonic style. These sections are separated from each other by a marked tectonic plane running along the southern edge of the large, northern quartzporphyry bed. As is seen from the map, Pl. 38 and fig. 4, the main strike is almost east-west, generally with a fairly steep dip towards the south. It will also be observed in the map that the quartzporphyry and greenstone beds in the southern part form fairly soft, but irregular folds, where the angle between the limbs of the folds, however, generally is not less than 45°. Exactly the same style is found in the minor folds of all outcrops. These conditions are specially apparent in those parts where the beds have a north-westerly strike, thus departing from the main strike. The contacts between the different rocks are not smooth, the folds being minutely crumpled with variations in the amplitude of the folds from one cm to a metre or two. Thus only when considering the average strike is it possible to get an idea of the major folds. The general development, however, clearly indicates that the axes of the major as well as of the minor folds coincide in this case.

In addition, the rocks in this region often reveal a decided linear structure. This is particularly conspicuous in the agglomerates where the fragments are often elongated to form long »rods» in the biotite-rich groundmass. As would be expected the direction of the linear structure here coincides with that of the minor folds, and we are thus most probably faced with a coincidence between tectonic details and the larger tectonic features. Within the section of the area discussed above the pitch of the linear structure is fairly uniform. Minor and major folds, linear structures, schistosity, and rock limits are orientated along fold-axes pitching 30°—50° towards WSW.

North of the great tectonic line mentioned the tectonic conditions are quite different. There we find a decidedly linear schistosity of rocks; the tectonic features have a definite character of "Einschaarigkeit", to use the German term (*70*, p. 45). Here, too, the structural features of the outcrops picture the tectonic style of the area. The difference in the appearance of the agglomerates in the areas north and south of the tectonic line constitutes an excellent example of the coincidence between minor and major structures. Pl. 4 a shows the agglomerate typical of the southern area, while Pl. 4 b portrays the same rock under the tectonic conditions of the northern area. A

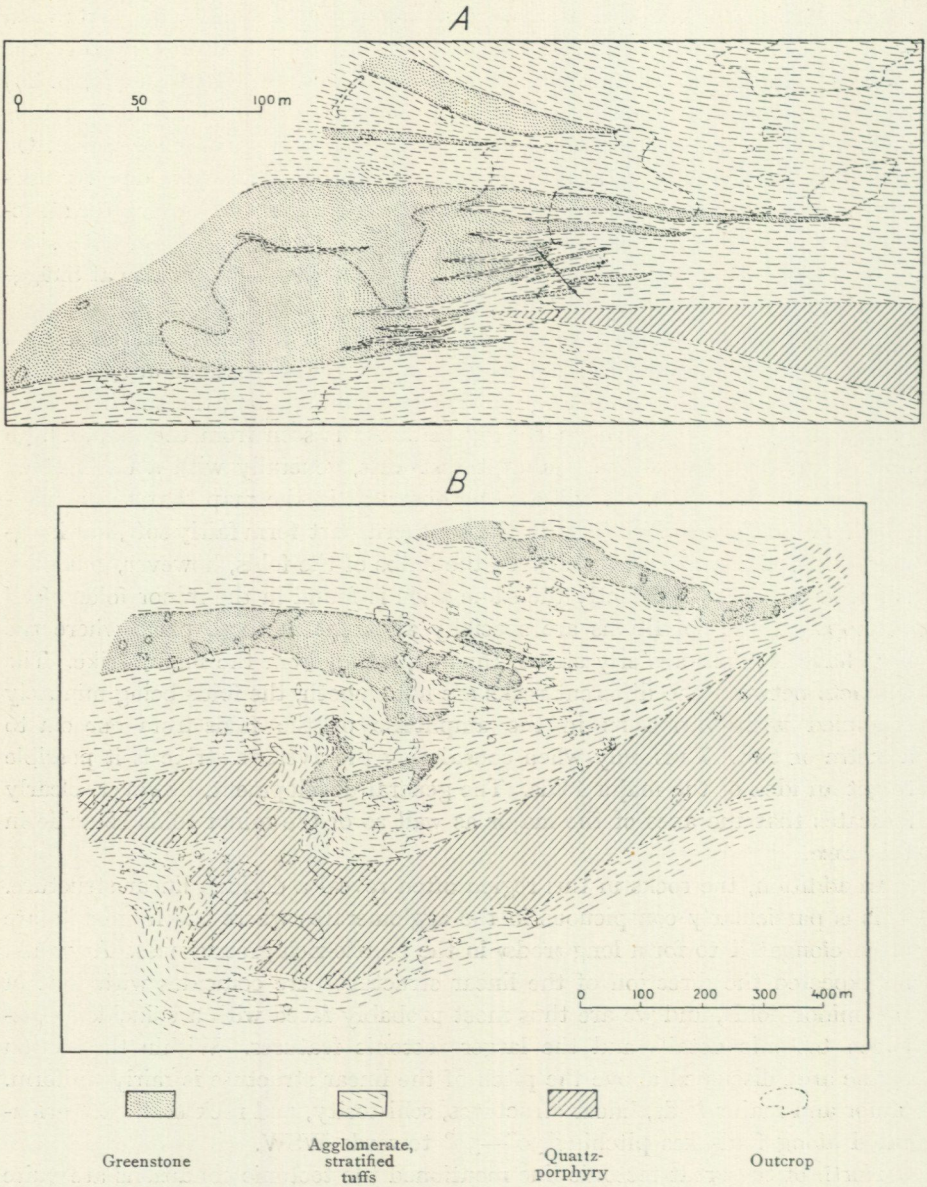


Fig. 2. Sketch-map showing the difference in the contact relations between rocks within areas with different tectonic styles.
A. The area 1 km N. of the Bjurträsk ores (S-tectonites).
B. The area around the Bjurträsk ores (B-tectonites).

sketch-map of the well exposed area immediately south of the river Malån, fig. 2 A shows the contact relations between greenstone, agglomerates or stratified rocks and quartzporphyry, as they appear in the northern zone. Fig. 2 B shows the contact conditions between the corresponding rocks with-

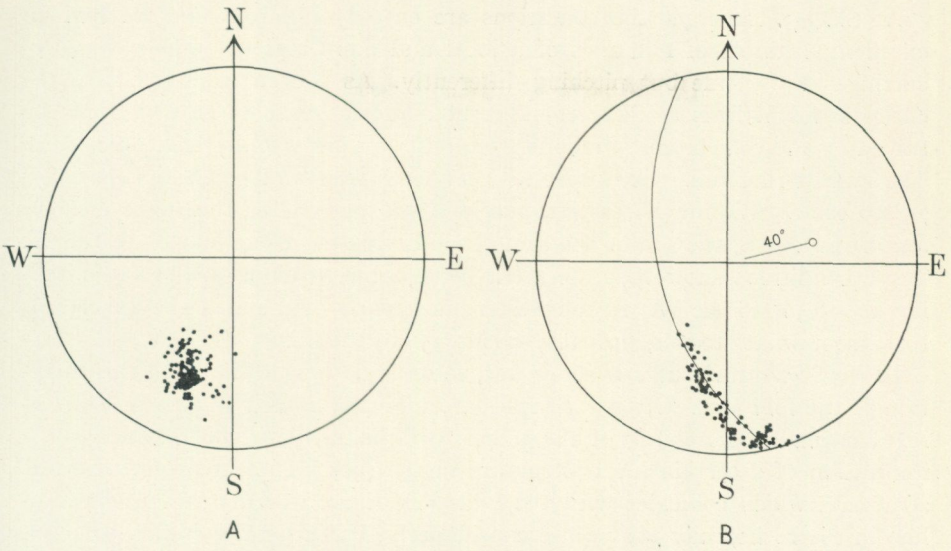


Fig. 3. Stereographic projection of planes of schistosity (projected on the upper hemisphere).
A. 105 dots from the northern zone (Fig. 2 A).
B. 85 dots from the southern zone (Fig. 2 B).

in the southern zone (around the Bjurträsk ores). The "einschaarige" style is found in the details in individual rocks also in the northern zone, while no smooth folds are ever found in that area. The linear structure of these rocks is much less pronounced and the pitch is also less regular than was the case in the southern zone, a circumstance that *a priori* could be expected in this complex with marked linear schistosity.

According to Sander's nomenclature (*67*, p. 58), B-tectonites dominate in the southern area while S-tectonites dominate in the northern. A statistical survey of a large number of measurements of schistosities performed by W. Larsson, both in the neighbourhood just west of the Bjurträsk ores and in the rocks south of the river Malån, gives a good idea of the dissimilarities, fig. 3. In the former case (fig. 3, B) the projected dots are arranged in a certain zone, in the latter case (fig. 3, A) they are grouped around a single point in the projection.

The marked tectonic line which separates the two tectonic styles from each other is conspicuously developed in the quartzporphyry. The porphyry is found to change from north to south and close to the assumed tectonic boundary it becomes almost mylonitic, though we still find quartz phenocrysts in a schistose groundmass of quartz, sericite, and biotite. Parallel to the planes of schistosity the rock easily splits into plane parallel slabs which still more contributes even megascopically to give the impression of a very important tectonic line. At the best exposed localities immediately S of the river Malån the schistose zone is exposed for a width of 60 m. The rocks immediately south of this zone, on the other hand, display no signs of strong tectonic influence.

At Skäggträskberget the conditions are entirely different and we find an excellent example of fold-axes of a local and more regional importance, occurring side by side but pitching differently. As is seen from the map the entire series of beds at Skäggträskberget makes a great curve which can be traced by the correlation of results from outcrops and geophysical indications. The main strike runs north-west to west-north-west and generally dips 65°—75° to the S. Within the eastern part of the exposed area the strike changes and runs N—S, the dip at the same time decreasing to about 30° to the W. These conditions show that the great bend occurred along a fold-axis pitching about 30° to the W. In the westernmost parts of the area the axis seems to be somewhat steeper, probably about 45° to the W.

In the individual outcrops, however, there is nothing to indicate this direction of the fold-axis. Often the layers are minutely folded and there is an irregular minute crumpling of the planes of schistosity, which often gives the impression of a certain linear structure in the rock. The pitch of this linear structure, which coincides with the fold-axes of the irregular, minute crumpling in the rocks, may vary quite considerably, but generally stands 50°—60° to the south or south-west. A careful examination of these structures discloses that their origin is connected with the formation of "Scheer"-planes along which there occur small glidings. The result of the deformation is the type that is called "Mehrschaarige Verformung" acc. to the German nomenclature (Sander (*67*, p. 101), Schmidt (*70*, p. 57)), and which here results in different "Schaaren" intersecting and superseding each other, and a certain linear structure being formed along the lines of intersection. The conditions for such a development of the tectonic structure, which, however, should be looked upon as an internal structure in a large series of beds, may be found in the heterogeneity of the material and in the marked anisotropic development displayed through the occurrence of abundant quantities of phyllites or other decidedly stratified rocks.

Although the movements causing the above-mentioned structures in all probability are of a comparatively small order, we find certain major tectonic lines which are of decisive importance for the deformation. One of these main structures runs N—S and generally stands vertical or steep towards the west. The northernmost phyllite bed, for instance, is deformed and broken according to this structure near the middle of the exposed area of the mountain.

Vertical structures striking N—S are occasionally found also in the structural details of the individual outcrops, and it often seems as if linear structures and minute folds were formed by the interference of this structure and the main strike of the rock beds.

Furthermore, structures striking E—W are of great importance. They are occasionally vertical, when they fit into the large fold-axis system. This is true, for instance, of the sharp fold in the westernmost part of the northern phyllite bed. In other cases the lines striking E—W also seem to coincide with the linear structures pitching to the S. Thus the mineralization which has led to the origin of the small sulphide ores at Skäggträskberget and of the

Ö. Högkulla ore, is orientated along east-west structures of this latter type (cf. Chapter VII, F).

As is the case at Skäggträskberget, it is impossible also within the large area between Maurliden, Kotjärn, and Ö. Högkulla, to find indications in the individual rocks of the tectonic structures that might be assigned regional importance. Within the phyllite rocks where the original beddings are most clearly visible, the layers generally display a steep inclination (70° N or S), the strike being on the whole uniform. These results indicate that the axes of the major folds within this area must be practically horizontal. These facts are particularly conspicuous in the exposed area about 800 m north of Kotjärn, where the position of the layers is less isoclinal. The dip of the beds has been found to show continuous variations from 45° to the S to 45° to the N, without any considerable variation in the strike. The small undulations in the direction of the strike, comprising large parts of the layers, in all probability also illustrate undulations of the axes of the major folds.

Often, however, minor structures in the individual outcrops are found also in this area, which might be looked upon as steep linear structures. As was the case at Skäggträskberget such structures have been formed by the intersection of narrow diverging zones of schistosity, and often only a fracturing is observed. Then, however, small glidings have occurred along the fractures. The result is that the linear structures in question are orientated into the large anisotropic planes formed through the bedding of rocks, but within these planes they can display greatly varying directions.

Measurements of the optic orientation of minerals in order to obtain contributions towards the solution of the tectonic questions touched upon have produced but negative results. The micas do present an unmistakable orientation, but this distinct orientation is the same as the one megascopically visible as "schistosity" of the rock. The quartz grains, on the other hand, show no decipherable orientation in the cases when the sizes of the grains were such as to allow the orientation of the quartz-axes to be measured on the universal stage. In the extremely fine-grained rocks, and by using the gypsum plate, there can be observed an unmistakable similarity of optic orientation between the different grains, but in those cases the orientation of the individual grains is not measurable under the microscope. The circumstance can probably be explained by the deformation being precrystalline in relation to the recrystallization to which large parts of the investigated area have been subjected. Another support for such an interpretation will be found in the circumstance that in the intensely recrystallized quartzites that surround the sulphide ores, even the indistinct traces of an earlier orientation, which actually can be observed here and there, are completely obliterated.

One of the most important tectonic boundaries within the area is found about 1 km west of the Norrliden ore deposit. Graphite-phyllites and bedded light tuffites enter here from the west and can be followed towards a line running south-westward, against which all indications of the graphite-phyllite beds suddenly cease. The southernmost phyllite bed makes a complete bend-

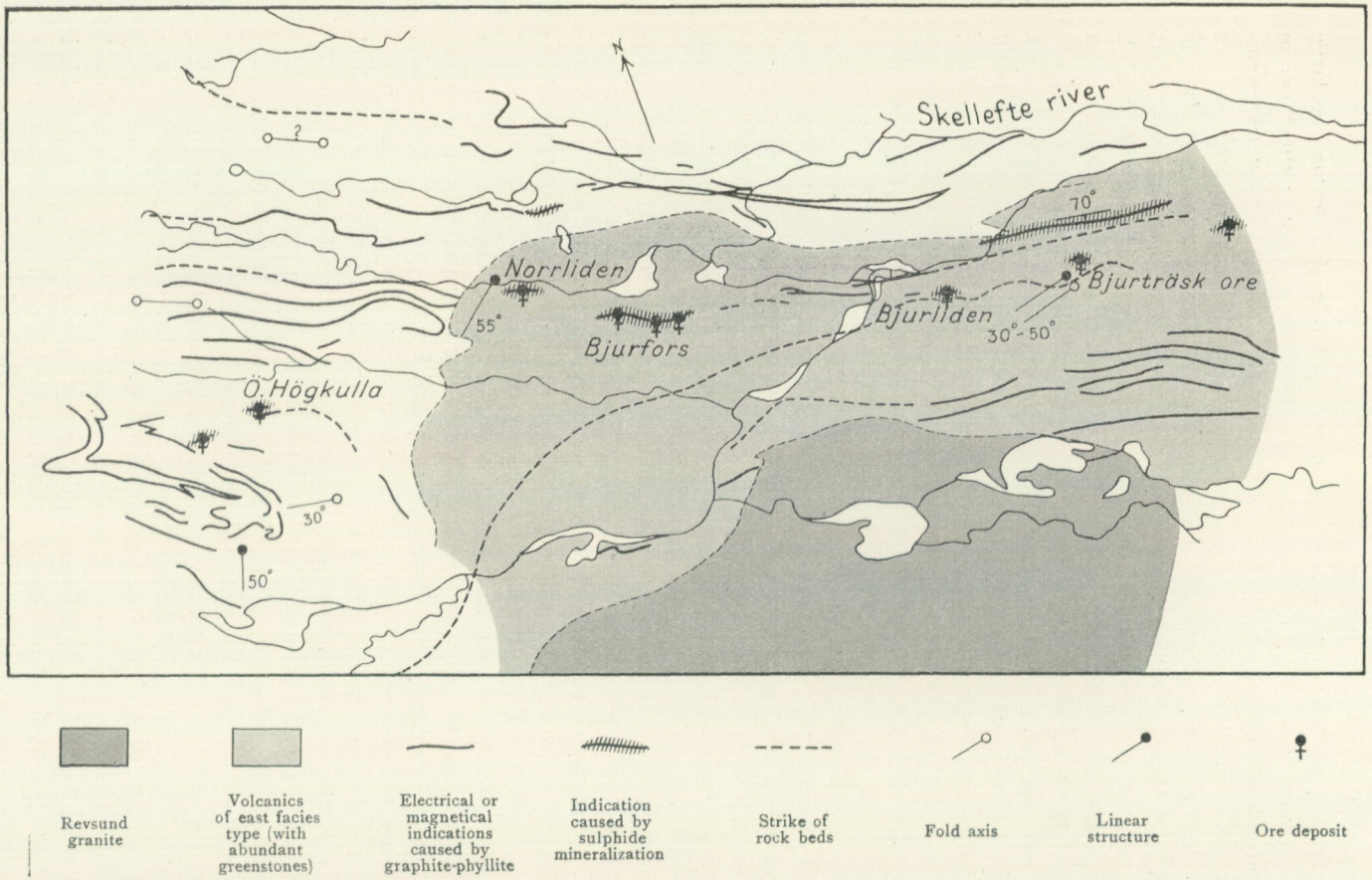


Fig. 4. Survey of the major tectonic features and the main lines of structure of the mapped area. Scale 1: 100000.

ing and has again been disclosed in a drill hole at Storstensberget. To the east of the above-mentioned line we find quite different rocks, viz. quartzporphyry and agglomeratic greenstones in alternating beds, also striking SW—NE.

The boundary between the rocks in the Bjurfors field and those of Skäggträskberget is probably of about the same character. In all probability the rock beds from both of these areas bend towards the S when they meet, and judging by the results from the drill holes in the easternmost phyllite bed of Skäggträskberget—Ö. Högkulla area, dipping about 30° to the W, the Bjurfors series should thus dip under the rocks of Skäggträskberget (see the map, Pl. 38 and fig. 4).

In fig. 4 an attempt has been made to give a survey of the most important tectonic lines and elements. It will be seen from the map and the general considerations that the greater part of the area south and south-east of Malån is a tectonic unity, the structural directions pitching to the WSW. On account of the scarcity of outcrops, the areas over to the Bjurfors field and Norrliden are so little known that no definite statement can be made regarding their relations to the above-mentioned area. Due to the great similarity in the composition of the rocks in these last-mentioned areas and the eastern parts, it would appear most probable that a repetition of stratigraphically corresponding rocks existing within the Bjurträsk area occurs within the Bjurfors—Norrliden area. In such a case thep hyllites between Bjurfors and Bjurliden would presumably represent a depression of the axes, and only west of the Bjurfors field and Norrliden do the quartzporphyries and greenstones from the eastern area definitely dive down below the rocks of Skäggträskberget and Storstensberget. At this limit a certain difference can be seen in the general composition of rocks. Thus we may speak of an eastern facies, mainly characterized by andesitic and quartzporphyric volcanics, and a western facies, characterized by more plentiful pyroclastic derivates and by a great distribution of keratophyric or intermediate rocks. The rocks of the eastern facies run in a wide arch southwards around the Skäggträskberget area and continue south of the mapped area. But when the rock series of the western facies meets the rocks of the eastern facies, the former becomes intensely curved and compressed, the Skäggträskberget area and the phyllite bend west of Norrliden at Storstensberget being striking examples.

V. Petrographic Description of the Rocks.

1. Quartzporphyry Series.

a. *Quartzporphyry with Large Phenocrysts.*

The coarse quartzporphyry is the most characteristic type of rock in the mapped area and is the rock most easily megascopically identified in the various sections of the area. Certainly the megascopic and microscopic charac-

teristics may display certain variations according to the location of the rock in high- or low-grade metamorphic areas but excepting very highly schistose types, the quartz as well as the felspar phenocrysts are always rather well preserved and give the rock its characteristic structure.

Usually the quartzporphyries of this type are very homogeneous and similar in their composition in different parts of the lava beds. It is only in the quartzporphyry bed south of the Bjurträsk ores that a regular change towards the contacts can be observed. The lower portion of the bed (facing north) is thus much richer in biotite than the normal porphyry, the phenocrysts become smaller, and finally the grains appear to be rather uniform in size. Towards the upper contact the porphyry becomes heterogeneous with an interchange between normal porphyritic streaks and light streaks without phenocrysts. In some cases these types without phenocrysts might be interpreted as baked-in tuffitic material, but often they seem to illustrate an originally dense, possibly glassy development of the quartzporphyry itself.

The general appearance of these quartzporphyries has prompted the question whether they might be intrusive, at least to a certain degree. No unmistakable intrusive contacts have ever been observed, however, nor have there been noted any distinctly chilled margins of the character that might be expected in a porphyry dike. In addition those textures dominate that are usually considered typical of effusive rocks, for which reason at least the greater part of the porphyries of this kind probably must be looked upon as effusive products. However, the possibility cannot be denied that certain types may represent superficial intrusions closely related to the volcanic activity. It would appear, for instance, as if quartzporphyries of this type occur more irregularly within different stratigraphic horizons than other types of rocks, as they are found either in the immediate proximity of the sedimentary series, or much deeper in the series. Certain observations have been made in the rocks immediately west of Norrliden which might indicate an intrusive form of the quartzporphyry in question. There its layers alternate with greenstone agglomerates. Close to the contact with the greenstone the porphyry there becomes far more femic, the groundmass becomes very rich in chlorite, and we find solitary hornblende needles of the same type as in the greenstone. The distribution of the phenocrysts, however, is exactly the same as in the normal porphyry.

When fresh, the groundmass in the more or less recrystallized types is grey, darker or lighter according to the variation in the biotite content. In the normal types, too, an alternation can often be seen between streaks rich in phenocrysts and biotite, and dense, light streaks without phenocrysts, probably illustrating an original flow-structure. In the less recrystallized porphyries the groundmass is usually almost flinty. The colour varies from light grey to greyish black.

The megascopically most characteristic feature of this type of quartzporphyries, whether in high- or low-grade metamorphic areas, however, is the appearance and distribution of the *quartz phenocrysts*. Megascopic examina-

tions disclose the larger phenocrysts to be of a fairly regular shape, round or egg-shaped. In the types carrying biotite a very characteristic bluish opalescence may be observed. The most common sizes are 2—3 mm but in some types quartz phenocrysts are found with a diameter of from 5 to 10 mm.

Generally speaking the quartz phenocrysts in this type are fairly uniformly distributed in the rock. Volumetric analyses of 10 thin sections of types originating from different parts of the area show from 8 to 14 per cent of quartz phenocrysts. The microscope discloses that also the larger, rounded grains often display a tendency towards crystallographic habit, *viz.* as short, bi-pyramidal prisms. The smaller phenocrysts in the better preserved types very often display a decided bi-pyramidal shape, with or without prisms. Very regular sections, parallel and normal to the c-axis, have been observed (Pl. 1, a). The phenocrysts have often been corroded by the groundmass, when either "soft" embayments have been caused in the otherwise straight outlines of the crystals or there have occurred very sinuous, irregular incisions in the grains (Pl. 1, b).

The quartz phenocrysts display a fairly strong undulatory extinction also in the best preserved types. In the more intensely recrystallized types the dynamic influence is often more intense, and large phenocrysts are often divided into a number of smaller, equidimensional grains with different optic orientation (Pl. 2, a).

The *plagioclase phenocrysts* are tabular, the dimensions usually varying between $1 \times 2 \times 3$ mm and $0.5 \times 1 \times 2$ mm. They are not at all so regularly distributed as the quartz phenocrysts, and, as already mentioned, it is not unusual to find an irregular alternation between bands rich and poor in phenocrysts. When the rock is sericitized and when subjected to strong tectonic influence, the felspar phenocrysts are first of all destroyed. In the best preserved types the plagioclase is decidedly idiomorphic; in the more recrystallized types the margins of the phenocrysts are usually more or less granulated, making the contacts of the phenocrysts towards the partly recrystallized groundmass less abrupt than in the case first mentioned.

Twinning according to the Albite, Pericline, or Carlsbad laws is quite common. In some cases, however, only a few isolated individuals are twinned. Usually the individual lamellae are fairly wide, and polysynthetic twinning with a large number of narrow lamellae is quantitatively of little importance, even though solitary individuals of such types have been observed in most of the specimens examined.

Determinations of the composition of the phenocrysts have disclosed that albitic plagioclase is present in most cases. Values between 2 % An and 10 % An were obtained for most of the specimens examined. In one specimen from the Bjurträsk ores there are plagioclase phenocrysts with up to 22 % An. There the phenocrysts are zonal, and in this specimen the kernel of a grain was for instance determined at $An_{12}Ab_{88}$ while the shell had the composition $Ab_{99}An_1$.

The quartzporphyry immediately north of Kotjärn is a remarkable exception from the normal types. There the plagioclase phenocrysts contain much more anorthite and are distinctly zonal with alternate zones rich and poor in anorthite. Measurements of three grains gave the following results:

	1	2	3
Kernel	35 % An	31 % An	49 % An
Shell	44 % An	39 % An	37 % An

This decided variation in the plagioclase composition, however, has no parallel in the form of a change in the general character of the rock. Its megascopic appearance, the general distribution of the quartz and plagioclase phenocrysts, and the appearance of the groundmass, are indentically the same as in the albite-bearing types. Still another specimen of such a type, richer in anorthite, is found at a locality north of the investigated area. Another circumstance indicating that types richer in anorthite occur or have occurred in certain parts of the investigated area or in its vicinity is that in the arkoses which are rich in quartzporphyry material, and which are abundant in the northern parts of the area, we often find plagioclase with andesine composition.

The original textures of the groundmass are best preserved within the northern sections of the area. Here the greater part of the groundmass consists of *quartz, plagioclase,* and *chlorite. Potash felspar* has been observed in a few cases, but never in important quantities. It should be pointed out, however, that in most cases the groundmass is far too fine-grained to allow a reliable determination of the components. The plagioclase in the groundmass appears always to be richer in anorthite than the albitic phenocrysts. Due to the fine-grained texture of the mass it is not possible to make exact determinations, but judging from the refraction as compared with quartz and Canada balsam, this plagioclase is mainly of oligoclase, sometimes perhaps of andesine composition. In the best preserved types micropoikilitic, possibly microgranophyric, textures are often found. In some cases we also find a spherolitic development, and in a specimen containing the most regularly developed spherolites these contain a black pigment with a beautiful zonal and radial arrangement (Pl. 3, a and b). Small inclusions of a stratified rock have also been observed, containing an abundant quantity of pigment of the same type as in the spherolites. These fragments in all probability consist of graphite-phyllite. It would thus seem probable that also the pigment in the spherolites consists of graphite, which thus should have entered the liquid quartzporphyry lava by assimilation of graphite-phyllite. Very regular plagioclase borders are often found around the quartz phenocrysts (Pl. 1, a and b) in the micropoikilitic and spherolitic types. The plagioclase in these borders is of the same type as in the spherolites or in the micropoikilitic parts of the groundmass, although there is less chlorite and quartz. In some cases the corroded concavities in the phenocrysts are filled with plagioclase of this kind (Pl. 1, b).

Analysis No. 1.

Quartzporphyry, about 700 m W. of the Bjurträsk ores.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	69.46	1 156.5	Q	27.7	Quartz	30	qz	+115	s	72.4
TiO_2	0.30	3.8	Or	15.4	Plagioclase		si	327	A	8.2
P_2O_5	0.05	0.4	Ab	37.3	$(Ab_{90}An_{10})$	42	ti	1.5	C	1.2
Al_2O_3	15.41	151.2	An	4.3	Biotite	10.5	al	43	F	5.1
Fe_2O_3	0.96	6.0	C	3.8	Sericite	17	fm	24.5	a	17.0
FeO	2.50	34.8	Σ sal.	88.5	Ilmenite	0.5	c	4.5	c	2.5
MnO	0.10	1.4	Hy $\{MgSiO_3$ 3.9 $FeSiO_3$ 3.5$\}$	7.4		100	alk	28	f	10.5
CaO	0.92	16.4	Il	0.6			mg	0.45	n	7.2
MgO	1.57	38.9	Mt	1.4			k	0.27	k	1.27
K_2O	2.60	27.6	Ap	0.1			c/fm	0.17		
Na_2O	4.41	71.1	Σ fem.	9.5						
$H_2O^{+110°}$	1.68	93.3	H_2O	1.7						
				99.7						
	99.96		I: 4: 2: 4 — Lassenose. Or: Ab: An — 27: 65.5: 7.5.							

In many cases the groundmass is microgranitic, the grain usually being rough and the sizes varying. Fine-grained and coarser parts often alternate in the same thin section. The most common sizes are from 0.01 to 0.03 mm, but it is not unusual to find coarser areas up to 0.05 mm. Where the grains are smaller than 0.01 mm, the groundmass is irregularly diffuse, and should rightly be called microfelsitic.

In the southern sections of the investigated area the sizes of the grains of the groundmass in the quartzporphyries are generally fairly irregular. Micropoikilitic, microgranophyric, and spherolitic textures can no longer be discerned. Microfelsitic textures are not infrequent, but always in connection with coarser grains, which in many instances should apparently be identified as recrystallized parts of the more fine-grained mass, but it is not possible to decide to what extent the original grain of the groundmass was irregular.

Biotite, instead of chlorite, appears in the quartzporphyries within the southern part of the mapped area, and, contrary to the chlorite, it often forms larger plates, usually in a regular flow arrangement around the phenocrysts (Pl. 2, b). In addition, the groundmass usually contains more or less fine-grained *sericite*, *clinozoizite*, and *epidote*. The quartzporphyries in the northern parts of the area are usually rich in *calcite* and *sericite*, which together are apt to replace the groundmass as well as the plagioclase phenocrysts, and occasionally also penetrate and maybe also replace the quartz phenocrysts. In some cases, at least, this mineralization is connected with the sulphide infiltration, and will be dealt with in greater detail in the account of the mineralization associated with the formation of the ores.

Analysis No. 2.

Quartzporphyry, 700 m E. of Maurliden.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	79.84	1 329.3	Q	60.1	Quartz	62	qz	+419	s	79.6
TiO_2	0.17	2.1	Or	6.7	Plagioclase		si	591	A	4.5
P_2O_5	0.05	0.4	Ab	15.0	($Ab_{76}An_{24}$)	20	ti	1	C	1.1
Al_2O_3	9.60	94.2	An	4.8	Chlorite	7	al	37	F	3.1
Fe_2O_3	0.20	1.3	C	3.7	Sericite	9.5	fm	24.5	a	15.5
FeO	1.60	22.3	Σ sal.	90.3	Calcite	1.5	c	14	c	4.1
MnO	0.04	0.6	Hy ($MgSiO_3$ 2.9, $FeSiO_3$ 2.6)	5.5		100	alk	18	f	10.4
CaO	1.94	34.6	Il	0.32			mg	0.53	n	7.1
MgO	1.16	28.8	Mt	0.3			k	0.29	k	2.6
K_2O	1.13	12.0	Ap	0.1			c/fm	0.63		
Na_2O	1.78	28.7	Cc	1.6			co_2	6.7		
$H_2O^{+110°}$	1.82	101.0	Σ fem.	7.8						
CO_2	0.71	16.1	H_2O	1.8						
				99.9						
	100.04		I: 2: 2: 4 — No name. Or: Ab: An — 25: 57: 18.							

In most of the specimens examined there were observed accessory *apatite* and *ores*, probably with a predominance of *ilmenite*, and occasionally there occur *zircon*, *rutile*, and *titanite*.

The chemical composition will be seen from two analyses, one of porphyry with chlorite and the other of porphyry with biotite (Analyses 1 and 2).

b. *Quartzporphyry with Small Phenocrysts.*

The quartzporphyries that occur at Skäggträskberget, Storstensberget, Malånäsudden, and sporadically between Skäggträskberget and Maurliden, contain smaller and more unevenly distributed phenocrysts. These rocks form decidedly less distinct types than the coarser porphyries, and it is thus more difficult to delimit the different beds in the map than was the case with the types described above. The weathered surface is light or pure white and often appears to be scoriaceous, the calcite having disappeared due to weathering. In these types the diameter of the phenocrysts is generally not more than 1 mm. Occasionally there occur small quartzporphyry or keratophyre fragments which sometimes become so abundant that it is extremely difficult to distinguish the porphyry from the clearly pyroclastic breccias. This is particularly true of a number of localities at Skäggträskberget.

Generally speaking the microscopic textures are the same as in the coarser porphyritic types, but here the variations are smaller. The groundmass is microgranitic to microfelsitic and the mineral composition is practically the same as in the coarse porphyritic types. Potash felspar, however, seems to

occur in considerably greater quantities in these types. The felspar phenocrysts in the quartzporphyries thus largely consist of antiperthite or perthite, the proportions between potash felspar and plagioclase varying considerably, from fairly pure *albite* to *microcline* practically free from albite. Albite phenocrysts in myrmekitic intergrowth with quartz have been observed in a quartzporphyry from Skäggträskberget. The proportions between the different components are usually about 1:1. Sometimes the quartz grows straight through whole phenocrysts, sometimes only one of the individuals in a twinned grain is developed as myrmekite (Pl. 5, a). There is an abundance of potash felspar also in the groundmass, but it is impossible definitely to determine the percentages on account of the minute grains of the mineral. In some cases we find a typical microcline twinning, but in many cases the felspar component, rich in potash, has only an irregularly flamy, undulatory extinction, from which transitional forms can be found to real microcline twinning as well as to albite twinning. The refraction is low and generally appears to be lower than for normal albite; the optic angle is often smaller than for normal microcline. Values between 72° and 76° have been determined for $2\,V_{\alpha}$. These results indicate that the mineral is an *anorthoclase*, at least in certain cases. As far as their microscopic character is concerned, these minerals, moreover, are identical to the anorthoclase on fractures in tuffites rich in chlorite (cf. p. 33), where optic angles down to 25° have been determined.

c. *Tuffs of Quartzporphyry Composition.*

Agglomerates of the Bjurträsk type. Agglomerates with well-developed fragments are found at the Bjurträsk ores as well as in the exposed areas south and north of it. The fragments are light, even-grained, and rounded, and lie embedded in a groundmass that is richer in biotite than the fragments themselves (Pl. 4, a). Due to the strong mechanic deformation, the fragments are usually greatly elongated and form long rods orientated parallel to the axes of the small folds. In the area north of the line Bjurliden to the Bjurträsk ores and immediately south of the river Malån, where the deformation results in the development of a decidedly linear schistosity, the fragments are so strongly foliated that the distinctly agglomeratic structure is largely obliterated (Pl. 4, b).

The mineralogical composition is quite uniform in these types. *Quartz*, *plagioclase*, and *biotite* are the main components, there also being more or less *sericite*, *chlorite*, *clinozoizite*, *epidote*, *calcite*, and *iron ore*. *Apatite* and *zircon* are accessory minerals. In some cases small quantities of *microcline* have been observed. The fragments differ from the groundmass mainly by their being poorer in biotite and occasionally richer in quartz. Near the contact towards the greenstones occurring in these agglomerates, we often find a transitional zone poor in fragments, richer in biotite and chlorite, and sometimes with small quantities of *hornblende*.

The composition of the plagioclase appears to vary quite considerably. It is generally not possible to make exact determinations, but upon comparing

Analysis No. 3.

Quartzporphyry agglomerate, 200 m. N. W. of the Bjurträsk ores.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	74.08	1 233.4	Q	44.0	Quartz	48	qz	+232	s	75.4
TiO_2	0.32	4.0	Or	14.3	Plagioclase		si	408	A	4.3
P_2O_5	0.05	0.4	Ab	17.2	($Ab_{61}An_{39}$)	29	ti	1	C	2.5
Al_2O_3	11.35	111.3	An	11.2	Microcline	1.5	al	37	F	5.5
Fe_2O_3	0.80	5.0	C	1.1	Biotite	12	fm	30	a	10.5
FeO	3.11	43.3	Σ sal.	87.8	Sericite	9	c	14	c	6.1
MnO	0.10	1.4	Hy {$MgSiO_3$ 3.6 / $FeSiO_3$ 4.3}	7.9	Ilmenite	0.5	alk	19	f	13.1
CaO	2.34	41.7	Il	0.6		100	mg	0.40	n	7.2
MgO	1.46	36.2	Mt	1.9			k	0.45	k	2.41
K_2O	2.41	25.6	Ap	0.1			c/fm	0.48		
Na_2O	2.03	32.8	Σ fem.	10.5						
$H_2O^{+110°}$	1.89	104.4	H_2O	1.9						
				100.2						
	99.94	I: 3: 3: 3 — Riesenose. Or: Ab: An — 33.5: 40.5: 26.								

the refraction of quartz and of Canada balsam, an approximate estimation of the composition can be made. In most cases the An-contents thus seem to vary between 25 % and 45 %, 30—35 % An dominating. In some cases purely albitic types have been observed. It would appear that the anorthite contents may vary considerably in one and the same thin section, a circumstance which also decreases the value of solitary, exact determinations.

The size of the grains varies a great deal in different cases, which probably is largely due to irregular recrystallization. In the southern areas we thus often find definitely granular types, the grains being up to 0.1 mm. Also in those cases, however, the same thin section may be found to contain decidedly fine-grained sections of an almost microfelsitic character. In the best preserved types we find textures indentical to those illustrated in Pl. 5, b, showing tuffites from Ö. Högkulla.

Analysis 3 shows the chemical composition of the agglomerate at the Bjurträsk ores. As will be seen the rock is of a quartzporphyry composition, but differs from the analysed quartzporphyries by the lime content being slightly greater, and a certain displacement in the proportion of alkalis towards types richer in potash.

Banded and stratified tuffs. The pyroclastic derivates of the type described above and with a distinct agglomeratic development have a rather limited distribution. Banded rocks are more abundant, in which bands or streaks interchange, the variations approximately corresponding to those between the fragments and the groundmass in the agglomerates. In these types, however, the chemical variations seem to be of a larger order than in the agglomerates, and occasionally even bands of andesitic composition appear. Bands

of limestone may also appear in such types, though always of very small quantitative importance. In the areas around Bjurliden and the Bjurträsk ores we find all structural gradations between the decidedly agglomeratic rocks and the banded tuffs. The whole southern part of the eastern section of the mapped area is dominated by banded tuffs, generally of a quartzporphyry composition. The variations in the chemical composition of the various bands depend upon the varying proportions of the main components, *quartz, plagioclase,* and *biotite.* These rocks occur in this south-eastern part of the area in close proximity to the phyllites, and in many instances it is a matter of taste where the boundary is to be drawn between the volcanic and the sedimentary rocks.

At Skäggträskberget, for instance, and also N of Kaffeheden—Storstensberget, light, evengrained tuffs are often encountered. Stratification is sometimes found and even cross-bedding has been observed in certain instances. At Skäggträskberget these types generally appear stratigraphically immediately under the graphite-phyllites and in the northern area exactly similar types may be found interstratified with graphite-phyllite layers.

Dense, massive quartzporphyry tuffs. At the Ö. Högkulla ore a flinty, dense rock is encountered, which upon microscopic examination is found to consist of an extremely fine-grained, microfelsitic groundmass of *quartz, plagioclase, microcline,* and some *chlorite,* in which there occurs irregularly distributed porphyritic quartz grains (Pl. 5, b). The irregular distribution of the quartz grains and their irregular "worn" edges (as compared with the usually very regular outlines of the quartz phenocrysts in the typical quartzporphyry lavas) produces an impression of the rock most likely being of a tuffitic character. Similar types have also been observed here and there in the mapped area, associated with the quartzporphyries, e. g. at Storstenberget south of Kotjärn, etc.

2. Quartzkeratophyre and Keratophyre.

It is somewhat uncertain to what extent rocks of a typical keratophyric composition actually occur in the mapped area. The most typical representatives of the rocks that have been described as keratophyres occur as fragments in the coarse volcanic breccias. When fresh they are of a dark or light grey colour and extremely fine-grained, the types poor in chlorite being almost flinty. Usually there occur sparsely scattered phenocrysts of *albite,* also visible megascopically.

Under the microscope the albitic phenocrysts are observed in a more or less fine-grained groundmass, consisting mainly of *albite, chlorite,* and *sericite.* Occasionally the chlorite is more or less replaced by *biotite.* The albite in the groundmass forms more or less well-developed laths, with a divergently radiating or fluidal arrangement, which gives the rock a very characteristic texture (Pl. 6, a and b). In most cases, when not replaced by calcite or sericite, the phenocrysts display an idiomorphic crystallographic development,

but irregular grains are occasionally found. The sizes of the albite plates vary between 2 × 1 mm and 0.4 × 0.2 mm. The phenocrysts as well as the plagioclase laths in the groundmass consist of fairly pure albite; in most cases the anorthite content is less than 5 %, and always less than 10 %. Besides sericite and chlorite, *calcite* usually also occurs in fairly plentiful quantities, either brecciating the groundmass or replacing the phenocrysts. Further, there are in most cases small grains of *ore minerals*, more or less regularly distributed in the rock. In some types there probably also occur small quantities of *potash felspar* in the fine-grained parts, but the insignificant size of the individual grains renders impossible an exact estimation of the percentage.

There is probably a certain quantity of *quartz*, too. In some of the types that occur as fragments in the volcanic breccias, the groundmass is sufficiently coarse-grained to permit an approximate estimation of the proportions of the components, but in many cases the individual grains are far too small to allow of the different components being clearly distinguished from each other. In the north-western parts of the mapped area there are independent beds of rocks which megascopically as well as microscopically resemble the types described above. An analysis of a light, extremely fine-grained type, however, disclosed a composition exactly corresponding to a comparatively acid quartzporphyry (Analysis 4).

Analysis No. 4.

Quartzkeratophyre, 200 m S. of Maurliden.

Analyst: Th. Berggren.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	76.10	1 265.6	Q	43.1	Quartz	43	qz	+237	s	82.5
TiO_2	0.26	4.1	Or	5.8	Plagioclase		si	463	A	7.4
Al_2O_3	12.39	121.5	Ab	39.4	$(Ab_{94}An_6)$	42	ti	1.5	C	0.6
Fe_2O_3	0.16	1.0	An	2.4	Chlorite	4.5	al	44.5	F	2.3
FeO	2.52	35.1	C	2.8	Sericite	8	fm	13.5	a	21.6
MnO	0.03	0.4	Σ sal.	93.5	Calcite	2	c	10.5	c	1.7
CaO	1.63	29.1	Hy $\{MgSiO_3$ 0.0 $FeSiO_3$ 3.8 $\}$	3.8	Ilmenite	0.5	alk	31.5	f	6.7
MgO	tr.	—				100	mg	0.00	n	8.8
Na_2O	4.67	75.3	Mt	0.2			k	0.12	k	1.65
K_2O	0.99	10.5	Il	0.5			c/fm	0.78		
$H_2O^{+105°}$	0.07	3.9	Cc	2.0			co_2	7.5		
CO_2	0.90	20.5	Py	0.3			s_2	0.9		
S	0.17	5.3	Σ fem	6.8						
	99.89		H_2O	0.1						
$H_2O^{-105°}$	0.04			100.4						
	99.93		I: 3: 1: 4 — Tordrillose. Or: Ab: An — 12: 83: 5.							

It is remarkable, however, that no unmistakable, separate quartz grains, with the exception of a few extremely rare quartz phenocrysts, can be observed even under the microscope. This implies that the quartz is so intimately intergrown with the plagioclase laths and the chlorite plates in the groundmass, that the in-

dividual components cannot be distinguished. The keratophyric texture being very pronounced, these rocks may suitably be called quartzkeratophyres, in distinction from the quartzporphyries. Our experience from the volcanic breccias indicates, however, that there are transitional types between such acid rocks and the somewhat coarser types, where it can be definitely established that quartz is lacking or at least appears in insignificant quantities. Due to the difficulty in drawing a definite boundary between types rich and poor in quartz, and also due to the close relationship between these types in the field, they have had to be grouped under one and the same heading on the map. In addition, the keratophyric texture affords further evidence of their close relationship.

3. Dense Tuffs Mainly of Intermediate Composition.

These rocks which have been grouped on the map under the same heading as keratophyres and quartzkeratophyres, in many cases differ but little, megascopically, from the latter, but they are usually darker than the typical keratophyres, owing to a greater chlorite content, and the weathered surface is generally more or less greenish. In many cases even a megascopic study discloses a certain fine-porphyritic development of small albite grains. Small fragments of keratophyres or other tuffites are occasionally found, and a certain tendency can thus be traced towards transitional types approaching the polymict agglomerates, rich in fragments.

The microscopic textures vary considerably. The groundmass consists of an irregular, granular mixture, mainly composed of *albite* and *chlorite*, more or less *quartz*, and also of *calcite, sericite, epidote, clinozoizite*, and *ore minerals*. Small quantities of *microcline* are also found in places. The proportions of the various components vary greatly from case to case. In addition to being finely diffused in the groundmass, calcite also occurs in irregular spots, and albite also appears in the shape of large, more or less broken crystal fragments.

In a type rich in chlorite, an interesting mineral has been observed occurring both in veinlets together with calcite and sporadically in the groundmass. The mineral has a low, double refraction and often displays an undulatory, flamy extinction. A determination of the refraction on powder made of the mineral grains found in the veinlets gave the following values:

$$\alpha = 1.516 \qquad \gamma = 1.521$$

A determination of the double refraction $\gamma - \alpha$ on the universal stage gave values from 0.005 to 0.008. The mineral is biaxial, optically negative with a varying optic angle. The optic angle being measured in three different grains, when in all three cases both axes were directly observed, the following values were obtained:

	1	2	3
$2\,V_\alpha$	52°	42°	25°—32°

Analysis No. 5.

Sericitized tuff, E. of Lake Önusträsket.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	73.27	1 220.0	Q	54.6	Quartz	57	qz	+278	s	72.6
TiO_2	0.24	3.0	Or	17.4	Plagioclase		si	434	A	4.3
P_2O_5	0.05	0.4	Ab	3.8	$(Ab_{100}An_0)$	4	ti	1	C	0
Al_2O_3	12.52	122.8	C	8.6	Chlorite	12	al	43.5	F	5.8
Fe_2O_3	0.83	5.2	Σ sal.	84.4	Sericite	24.5	fm	35	a	16.7
FeO	2.94	51.3	Hy $\{MgSiO_3$ 4.6 $FeSiO_3$ 4.4 $\}$	9.0	Calcite	2	c	7.5	c	0
MnO	0.05	0.7			Ilmenite	0.5	alk	14	f	13.3
CaO	1.18	21.0	Mt	1.2		100	mg	0.47	n	1.7
MgO	1.84	45.6	Il	0.5			k	0.81	k	1.45
K_2O	2.95	31.3	Cc	2.1			c/fm	0.21		
Na_2O	0.45	7.3	Σ fem.	12.8						
$H_2O^{+110°}$	2.87	159.3	H_2O	2.9						
CO_2	0.93	21.1		100.1						
	100.12		II: 2: 1: 2 — No name. Or: Ab: An — 82: 18: 0.							

Judging by these values the mineral would seem to be an *anorthoclase*. The optic angle does seem to reach lower values than is usually the case, but according to recent investigations the anorthoclase may have smaller optic angles than those usually stated in the text-books. Hjelmqvist (*35*, p. 142), thus reports an anorthoclase in Romelite from Romelåsen with values for 2 V_α down to 12°.

As will be seen from the microscopic observations, the chemical composition of this group of rocks must vary quite considerably. Analyses 5 and 6 show the chemical compositions, one of a type rich in chlorite, the other of a highly sericitized type, poor in chlorite.

It will be seen that neither the mineralogical composition nor the analysis of No. 6 disclose a true keratophyric composition. The comparatively high quartz content as well as the abundance of chlorite give higher values for silica, iron, and magnesia, than those found in normal keratophyre compositions, while the alkali content does not suffice to confer upon the rock the alkaline character that is one of the special characteristics of the keratophyres. On the other hand, the comparatively low SiO_2 content, in conjunction with high values for FeO and MgO, indicate rocks of a far more femic character than the normal quartzporphyries.

Analysis 5 certainly does correspond to the quartzporphyry composition, but in this case the mineralogic composition shows that the rock is considerably altered, for which reason the original composition is somewhat doubtful. A certain silicification might be conjectured in connection with the sericitization, and such an introduction of quartz is in certain cases found to be indicated by the microscopic examination. These acid types, however, are

Analysis No. 6.

Chlorite-rich tuff, N. of Lake Önusträsket.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Calculated Mode %		Niggli's System		Osann's System	
SiO_2	59.60	998.3	Q	24.2	Quartz	28	qz	+58	s	57.7
TiO_2	0.78	9.8	Or	4.0	Plagioclase		si	210	A	7.5
P_2O_5	0.24	1.7	Ab	29.3	($Ab_{98}An_2$)	30	ti	2	C	0.5
Al_2O_3	14.18	139.1	An	0.6	Chlorite	31	al	29	F	13.7
Fe_2O_3	0.73	4.6	C	7.5	Sericite	6	fm	50	a	10.4
FeO	8.20	123.3	Σ sal.	65.6	Calcite	3	c	8	c	0.7
MnO	0.15	2.1	Hy ($MgSiO_3$ 11.2, $FeSiO_3$ 13.4)	24.6	Ilmenite	1.5	alk	13	f	18.9
CaO	2.02	36.0			Apatite	0.5	mg	0.47	n	8.9
MgO	4.50	111.6	Il	1.5		100	k	0.11	k	0.88
K_2O	0 68	7.2	Mt	1.1			c fm	0.16		
Na_2O	3.46	55.8	Ap	0.6						
$H_2O^{+110°}$	4.18	232.0	Cc	2.8						
CO_2	1.24	28.2	Σ fem.	30.6						
			H_2O	4.2						
				100.4						
	99·96		II: 3: 1: 5 — No Name.							
			Or: Ab: An — 12: 86: 2.							

undoubtedly of very little quantitative importance, and their geological appearance makes it impossible to separate them from the more femic types, which in turn cannot be separated from the typical keratophyric rocks.

4. Polymict Agglomerate, Coarse Volcanic Breccia.

The coarse polymict tuff breccias are mainly found in the eastern part of the investigated area. At Skäggträskberget and in Jonkmyrliden they lie immediately under graphite-phyllite. Usually such breccias form fairly sharply delimited, continuous beds, which readily can be traced during the work in the field, thanks to their characteristic structure. On the other hand, isolated fragments also occur here and there in the dense tuffites, and due to an increase in the quantity of fragments such tuffites in some cases grade into coarse tuff breccias.

These tuff breccias mainly consist of abundant, usually angular fragments of various volcanic rocks. Generally the fragments, clearly visible megascopically, vary in size from one or two dm to one cm or two in diameter. The groundmass between the larger fragments, however, is composed of a mixture of extremely finely diffused volcanic ash and fragments with diameters as small as 1 mm and less. In the north-western parts of the investigated area extremely coarse types sometimes occur with fragments having diameters of up to one metre. The structure will be seen from Pl. 7 a and b and Pl. 8 a; Pl. 8 b shows the texture of the groundmass.

In the normal types the groundmass is usually rich in *chlorite* or *biotite* as

well as in *calcite*. In the types immediately underneath graphite-phyllites, the groundmass next to the phyllite is dark, owing to finely scattered *graphite*, and often appears somewhat denser than elsewhere. The breccia structures and the fragments, however, are exactly the same as in the normal types.

The fragments consist of different rocks. Quartzporphyry and keratophyre are predominant, but often fragments of an almost andesitic composition, rich in chlorite, are also found, and in some cases rocks have been observed corresponding to the most basic types of the greenstones containing bytownitic plagioclase. The femic fragments, however, are generally quite small; as mentioned above, quartzporphyry and keratophyre are predominant among the larger fragments, but small quantities of stratified tuffs also occur, and in several cases fragments of a greyish black phyllite have even been observed. Immediately east of Kotjärn, finally, there are isolated, sharply delimited, angular fragments of a very graphite-rich phyllite, in a tuff rich in chlorite.

The microscopic examination of the groundmass between the larger fragments in coarse tuff breccias discloses that it consists of a mixture of various volcanic rocks, the original textures usually being very well preserved. Small fragments of quartzporphyry, quartzkeratophyre, keratophyre, and smaller quantities of andesite, can be distinguished in an irregular groundmass of *chlorite* or *biotite*, *sericite*, *calcite*, *epidote*, *quartz*, and *plagioclase*. The two last-mentioned minerals occur either in an extremely fine-grained development or as larger, more or less well-defined crystal fragments. Among the minerals in the groundmass, especially calcite is plentiful, and in certain cases there are found very highly calcareous tuff breccias.

5. Effusive Greenstone.

On the map all rocks of andesitic to basaltic composition appearing within the area have been classified under the heading effusive greenstone, regardless of their mineralogical aspect and whether they should be looked upon as lavas or tuffs. The reason for a further division of these rocks not having been possible is that the thermo-metamorphism in the area displays continuous changes from green schist facies to amphibolite facies. In greenstones more than in any other rocks this circumstance helps to create different appearances in chemically similar rocks in different zones of metamorphism, and in the more highly metamorphic areas the original features of texture and structure are more or less effaced. For these reasons, the subdivision of this group of rocks as adopted below has been based mainly on the mineralogical variations. The relation to other rocks as well as the textures in the low-grade metamorphic types show that the great majority of the greenstones consist of lavas and tuffs. Really intrusive types are generally lacking, and only in two places, west of the Bjurträsk ores and immediately south-east of Maurträsket, have unmistakable dikes been observed. In both cases, however, these dikes give the impression of belonging to the volcanic epoch.

a. *Amphibolitic Greenstone.*

The hornblende-carrying greenstones mainly occur in the eastern and central parts of the investigated area. As indicated by the name, the occurrence of *hornblende* is characteristic of this group. The megascopic structures may vary quite considerably from case to case; at the Bjurträsk ores and west and north of them we find mainly homogeneous, dark amphibolites, rich in hornblende, sometimes with a distinct porphyritic development. Probably the majority of these rocks represent lavas of a composition corresponding to andesite or basaltic andesite. In certain areas, particularly west of the Bjurträsk ores, the greenstones become inhomogeneous with an irregular alternation between black types rich in hornblende and types rich in biotite but poor in hornblende. In many cases it can be seen how the hornblende formation is intensified around fissures or quartz-hornblende veinlets in the rock. Generally one receives the impression that the irregular heterogeneousness of the greenstones to a great extent is due to tectonic deformation and consequent irregularities in the formation of hornblende.

It will be seen from the map that there occur a number of greenstone beds south of the Bjurträsk ores, interstratified with acid tuffs. There we find dark, porphyritic amphibolite beds, too, but these greenstones are more often found to consist of lighter, dense types with no megascopically visible plagioclase phenocrysts. Lavas as well as tuffs probably occur among these types. In some cases there have been observed beautiful amygdaloidal rocks, the vesicles being filled with *quartz* or *albite*. In other cases there exists a distinctly agglomeratic development with solitary angular fragments of dense greenstone in a dense groundmass. There often occurs a band-shaped or irregularly schlieren-shaped alternation between light, dense greenstone and darker, porphyritic greenstone. More acid layers frequently appear, and fairly often pure quartzporphyry tuffs are found as small interstratifications in the banded greenstone complexes. In all probability these types represent tuffitic types, which, however, have become greatly deformed owing to the mechanic deformation, and the original positions of the strata have then often been dislocated. The outcrops in the area south of Bjurfors display a similar distribution of rocks, and there, too, agglomerates often occur.

As will be seen from the map, greenstones are at Norrliden interstratified with quartzporphyry of the coarse porphyritic type. There the greenstone consists of very beautiful agglomerates of varying composition. The groundmass is either a dense, light green amphibolite or, more often, a greenstone rich in chlorite, with more irregularly distributed hornblende needles. The character of the fragments varies quite considerably. The great majority of the fragments are greenstones, occasionally with very beautiful quartz- or calcite-filled vesicles. In many instances the fragments are rounded or diffuse and are always lighter in colour than the surrounding groundmass. Pl. 9 a illustrates the structure in a typical agglomerate; Pl. 9 b shows a similar development as a bed in otherwise dense greenstone. Angular fragments of

lighter, dense greenstones also occur, however. In Pl. 10 a the lower one of the two distinct fragments in the middle consists of such greenstone; the upper one, on the other hand, consists of an even-grained, white, quartz-porphyritic tuffite. The quantitative importance of the latter as compared with that of the greenstone fragments is very small, but they are fairly uniformly distributed, so that at least some fragment of this character is encountered in almost every outcrop having agglomerate types with angular fragments. In addition, fragments of stratified tuffitic rocks are not infrequent and in one case a small fragment of the coarse quartzporphyry has been observed.

Microscopic examinations show that the hornblende greenstones mainly consist of *plagioclase* and *hornblende*, certain types also containing more or less *chlorite*, *biotite*, and *quartz*. The hornblende usually forms more or less distinct needles, often arranged as rosettes, penetrating phenocrysts as well as groundmass. The texture is seen in Pl. 10 b. It has undoubtedly in most cases been formed by reaction between calcareous, low-grade minerals (calcite, epidote) and iron-magnesium minerals (mostly chlorite).

It has not been possible anywhere to trace the rest of an earlier pyroxene generation from which hornblende might have been formed. Diffuse remains of a heterogeneous, brown hornblende in the normal, green hornblende were found in one instance in a special, dense greenstone of a very local character. The fact that the green hornblende in the majority of cases is a reaction mineral is to a certain extent borne out by its occurrence in relation to other minerals as well as by the order of crystallization. In types rich in biotite and chlorite the following order of crystallization is always found: Chlorite ⟶ biotite ⟶ hornblende.

The optic properties of the *hornblendes* show that they belong to the group generally covered by the expression common hornblende. The pleochroism is considerable in the most brightly coloured types that are richest in iron:

γ *deep bluish green*
β *bright grass-green*
α *greenish yellow*

The types poor in iron generally display the same shades although the variations are smaller, and particularly the most brightly coloured sections are often much fainter.

Due to the extremely complicated substitution conditions between the various elements of the hornblendes, it is impossible to obtain a simple linear correlation between the optic data and the chemical compositions. The data most valuable for the conclusions regarding the composition, seem to be the values for refraction and optic angle. Generally it would appear to be true that an increase in the Fe^{++} content increases the values for the refraction and decreases the values for the optic angle ($2\,V_\alpha$). In the diagram, fig. 5, a summary has been made of the relations between $\frac{\alpha + \gamma}{2}$ and $2\,V_\alpha$ in 16 different greenstone hornblendes, and for the sake of comparison some horn-

blendes have also been included from the "skarn" parageneses in the sulphide ores. In certain cases the optic angle may vary considerably even in the same thin section, for instance in No. 28, but in most cases the variations do not exceed 2°—3°. It will be seen that on the whole the dots are arranged in a zone where a decrease in the refraction corresponds to an increase in the optic angle.

In a similar summary of hornblendes from a district in the Caledonian mountains of Sweden, Du Rietz (9, pp. 72—75) has made a comparison with chemically as well as optically examined hornblendes of a corresponding type from different districts. In fig. 5 only seven of these types have been included (see Table 1) which may contribute to giving a general idea of the composition of the hornblendes occurring in the greenstones in question.

As will be seen from the table, hornblendes I—V, around which the hornblendes of the investigated area are chiefly grouped, represent a series with, on the whole, an increasing FeO-content and an MgO-content decreasing at the same rate. The ratio FeO : MgO thus to a certain extent displays continuous variations. As, however, many of the greenstone hornblendes in question show a still greater refraction and a smaller optic angle than No. V, they might be expected to be still richer in FeO. Samples VI and VII differ from I—V mainly by a greater content of the trivalent oxides Fe_2O_3 and Al_2O_3, but these samples vary mutually, as did samples I—V, with regard to the ratio FeO : MgO.

The phenocrysts of the amphibolites consist of large, uniform *plagioclase* plates from 1 mm to 4 mm in diameter. Twinning according to the Pericline, Albite and Carlsbad laws has been observed, the individuals usually forming broad lamellae. The outlines of the phenocrysts are usually very diffuse under the microscope, the hornblende needles to a great extent growing into them. Often the centre of the large plagioclase plates is perfectly crowded with small hornblende needles. Small inclusions of small, rounded plagioclase or quartz grains with varying optical orientations are generally also more or less abundant, tending to give the phenocrysts a poikiloblastic character. In some cases the inclusions may be so abundant that the phenocrysts can hardly be distinguished from the groundmass.

The composition of the *plagioclase* in the more or less distinctly porphyritic amphibolites generally varies between $Ab_{70}An_{30}$ and $Ab_{60}An_{40}$. In some cases more acid plagioclase has been observed, the composition ranging to $Ab_{80}An_{20}$.

The groundmass is an aggregate of usually fairly round *plagioclase* grains, occasionally with more or less *quartz* and *chlorite*. The texture is practically granular and the sizes of the grains vary quite considerably even in the same thin section, from 0.06 mm down to 0.01 mm and less. In some cases chlorite is abundant, then appearing as small plates fairly regularly distributed in the groundmass and with no particular parallel arrangement.

Pure albitic greenstones sometimes occur, the An content of the plagioclase being less than 10 %. Such types occur in the vicinity of the Bjurfors

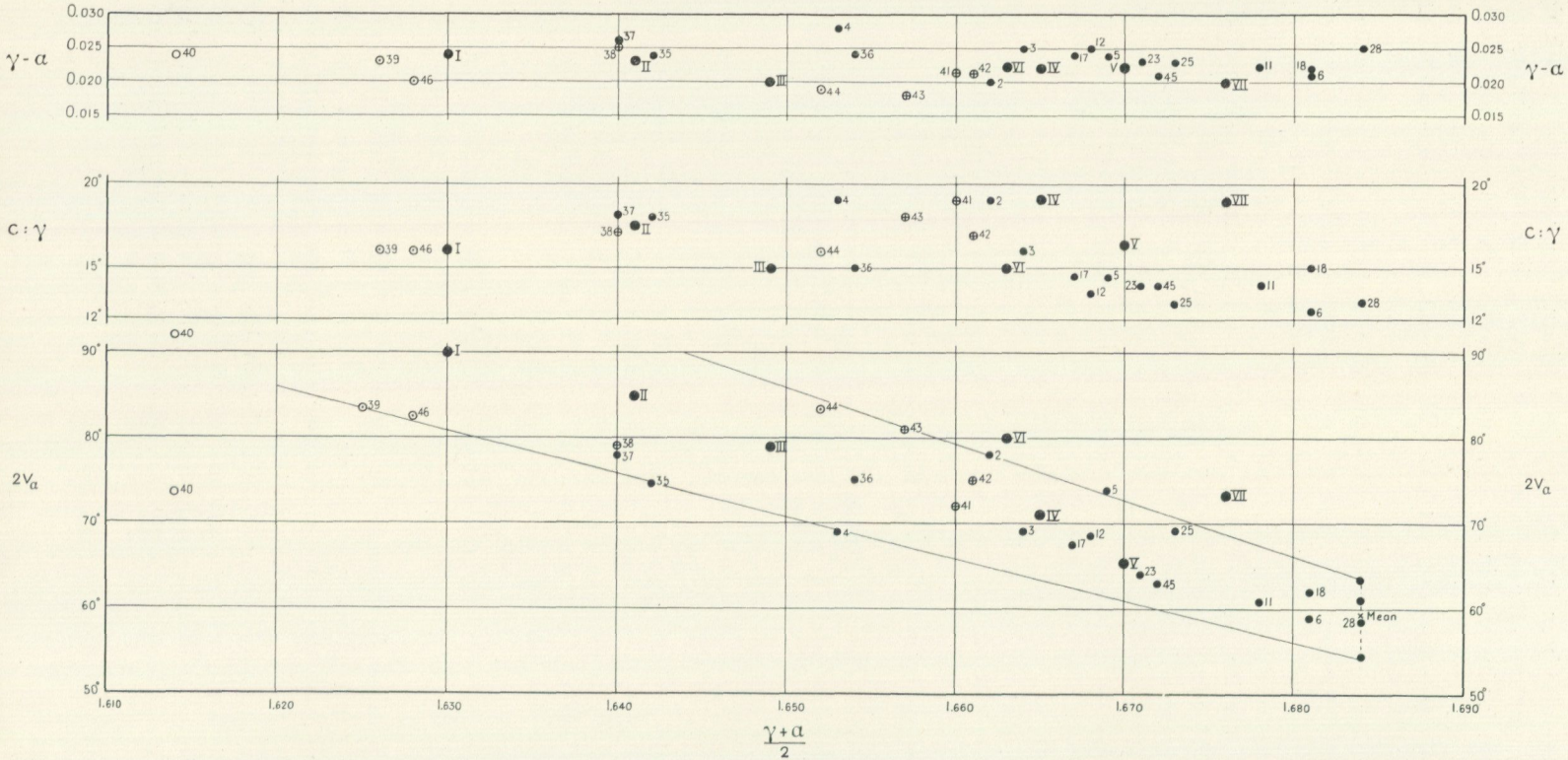


Fig. 5. Diagram of the optical properties of hornblendes. Filled circles = hornblendes from amphibolites (figures 3—28 refer to amphibolites in fig. 6 and Table 2, pp. 54, 55. I—VII = analysed hornblendes from other areas, Table 1. Crossed circles = hornblendes from altered quartz-porphyries. Circles with a dot = green hornblendes from hornblende-rocks (skarn) at the ores. Open circles = colourless hornblende from skarn.

Table 1.

Analysed hornblendes (Mol. %) of the same type as in the Malånäs District.

	I Jones, Univ. Tor. Stud. 1930, p. 68	II St. Kreutz Sitz. ber. Ak. Wiss. Wien, 1908, p. 947	III G. Beskow S. G. U. Ser. C, No 350, p. 73	IV Billings Bull. Geol. U. S. A. 1937, p. 556	V Kunitz N. J. B., A, 1930, p. 207	VI G. Beskow S. G. U. Ser. C, 1929, No. 350, p. 97	VII G. Beskow S. G. U. Ser. C, 1929 No. 350, p. 158
SiO_2	49.2	48.5	44.9	43.7	42.0	44.3	44.1
TiO_2	0.3	—	0.7	0.9	0.8	0.6	1.0
Al_2O_3	4.1	7.4	5.8	6.0	6.4	9.5	8.0
Fe_2O_3	0.8	0.6	0.7	1.1	1.3	1.5	2.6
FeO	4.5	3.8	8.0	11.5	12.4	7.9	11.7
MnO	0.2	—	—	—	—	0.1	0.1
MgO	23.2	25.6	19.1	16.9	16.8	12.7	11.6
CaO	13.9	10.5	12.1	13.1	11.9	11.5	11.8
Na_2O	0.4	2.2	2.6	1.1	1.3	2.3	3.8
K_2O	0.4	0.4	0.3	0.5	0.3	0.3	0.4
H_2O	3.0	1.0	5.8	5.2	6.8	9.3	4.9
Sum	100.0	100.0	100.0	100.0	100.0	100.0	100.0
% $\frac{(Fe, Mn)\ O}{(Fe, Mg, Mn)\ O}$	17	13	29.5	38	42.5	38.5	50.5
% $\frac{(Al, Fe)_2O_3}{(Mg, Fe, Mn)\ O + (Al, Fe)_2O_3}$	15	22	19	20	21	35	31

Analysis No. 7.

Porphyrite, 600 m W. of the Bjurträsk ores.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Niggli's System		Osann's System	
SiO_2	51.08	850.5	Q 4.0		qz	± 0	s	54.0
TiO_2	0.38	6.0	Or 4.6		si	130	A	3.0
P_2O_5	0.09	0.6	Ab 21.0		ti	1	C	9.0
Al_2O_3	19.43	190.6	An 39.6		al	29	F	17.1
Fe_2O_3	2.99	18.7	Σ sal. 69.2		fm	36	a	3.1
FeO	7.17	99.8	Di $CaSiO_3$ 4.1		c	27.5	c	9.3
MnO	0.19	2.7	Di $MgSiO_3$ 1.9	8.6	alk	7.5	f	17.6
CaO	10.08	179.7	Di $FeSiO_3$ 2.6		mg	0.40	n	8.3
MgO	3.83	95.0	Hy $MgSiO_3$ 7.6		k	0.17	k	1.02
K_2O	0.78	8.3	Hy $FeSiO_3$ 8.3	15.9	c/fm	0.76		
Na_2O	2.48	40.0	Il 0.9					
$H_2O^{+110°}$	1.40	77.7	Mt 4.3					
			Ap 0.2					
			Σ fem. 29.9					
			H_2O 1.4					
			100.5					
	99.90		II: 5: 3: 4 — Andose.					
			Or: Ab: An — 7: 32: 61.					

ores. They are usually rich in chlorite, and with the disappearance of the hornblende they become pure chlorite-albite greenstones.

In the megascopically dense agglomeratic greenstones, light green on a weathered surface, the hornblende appears in a more finely diffused form, forming a fibrous mass together with the albitic plagioclase. Further, albite also occurs as unmistakable vesicle-filling. The difference in the chemical composition of dense and porphyritic greenstones is seen from two analyses of these types. The greatest difference will be seen to be in the proportion between lime and magnesia, the porphyritic type being richer in lime but poorer in magnesia than the dense type (see analyses 7 and 8).

Besides the minerals so far mentioned, we often find more or less *clinozoizite*, *epidote*, and *calcite*. These calcareous minerals are found in fairly large quantities, particularly in the areas that represent transitional stages to green chist facies. The groundmass in the low-grade greenstones is very rich in chlorite, and the hornblendes form megascopically well-developed needles, irregularly distributed in the groundmass.

Small quantities of *ore minerals* occur in almost all greenstones. Microscopic examinations of these grains show that in most cases the ore mineral is *ilmenite;* occasionally there is a small amount of *sulphides*, while no magnetite is encountered. In addition, *titanite* and small *apatite* grains have been found here and there.

Immediately north of the granite contact at Bjurberget there appears a scoriaceous, *pyroxene*-bearing greenstone. The pyroxene crystals have a

Analysis No. 8.

Agglomeratic greenstone, 600 m S. of the Bjurträsk ores.

Analyst: L. Borgstedt.

	%	Mol. Prop. × 1000	Norm		Niggli's System		Osann's System	
SiO_2	51.34	854.8	Or 2.7		qz	−15	s	50.4
TiO_2	0.85	10.6	Ab 36.1		si	129	A	4.3
P_2O_5	0.04	0.3	An 20.8		ti	1	C	4.4
Al_2O_3	15.14	148.5	Σ sal. 59.6		al	22.5	F	21.3
Fe_2O_3	1.97	12.3	Di $CaSiO_3$ 3.0	6.0	fm	51	a	4.3
FeO	9.02	150.2	Di $FeSiO_3$ 1.3		c	15.5	c	4.4
MnO	0.25	3 5	Di $MgSiO_3$ 1.7		alk	11	f	21.3
CaO	5.72	102.0	Hy $MgSiO_3$ 10.1	17.6	mg	0.55	n	9.3
MgO	7.47	184.8	Hy $FeSiO_3$ 7.5		k	0.07	k	0.90
K_2O	0.45	0.3	Ol Mg_2SiO_4 4.8	8.7	c/fm	0.33		
Na_2O	4.27	68.9	Ol Fe_2SiO_4 3.9					
$H_2O^{+110°}$	3.38	187.6	Il 1.6					
			Mt 2.8					
			Ap 0.1					
			Σ fem. 36.8					
			H_2O 3.4					
			99.8					
	99.90		III: 5: 3: 5: — Ornose.					
			Or: Ab: An — 4.5: 60.5: 35.					

short-prismatic habit. The optic data $2V_\gamma = 59°$, $c : \gamma = 58°$ indicate a pyroxene of angite-type.

The *plagioclase* in this type is much richer in anorthite than in the common amphibolitic types, and is often zonal. The greatest variations observed in the same grain are: Kernel $Ab_{37}An_{63}$, shell $Ab_{53}An_{47}$. In addition, this type contains a fairly abundant quantity of *calcite*, and — which is quite remarkable — a fair quantity of *microcline*. The mineralogical parageneses and their significance will be more exhaustively discussed in the chapter on regional metamorphism, and there a survey of the mineralogical composition of different types of greenstones, based on volumetric determinations (see pp. 54, 55), will also be found.

b. *Amphibole-free Greenstones Rich in Chlorite.*

Rocks of andesitic composition are much rarer in the well exposed areas in the northern parts of the investigated area than in the southern parts. In a few cases only do we find well-definable types. North of Kotjärn there is a belt of calcareous greenstones. The rock is generally developed as a calcite breccia, angular, irregular pieces of greenstone being cemented with calcite, giving the outcrops an irregularly scoriaceous, weathered surface. Judging by the megascopic character of the rock it seems to represent a block lava.

A microscopic examination discloses a texture of slightly varying character in different fragments of the rock. In the most common development sparse

plagioclase phenocrysts (0.5—0.8 mm in diameter) are found in an irregular, fine-grained groundmass, consisting of practically isotropic, light green *chlorite*, *epidote*, *quartz*, and fine-grained aggregates of *iron oxide* minerals. Sparse plagioclase laths with a fluidal arrangement also appear in the groundmass (Pl. 12, a). Calcite also occurs in the fragments in the shape of scattered spots, in amygdales, and as small veinlets.

The larger plagioclase phenocrysts are often very rich in anorthite. Examinations of homogeneous grains disclosed An-contents of from 75—80 %. Usually, however, the phenocrysts are zonal with an interchange of zones rich and poor in anorthite. Measurements of two zonal phenocrysts gave the following values (the measurements refer to different fragments in a calcite-breccia):

	Kernel	*Intermediate zones*			*Shell*
1.	53 % An	41 % An	52 % An	43 % An	50 % An
2.	71 % An				50 % An

The plagioclase laths in the groundmass are usually poorer in anorthite than the larger phenocrysts. In the case when the anorthite content of the phenocryst was determined at 70—80 %, values between 50 and 55 % An were obtained for the plagioclase laths, and in the fragment in which No 1 of the zonal plagioclases was determined, the composition $Ab_{58}An_{42}$ was obtained for the plagioclase laths.

Twinning according to the Albite and Carlsbad laws has been observed in the larger phenocrysts; Carlsbad twins were found here and there in the smaller plagioclase laths.

Idiomorphic plagioclase laths and phenocrysts are lacking in some of the fragments in the calcareous breccias of the above-mentioned type. Abundant amygdales are instead found in these types, containing one or several of the minerals chlorite, quartz, zoisite, and calcite.

Very beautiful amygdaloidal greenstone is found in the greenstone bed north of Örträsket. Megascopically the rock may be described as a dense, somewhat heterogeneous greenstone rich in chlorite. Under the microscope about one fourth of the rock is found to consist of vesicles. The groundmass is an extremely fine-grained mixture of *quartz* and *chlorite* and a fine-grained, partly opaque mass, presumably consisting of *epidote* and *oxides*. Isolated *plagioclase* plates of sizes up to 2 × 2 mm are also found. The composition corresponds to basic andesine; determinations made give values varying from 41 % An to 47 % An. Twinning according to the Albite and Carlsbad laws has been observed. Usually these plagioclase phenocrysts are highly altered and crowded with zoisite, chlorite, and iron oxide. The extinction is usually very irregular and undulatory, often making determinations of the anorthite contents rather uncertain.

The rock is highly influenced by stress which generally gives the amygdales an elongated form. Most of the vesicles are filled with chlorite and quartz, fine-grained quartz forming an outer border around a chlorite kernel (Pl. 11, a).

Zoisite- or epidote-filled amygdales also occur. The minerals then often had a tendency towards orientation with the longitudinal direction at right angles to the wall of the vesicle. In other instances, zoisite occurs together with quartz and chlorite as a transitional zone between these minerals, but in many cases one of the minerals becomes scarce or is entirely lacking. On the other hand, very regularly developed amygdales are also found, with quartz in the middle, surrounded by epidote (Pl. 11, b). Calcite also occurs abundantly, either as independent vesicle-filling or as the outermost zone in the quartz-chlorite amygdales.

Ore grains are always found fairly regularly distributed in the rock in the amygdaloidal greenstones as well as in the homogeneous types richer in plagioclase. They are often developed as short laths, and examinations of some samples under the microscope shows that the ore consists of *ilmenite*.

To the east of Kotjärn we find a greenstone with well-defined calcite amygdales and carrying clear plagioclase phenocrysts of albitic composition. The composition varied between Ab_{94} An_6 and Ab_{90} An_{10} in the cases examined. Here and there, however, cloudy, irregular remainders of a plagioclase very much richer in anorthite are found in these phenocrysts, which, judging by the refraction at any rate, are andesine. The small plagioclase laths in the pilotaxitic groundmass also consist of andesine with an anorthite content of from 30 % to 35 % An.

Similar rocks in which the plagioclase is completely albitic have occasionally been observed in small fragments of the volcanic breccias, these types thus representing transitional forms to the keratophyres. It is of course impossible to draw a sharp boundary between true keratophyres and the types characterized as albitic greenstones.

In this respect the pure chlorite-albite greenstones that occur in drill holes and outcrops of the Bjurfors ores are exceptions. Although the type found there is fairly common in that section, it has neverheless not been observed in other parts of the investigated area. In its most typical form the rock consists of fairly well defined idiomorphic *plagioclase* laths in a groundmass of *chlorite* and more or less *quartz* (Pl. 12, b). Further we generally find *magnetite* as irregular poikiloblasts, *ilmenite*, and — around the latter — often narrow zones of *titanite*. In many cases the chemical composition greatly resembles that of the rocks that have already been described as keratophyres. The geological appearance, however, which indicates a very intimate association with amphibole-bearing greenstones, renders it impossible to distinguish such keratophyric types from the greenstone series. Gradations into the normal, massive amphibolites are created by types rich in chlorite, with sparse, isolated hornblende needles. The albite laths are often visible also in the hornblende-bearing types, although they are usually somewhat granulated and fractured. Areas with preserved plagioclase laths and others with granular quartz-plagioclase-chlorite groundmass, common in the amphibolitic greenstones, may occasionally be found in the same thin section.

The texture of the rock with its well-preserved plagioclase laths may cause

certain doubts as to whether it really is to be looked upon as belonging to the volcanic series. In other areas within the Skellefte field, basic dikes have been found, which evidently are closely connected with the ore formation, and which have textures to a certain extent resembling those in the greenstone types in question. In this case, however, we have the intimate geological association with amphibolites of exactly the same character as those that definitely belong to the volcanic series, an association that makes it impossible to accept any other genetic interpretation of the chlorite-albite-greenstones than of the amphibolites. It is thus most probable that also the chlorite-rich types with albite laths are a special development of the volcanic rocks.

6. Phyllite Series.

A. Högbom has summarized the upper, sedimentary part of the lower supercrustal formation under the heading phyllite series. As indicated by the name it consists mainly of phyllites, and, these often being very graphite-rich, they are usually black. There are, however, also lighter grey, graphite-free phyllites, and a classification according to colour, black and grey, practically corresponds to a classification into graphite-bearing and non-graphitic phyllite. Arkose also occurs in small quantities, occasionally with a tendency towards conglommeratic development, and, locally, we find limestones, too.

Within the southern parts of the mapped area the metamorphism is so high that the phyllites should rightly be termed mica-schists. As, however, the majority of the argillaceous sediments of the present area are either real phyllites or represent transitional stages between phyllite and schist, the term phyllite will be used throughout in this paper.

a. *Graphite-Phyllite.*

The relatively common development is a jet-black phyllite with a marked linear schistosity and then often without any signs whatever of original stratification. The splitting along the planes of schistosity is very pronounced, but the small phyllite plates are very brittle, and when subjected to blows the rock is usually split into small parallel plates. Sulphides can be seen already megascopically, *pyrrhotite* as well as *pyrite*, but the contents vary greatly. The high contents of *graphite* and pyrrhotite generally cause the black phyllites to produce strong indications in the geophysical measurements made in the investigated area for prospecting purposes. The graphite content creates good electrical conductivity, and a content of pyrrhotite gives indications for magnetic prospecting and helps to increase the electrical conductivity.

The stratification is often well preserved in the slightly metamorphosed phyllites. In the westernmost part of Skäggträskberget, in the area between Ö. Högkulla and Önusberget, immediately east of Önusträsket, where the river Maurbäcken joins the Skellefte river, there are thus phyllites the original structures of which are more or less well preserved. In these types there

Analysis No. 9.

Graphite-phyllite, 800 m N. W. of Bjurliden. Drill hole Rutselheden 4, 23.7—32.9 m.

Analyst: Th. Berggren.

	%	Mol. Prop. × 1000
SiO_2	61.66	1 022.5
TiO_2	0.35	4.4
P_2O_5	0.06	0.4
Al_2O_3	11.82	115.7
Fe_2O_3	0.00	0
FeO	[1] 12.15	155.8
MnO	0.08	1.1
CaO	1.50	26.7
MgO	1.30	32 2
Na_2O	1.66	26.8
K_2O	3.34	35.5
$H_2O^{+105°}$	1.39	77.1
CO_2	0.55	12.5
S	5.33	166.2
C	1.39	
	102.58	
$H_2O^{-105°}$	0.19	

is usually an interchange of dense phyllite layers, richer in graphite, and arenaceous layers poorer in, or entirely free from graphite. The thickness of the individual layers usually varies between one mm and one or two cm. In certain cases the stratification may coincide with the schistosity, but usually the layers are crossed by the planes of schistosity.

The microscopic textures are very uniform: *quartz, plagioclase,* on rare occasions a little *microcline, sericite,* and *chlorite,* make an extremely fine-grained groundmass in which isolated, large quartz and plagioclase grains appear, distributed in a fairly regular manner (Pl. 13, a). The graphite occurs in a very finely scattered form, often enriched in certain layers, and usually also in the shape of irregular spots. As a rule the biotite also forms isolated flakes of a porphyroblastic character in the biotite-phyllites (Pl. 13, a). The micas, particularly the small sericite and chlorite flakes, are regularly arranged parallel to the planes of schistosity. *Calcite* may appear in small quantities, and in the southern parts of the area *hornblende* needles have occasionally been seen in graphite-mica-schist, evidently formed by thermal metamorphism of calcareous phyllite. Small quantities of *epidote* occur in a few types, and here and there insignificant grains of *zircon* and *apatite* can be found.

As already mentioned, *sulphides* are common. They may appear in veinlets or schlieren, as is usually the case in high-grade metamorphic types, or

[1] All iron determined as FeO. Much of the iron, however, occurs in pyrrhotite and pyrite. If we count with the mean FeO:MgO ratio as obtained in the other analyses, the FeO-percentage will be = 2.05 % and the rest of the iron will occur in 10.3 % pyrrhotite and 2.9 % pyrite. The sum of the analysis will then be 100.50 %. The proportion between pyrite and pyrrhotite is in relatively good agreement with a rough estimation.

— as is mainly the case in the low-grade types — they form even disseminations where the individual sulphide grains lie fairly uniformly distributed in the phyllite.

The chemical composition of the most common types of graphite-phyllite in the area is seen in analysis No. 9.

b. *Grey Phyllite.*

Graphite-free, phyllitic sediments are much rarer in this area than the types richer in graphite. At Skäggträskberget, and south-east and east of Önusträsket, however, larger beds of grey phyllite are found interstratified with the graphite-bearing types. Usually the grey types appear to be slightly coarser than the black ones, and arenaceous interstratifications play an important part. Real sandstone beds often occur, but with a fairly high felspar content, and they thus constitute transitions to the real arkoses. The microscopic textures are identical to those described above for the graphite-phyllites, and as far as the mineralogical composition is concerned, it is only the difference in graphite content that separates the two groups.

c. *Arkose and Limestone.*

In the lower parts of the phyllite series there often occur sediments which seem largely to consist of rather unsorted quartzporphyry or keratophyre material. It is only in exceptional cases that the sedimentation has led to the development of more quartzitic types, the quartz having been enriched to a considerable degree at the expense of the felspar. Generally the arkoses and arkose sandstones are quite free from graphite, but sometimes a small graphite content has been observed. On the other hand, small fragments of black and grey phyllite sometimes occur in the arenaceous products of weathering, thus displaying a certain tendency to a conglomeratic development. The clastic structure is megascopically most decided in the arkoses having quartzporphyry material as an important component, as in these types the quartz and plagioclase phenocrysts of the quartzporphyries are distinctly visible in the grit of weathering. Rounded fragments of quartzporphyry or keratophyre, as large as hazel-nuts, are occasionally found, e. g. in the area just east and south of Önusträsket. Pl. 14 a and b illustrate the beautifully clastic structure with angular or sligtly worn quartz fragments, and in the middle a small rounded fragment of preserved quartzporphyry.

The arenaceous groundmass in the arkoses is often very rich in *sericite* and *calcite*. A finely diffused black pigment is occasionally found in the latter, in all probability *graphite*. In certain types the calcite constitutes the predominant cement between the well-defined fragments, and in some beds the calcite content is as high as 75—80 % of the entire mass. Such impure limestones are found north and north-east of Kotjärn, immediately south of Maur-

bäcken, and appear there either as regular layers or as small lenses in the phyllites. The widest limestone bed is at least 3—4 m thick, but usually the interstratified beds of limestone are much thinner in this area.

The microscopic examination of the quartzporphyry arkoses shows that in the majority of cases the plagioclase consists of *andesine*. This is particularly remarkable as the plagioclase in practically all the quartzporphyries examined carries albitic plagioclase. Thus the larger plagioclase plates in a quartz-rich arkose 1 km west of the Norrliden sulphide deposit, have the composition Ab_{60} An_{40}, while the quartzporphyries immediately east of the same locality, which judging by their structure should have supplied the material, contain pure albites. In this case, however, there is reason to assume a large tectonic boundary between these localities, and such a phenomenon need thus not imply a long transportation of the material. It is more remarkable that also the arkoses at Skäggträskberget contain andesine while all other rocks at Skäggträskberget are purely albitic. In this case there must thus have been an important transportation of the material in the process of sedimentation.

7. Quartz Veins.

Outside the limits of the large granite and diorite massives there are no really intrusive rocks in this area. On the other hand, the country rocks often contain large numbers of quartz veins. These can vary in thickness from 0.5 m down to quartz fissures only a mm wide. The vein-quartz has evidently appeared at widely different periods of the geological development, which is seen in the varying relations to the tectonic structures. There is thus a generation of quartz veins which is definitely later than the development of the linear structure and the small folds, and which sometimes is orientated mainly along joint planes at right angles to the fold-axes. In other cases, on the other hand, the quartz may also be included in the folding, when veins parallel to the layers distinctly follow the folds.

The richest quartz invasion, however, is probably the one intimately connected with the formation of the sulphide ores. The relations of these quartz veins to the ores will be dealt with in detail in connection with the description of the individual ore bodies.

In the great majority of cases the material in the veins consists of pure quartz, occasionally with a little chlorite. The quartz is fairly coarse-grained and also in the latest types of veins it has been subjected to a rather strong mechanical deformation. Probably for this reason, attempts to distinguish hightemperature quartz from low-temperature quartz, by means of etching, turned out a failure.

Calcareous quartz veins appear in some of the series of veins that are directly connected with the sulphide ores, but seem possibly to have occurred also locally in areas where there is no reason for directly connecting the veins with the development of sulphide ore. An observation has thus been made in the eastern part of the area, about 800 m east of the Bjurträsk ores, where

a quartz vein penetrates quartzporphyry, simultaneously forming hornblende in the wall rock. At the locality in question the quartzporphyry has a strongly marked linear schistosity, the original plagioclase phenocrysts are destroyed to a great extent, and the groundmass consists of a quartz-plagioclase mass, rich in biotite and partly also in sericite. Hornblende enters next to the brecciating quartz vein, occasionally so abundantly that the rock acquires the appearance of greenstone. But also in this case the original quartz phenocrysts are preserved and are distinctly visible to the naked eye. Under the microscope the hornblende is found to consist of light green needles with poikilitic quartz inclusions, thus of the same type as those occurring in the normal greenstones. There is also evidently a regeneration of plagioclase, richer in anorthite, (basic andesine), which forms irregular poikiloblasts enclosing quartz, or appearing in a fine-grained mixture with quartz.

VI. Regional Metamorphism.

When discussing the problems associated with the metamorphism, which here may be said to have a regional appearance, it would seem most advantageous to apply the principles presented by Eskola (*15*, *16*, *17*, *18*) in his facies-classification, which have been further discussed and applied by Barth (*2*), Tilley (*81*), Thorolf Vogt (*82*), and others. For rocks of different chemical bulk-compositions but which have been overtaken by the same degree of metamorphism (identity in P-T-time conditions), Tilley (cit. above) proposed the term isogradic or isofacial. It is most interesting in the study of the development of the facies-principles to recognize the same degree of metamorphism in rocks which due to differences in their chemical composition display quite different mineral assemblages, and thus to be able to follow the isogrades in spite of great variations in the mineral composition of the material studied.

Rocks of a gabbro composition were of great significance in Eskola's original definition of the main facies-types, and the most complete facies-series were first nominated among the gabbros and their metamorphic derivates. It is thus tempting to correlate rocks of a femic composition with the other rocks in the area investigated, as was done for instance by Vogt. In this manner we check the parageneses proposed by Eskola in the C-F-A-triangles, also used by Vogt and further developed by Barth.

When applying the facies-principles on the metamorphic rocks in the Malånäs area, it should be kept in mind that the conditions in several cases differ from those described in the publications of Eskola, Barth, and Vogt. The chemical variations thus range from basic andesites to rocks of natron-granitic composition, but especially aluminous and calcareous sediments are insufficiently represented to contribute to any great degree in the classification of the regional metamorphism. For it must be kept in mind that the mineral assemblage of a certain facies making a true equilibrium, as for instance the amphibolite-facies of the gabbro-rocks, does not represent a point in the P-T

curves, but rather an interval. Thus changes in the mineral composition of one rock need not be contemporaneous with those in another rock, which due to a different chemical composition has quite another mineralogy. It is thus necessary to ascertain where in the metamorphic development the change from one stable association to another takes place in the chemically different rocks, and to establish the position of these changes in relation to each other. In areas displaying a continuously increasing metamorphism, the actual location of the different types of rocks will supply the most exact solution of these problems. For this purpose, however, rocks of quartzporphyry or of andesite composition are the only ones distributed in a sufficiently uniform manner to be considered in this respect.

The change from one facies to another, however, is generally represented by a mineral assemblage which has no true equilibrium, probably due to very slow velocity of reaction close to the reaction temperature. This fact, however, does not occasion any great difficulties, for if the main facies are once defined, the mutual proportions of minerals belonging to different facies are, as such, a gauge of the degree of metamorphism. As already pointed out by Eskola, the occurrence of unstable relics is by no means a drawback when applying the facies-principles. It may, on the contrary, be the source of important information as to the nature of the metamorphism. The proportions between stable and unstable zones within an area investigated may, for instance, give at least a relative conception of the time conditions or perhaps of the part played by catalytic agents during the metamorphic process, which often may be of great importance for a good conception of the problem. As will be seen below, mineral associations are often found in the Malånäs area, which do not represent true equilibria.

The rocks in the Malånäs area represent a rather limited part of a complete facies-series, as no members of the highest metamorphic grade are found as well-defined types. As also pointed out above, it is only certain parts of the rocks that really can be correlated with each other with regard to chemical composition. Thus in the A-C-F-triangle the members tending towards the A- and C-corners are comparatively rare. True limestones certainly do exist, but they are not sufficiently wide-spread to permit an investigation of the gradual change of metamorphism throughout the area. The quartzporphyry lavas, on the other hand, do answer this last-mentioned condition, and their initial compositions also seem to have undergone but slight variations. These rocks are also rather similar in their relations to the tectonic forces, which means that stress probably does not give rise to complications of any great importance. Their metamorphic derivates are therefore well suited to form the scale of metamorphism to which rocks of analogous chemical compositions may be referred.

In the basic members of the volcanic rocks it is possible to suggest equivalent facies-series though they have a more varying original composition. The types already defined by Eskola and Vogt as fixed facies-types are also found in the metamorphic derivates of these rocks. As their definitions referred to

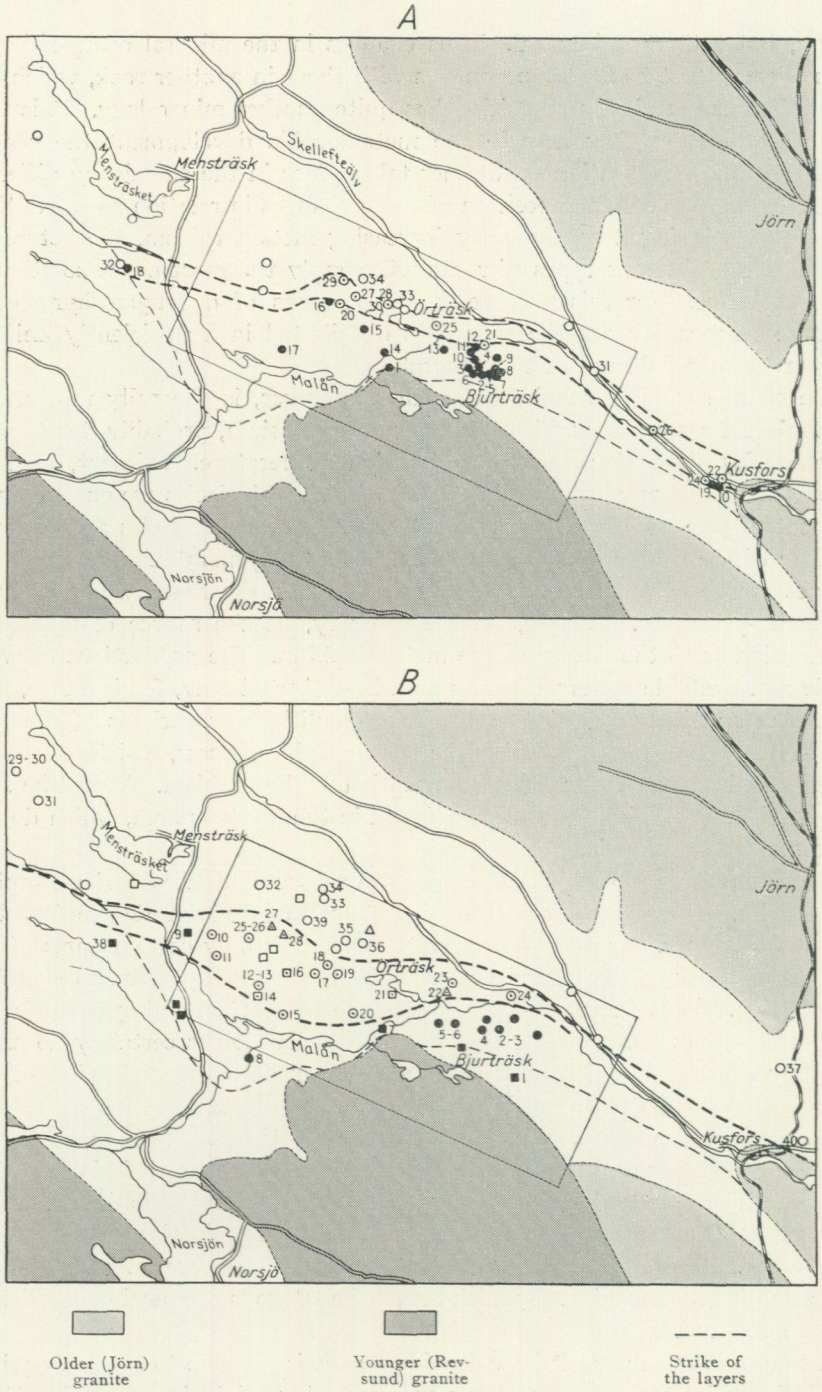


Fig. 6. Sketch-map showing the progressive metamorphism of the area; A in the greenstone series; B in the quartzporphyry series. The rectangle shows the extension of the mapped area, Pl. 38. The heavy broken lines, the isogrades, delimit, in A, areas with complete amphibole facies (filled circles) and complete calcite-chlorite facies (open circles), and, in B, areas with complete biotite facies (filled signs) and complete chlorite facies (open signs). Signs with a dot = transitional zones. In B circles = quartzporphyry lava; squares = banded quartzporphyry tuff; triangles = arkose. The figures in A are the same as in Table 2, the figures in B are the same as in fig. 7.

variations ranging from high-grade to low-grade facies, there is a difference in the direction of the alteration of the rocks now discussed, where low-grade minerals are followed by minerals of a higher grade. According to the definition of the facies-principles, this would be of no importance for the true facies-associations. It may, however, have some bearing upon the incomplete alterations from one facies to another, which will be discussed in the chapter on the metamorphism of the andesitic greenstones.

1. Metamorphism in the Greenstone Series.

The best picture of the successive changes in the metamorphic grade is obtained by examining the form in which CaO appears in the andesitic or basaltic derivates of the supercrustal series. It became evident already during the mapping in the field that the area could be divided into two large main parts with reference to the regional metamorphism, i. e. one where hornblende was never encountered, but where the greenstones were rich in calcite, and another where calcite was rare but where the greenstones instead were developed as amphibolites. The microscopic examinations made it possible to follow the successive intensification of the metamorphism in greater detail, and to determine the minerals that are of decisive importance for the metamorphic classification. Table 2 shows the results of a number of geometric measurements of the volume percentages in thin sections, demonstrating the mineralogical variation. Quartz and plagioclase make their appearance and make up the portion necessary to complete the 100 %, but as the very insignificant dimensions of the grains often made it impossible to determine the mutual proportions of these minerals, and as they have no decisive bearing on the problem in question, they have not been included in the table. The respective localities where samples were taken are denoted on the metamorphism map, fig. 6, A, and also a number of localities for which no volumetric determinations have been made, as it was possible to decide immediately to which type of metamorphism the sample in question belonged. With regard to the map it should also be mentioned that it naturally has been completed with field observations between the spots denoted, for which reason the samples in the table may be considered typical of their immediate neighbourhood. The exact course of the isogrades in the areas not covered by the mapped area proper is of course less certain, the observation material there being inadequate. But the general course is clearly denoted even by the few spots examined.

As will be seen, the grouping made in the tables is mirrored in a regional distribution of the respective rocks. The group representing complete amphibole facies first being examined, it will be seen that calcite and epidote never occur here together with chlorite of an "original" character. To be sure calcite may occur in rocks within areas that advance rather far on the high-grade side of the isograde for complete amphibole formation, for instance No. 10 and No. 1, the latter being particularly remarkable, but in those in-

Table 2.

Mineral composition of greenstones given in volume per cent.

A. Complete amphibole facies

	Amphibole	Chlorite	Epidote	Calcite	Biotite	Sericite	Ilmenite	An-content %	Secondary Chlorite[1]	Pyroxene
1 . .	38	—	—	3	—	0.5	—	50—65	—	22
2 . .	69	1	—	—	2.5	—	1	5—7	—	—
3 . .	59	—	—	—	2	—	1	35—40	0.5	—
4 . .	45	—	—	—	23	—	0.5		—	—
5 . .	44	—	—	—	24	—	1		5.5	—
6 . .	41	—	—	—	27	—	—		—	—
7 . .	41	—	—	—	—	—	2.5		—	—
8 . .	39	—	1	—	5	—	1		2	—
9 . .	35	—	—	—	5	—	0.5	about 10	25	—
10 . .	41	—	1	1	1	—	1	32	—	—
11 . .	37	—	2	—	12	—	2	15—25	—	—
12 . .	20	26	—	—	0.5	—	2	20—25	—	—
13 . .	10	—	14 tog. with sericite	1	26	14 tog. with epidote	1	about 30	—	—
14 . .	34	—	2	—	29	—	0.5		5.5	—
15 . .	56	1	—	—	—	—	2	30—33	—	—
16 . .	24	21	—	—	12	—	1	31—33	—	—
17 . .	40	1(?)	—	1	8.5	—	—	30	—	—
18 . .	34	17	—	—	1	—	1.5	30—35	—	—
19 . .	47	1.5	—	—	5.5	—	2.5		—	—
20 . .	41	—	4.5	17	0.5	—	1	<10	—	—

[1] Chlorite formed later than hornblende.

B. Incomplete amphibole facies

	Amphibole	Chlorite	Epidote	Calcite	Biotite	Sericite	Ilmenite	An-content %	Secondary Chlorite	Completeness of the formation of amphibole from chlorite and calcite + epidote	Completeness of the formation of amphibole from chlorite and calcite
21 . .	27	1 5	1	—	4	—	—	35--40	—	94 %	100 %
22 . .	40	5.5	12.5	—	—	—	1		—	84 %	100 %
23 . .	19	29	2.5	—	10	—	4	31—33	1	85 %	100 %
24 . .	29	16	5.5	—	—	—	1		2	75 %	100 %
25 . .	14.5	29	7	—	4.5	2	1	25—35	—	55 %	100 %
26 . .	18	21	0.5	0.5	7.5	—	—		—	87 %	91 %
27 . .	42	11	—	2	0.5	—	1.5		—	86 %	86 %
28 . .	19.5	42	6.5	2	1	—	3		—	52 %	73 %
29 . .	46	33	—	12	4	—	—		—	52 %	52 %
30 . .	1	20	19	8	7.5	1	1	20—25	—	3 %	3 %

C. Complete chlorite-epidote-calcite facies

31(?) .	—	31	1.5	—	19	—	2		—	
32 . .	—	45	1	12.5	11	1.5	1	about 10	—	
33 . .	—	33	16	—	16	—	1		—	
34 . .	—	28	—	10	—	4	1.5		—	

stances chlorite is entirely lacking. On the other hand, there are types rich in chlorite, at least near the high-grade side of the isograde, in which calcite and epidote are entirely lacking.

The most prominent feature in the metamorphic development here is thus that CaO in calcite or epidote reacts with iron-magnesium-aluminum-silicate in the form of chlorite, hornblende thus being formed. The other Fe-Mg-mineral, biotite, occurring in these parageneses, on the other hand, seems to be stable, even in the presence of calcite, at least in part of the amphibolite facies. It has always been found that biotite is formed slightly earlier than amphibole, probably by the reaction between chlorite on the one hand and sericite or potash felspar on the other. It would therefore seem plausible that as long as no other mineral containing potash is stable, the reaction biotite + calcite → amphibole is restrained. A support for such an opinion is found in the association represented by No. 1 where the association amphibole, pyroxene, calcite, microcline, is present. The occurrence of pyroxene indicates a comparatively high-grade metamorphism as compared with the other associations stated, and it is then characteristic that the potash content present is here found in microcline, and all iron and magnesium oxide in the form of amphibole or pyroxene, the potash in lower-grade metamorphism otherwise being bound with the iron-magnesium oxides in the mineral biotite. It is thus close at hand to presume part of the amphibole or possibly the pyroxene to emanate from an earlier biotite generation, now completely destroyed, so much the more as there is here an excess of CaO in the shape of calcite. The reaction between calcite and biotite would in such a case be regulated by the fact that the physical-chemical requirements for the formation of microcline are filled. If, however, as is usually the case, the original lime content is insufficient to transfer all iron and magnesium oxide into amphibole and pyroxene, respectively, biotite may of course be stable at a much higher degree of metamorphism.

Between the area where complete amphibole formation has occurred and that where no amphibole formation has as yet begun, a zone is found, characterized by incomplete metamorphism, whose mineral associations are shown in the middle part of the table (Table 2, B). The comparatively high content of epidote in most of the types is characteristic of this group.

In the works of Eskola and Vogt, the development of epidote from chlorite or muscovite plus calcite is stated to be the first step in the direction of amphibolite facies, and it is highly probable that in this epidote content we here have the initial development of a transitional facies in agreement with this definition. On the other hand it is not possible to establish any transitional zone within the area in question with a mineralogy completely corresponding to such a transitional facies. The reason probably is that it is often very hazardous to decide whether the epidote constitutes a mineral formed as a result of the regional metamorphism, or whether in its present association it is an unstable relic from an earlier period. For epidote is in many cases found as

vesicle-filling and thus probably belongs to a late- or post-magmatic mineralization, but at all events its development would appear closely related to the volcanic epoch. The rocks in addition being greatly stressed, it is often impossible to decide definitely whether we are dealing with "primary" or "secondary" epidote. The observations made in thin sections have afforded no decisive support for the conception that the epidote was developed from chlorite and calcite. On the other hand there are many observations showing that the formation of epidote from basic plagioclase is of a certain importance. In this connection we must thus consider the behaviour of the plagioclase under different facies conditions.

All experiences of the equilibrium in the lime-chlorite facies indicate that albitic plagioclase should be expected here. Albite is certainly common in this area but plagioclase with an anothite content varying between 40 and 65 % is found quite frequently. When applying the facies principles, such an association thus implies a non-equilibrium, most likely illustrating a mineral composition unaffected by metamorphism. The fact that it does not correspond to a true equilibrium is really not very remarkable, considering that equilibrium conditions are often not realized in the rapidly solidified volcanic rocks. In this association anorthite thus occurs as unstable relics, and it is generally impossible to determine whether the beginning epidotization is to be looked upon as belonging to the regional metamorphism, or if it is to be considered as a result of the late-magmatic reactions of the volcanic period.

Only in complete amphibole facies may we expect the anorthite in the plagioclase really to be in true equilibrium with its surroundings. Here the composition of the plagioclase is also fairly uniform and usually includes between 30 and 40 % An.

Under such conditions, however, it is impossible to determine in detail to what extent the lime content of the plagioclases influences the formation of amphibole. The results on the whole indicate, however, that it plays but an insignificant part. The most important reaction remaining for determining the grade of metamorphism is then that between calcite and epidote on the one hand and chlorite on the other. On the basis of earlier results it may also be assumed that the range of stability of the epidote lies between complete amphibole facies and lime-chlorite facies.

As certain difficulties are encountered in making direct comparisons of the grade of metamorphism only on the basis of the figures in the table, an attempt has been made to calculate to what extent the main reactions mentioned have been realized. In the reaction calcite + chlorite → amphibole, I have then calculated with the ratio FeO : MgO : Al_2O_3 being the same in the chlorite and in the amphibole, an assumption, anyway, that is not at all contradicted by the optical properties of the minerals in question. In such a case a quantity of free silica is also required for the reaction which then takes place by the liberation of CO_2 and water. We thus find that, expressed in volume per cent, 2 parts of calcite and 5 parts of chlorite are needed to form 7 parts of amphibole. Supposing that only CaO is taken from the epidote in the reaction epi-

dote + chlorite → hornblende, we find that 5 parts of chlorite and 4 parts of epidote are needed for a corresponding quantity of amphibole. The figures in the right-hand part of the table now show to what extent the mineral composition found in the thin section corresponds to complete reaction in one case or the other. One column refers to the conditions if only calcite-bound CaO is included in the reaction, the other if CaO for the amphibole formation is taken from calcite as well as from epidote. As the proportions in the rocks between calcite and epidote on one side and chlorite on the other usually do not correspond to the proportions assumed to be necessary for the formation of amphibole, a certain excess of one or the other mineral is obtained, which has not been included in the calculations in these columns.

Of course the figures are primarily only a manner of expressing the mineralogical proportions found in the thin section. A comparison of the different values and the resultant conclusions with regard to the regional metamorphism depend upon certain conditions whose realization must be discussed from case to case.

When applying the facies-principles, one chief condition is that no great transportation of substances takes place and thus that the chemical composition remains unchanged during the course of the metamorphism. This condition, however, holds an uncertain factor unless a definition is made of the size of the part of the investigated area that is assumed to have an unchanged composition during the course of the metamorphism. As a matter of fact there is by necessity always a certain transportation of material. The extreme case is the formation of a new mineral grain, which already in itself implies a transportation of material from one point to another. The area to which a direct expression of the average metamorphic grade is to be referred — which expression in other words is intended to express the relative pressure-temperature conditions in the area mentioned — should thus be chosen so large that as many as possible of all the variations caused by local transportations of material are covered in the selected area. The experiences from the field in the Malånäs area indicate that an outcrop of a few square metres in some cases is sufficient to give a univocal expression for the grade of metamorphism, in other cases a comprehensive survey of a larger group of exposures is necessary. In the area characterized by incomplete amphibole facies we often find a fairly irregular distribution of amphiboles forming schlieren and veinlets, and sometimes even distinctly orientated along fissures in the rock. Such a heterogeneousness can naturally not correspond to variations in the P-T-conditions, which in these cases cannot reasonably be conceived to vary greatly within quite small areas. The explanation must probably be sought in other factors. The general opinion of the metamorphic reactions is that they occur with the aid of a liquid or gaseous phase, usually water, whose influence in many cases is merely catalytic. When metamorphism takes place simultaneously with tectonic movements, as is the case here, it is clear that the liquid phase in question will be somewhat irregularly distributed

— at least in detail — and that its catalytic function thus will be unevenly distributed in certain areas. As mentioned above this factor is naturally of great importance, when considering only such a small area as is represented for instance by a thin section. A summary of the results from an number of thin sections, however, can give a comparatively reliable expression for the metamorphic grade. When selecting the material, it is of course necessary to proceed from the observations made in the field, and to decide on that basis the size of the area that should be summarized to give an univocal idea of the metamorphic conditions. In this area with sparse outcrops it has proved suitable to arrange the neighbouring outcrops in groups which subsequently can be mutually compared. Thus Nos. 28, 30, and 33, for instance, have been taken from outcrops close to each other, and they were chosen to represent the megascopically most extreme types of this group. The variations in these values should thus represent the variations occurring in the group of outcrops mentioned. In other words, they express the metamorphic differentiation which has a certain significance as regards the minor features, but has no decisive influence on the major ones. The heterogeneousness described above is mainly predominant in the area with incomplete amphibole facies; a corresponding heterogeneousness is generally not at all noticeable in the area with complete amphibole facies.

If we figure with a migration of substances according to the description above, we must not overlook the possibility, however, that an interchange of a more regional character also may have occurred. In dealing with the metamorphism of the Sulitelma greenstones, Vogt has been able to establish a leaching of lime in certain low-temperature facies, and also within the Malånäs area the lime seems to have had a fairly great mobility in the corresponding types of facies. There is thus the possibility that for instance the association chlorite—amphibole does not always represent complete amphibole facies, *viz.* in cases when the remaining calcite has been removed. On the other hand, the occurrence of a calcareous liquid phase naturally contributes to forming amphibole from chlorite beyond what the original lime content of the rock would have allowed, and thus the original variations in the lime-iron-magnesia proportions within the rocks might be adjusted. It seems undeniable that such an adjusting interchange actually does occur, but its being of a fairly local significance, on the other hand, is carried out by the fact that mineral associations are actually found that are absolutely dependent upon the original chemical composition.

Another detail deserving a certain amount of attention in connection with the discussion of the regional metamorphic processes within the greenstone series, is the manner in which titanium occurs in different grades. A number of polished sections were made from greenstone types from areas of different metamorphic grades, in order to examine the opaque oxides. In all cases ilmenite alone was found, while magnetite was never encountered. According to the general experience from other areas examined with a view to studying the regional metamorphism, the ilmenite would appear to be stable mainly

in facies conditions corresponding to amphibolite facies or even higher grade. If this were true in a general way, ilmenite should thus here be looked upon as unstable relics from the volcanic epoch, about in the same manner as the anorthite in the basic plagioclases in certain types of chlorite facies. As and when titanite or leucoxene can be established, it is quantitatively always far inferior to the ilmenite, and the formation of titanite from ilmenite has thus generally hardly even begun here during the course of metamorphism. It is remarkable, however, that the sample representing the highest grade of metamorphism has the highest titanite content (1—1.5 %), but on the other hand no signs of oxides. The excess of CaO occurring here may possibly have had decisive importance.

2. Metamorphism in the Quartzporphyry Series.

In the acid volcanic rocks it is often more difficult to deduce directly the grade of metamorphism from the mineralogical composition. The only really evident change in the mineralogy that can be established in increasing metamorphism is the formation of biotite from chlorite. In analogy with the conditions in the greenstone series, where two divisions can be discerned, one where amphibole never occurs, and one where calcite and chlorite never appear together, we find that in the salic rocks there is one area where biotite is never found and one where original chlorite is entirely lacking. The isograde for an initial formation of biotite can thus easily be drawn also on the map. It is more difficult to form an opinion, based directly upon the mineralogical composition, of the relative grade of metamorphism in different areas on the high-grade side of the biotite isograde. In some cases chlorite as well as biotite occur in the same specimen, the mutual proportions of these minerals being a measure of the extent to which the change chlorite → biotite has been realized. These conditions are similar to those in the greenstone series where a transitional zone is found where the reaction chlorite + calcite → hornblende has been completed in part only. Very often, however, rocks occur in the same areas, in which all iron and magnesia is bound in biotite, and which thus — if the ratio biotite: chlorite only is used — do not differ in their metamorphic grade from types in areas where primary chlorite is never found. The occurrence of incomplete biotite formation in rocks where chlorite is partly preserved, alternating with the chlorite-free, biotite rocks shows, however, that the area as a whole must represent a transitional type between high-grade and low-grade metamorphism. In the whole area, comprising Malånäsudden itself, the district around the Bjurfors ores and immediately south of them, the district between Bjurfors and Ö. Högkulla, immediately north of Ö. Högkulla, and Skäggträskberget, we find examples of a medium-grade metamorphism in that meaning. Completely biotite-free rocks are for instance found also on the high-grade side of the isograde for initial biotite formation, carrying the components necessary for the formation of biotite in the form of chlorite and sericite or microcline. On the other hand, No. 9 is an example

of a locality quite near this isograde, representing a fairly high-grade metamorphism. The distribution of the outcrops in the area does not permit a very thorough examination of the proportions between more or less biotite-metamorphosed types. In this case the zone must be considered as a unit, and as a whole it should be placed in relation to areas north and south of it.

In the transitional zone between complete biotite and complete chlorite facies we often also find beautiful primary textures, i. e. the recrystallization has often been rather incomplete. It is unfortunately not possible to make a classification of the grades on the basis of the grain-sizes, the original variations in the sizes also in such rocks as the quartzporphyries being so great that they sometimes exceed the variations caused by the difference in recrystallization. We receive a general impression that also the recrystallization in the area as a whole is not at all so complete here as in the exposed areas immediately towards the south, even though this dissimilarity cannot be illustrated in figures.

In low-grade metamorphism, however, still another mineral must be considered, apparently of a certain importance for this very zone, i. e. sericite. The importance of sericite in the regional metamorphic parageneses has not yet been touched upon, it often being difficult to decide to what extent the mineral should be referred to the associations created in connection with the regional metamorphic processes. In the southern part of the Malånäs area, for instance in the district around the Bjurträsk and Bjurliden ores, the development of sericite and muscovite is always connected with the introduction of sulphides and must thus be referred to an epoch separated from the true regional metamorphism. Here the sericitization also has a decidedly local character, i. e. is localized to certain belts or zones into which the mineralizing solutions have penetrated.

The conditions are different in lower grade metamorphism. There the sericitization is of a perfectly regional character, and an area can be pretty well delimited where the acid rocks are practically always fairly rich in sericite. In order to give a summary of the mutual proportions between the mica minerals, the ratio chlorite : biotite : sericite has been plotted in a triangle diagram, fig. 7. As far as possible such samples have then been taken as may be considered to be regionally representative of the respective rocks in the area, and types from the distinctly mineralized belts have been avoided. In a couple of instances, however, they have been included, but then they appear in brackets. The side of the triangle chlorite—sericite thus denotes rocks belonging to complete chlorite facies, the side biotite—sericite denotes complete biotite facies, and all dots between them denote incomplete biotite facies, at least in the degree that potash occurs.

As will be seen the rocks from the areas within complete chlorite facies are generally quite considerably sericitized; only a couple of specimens rather far from the biotite isograde approach the very chlorite corner. The projection points of the rocks from the zone nearest south of the isograde for initial biotite formation represent either incomplete biotite facies or fall on the biotite—

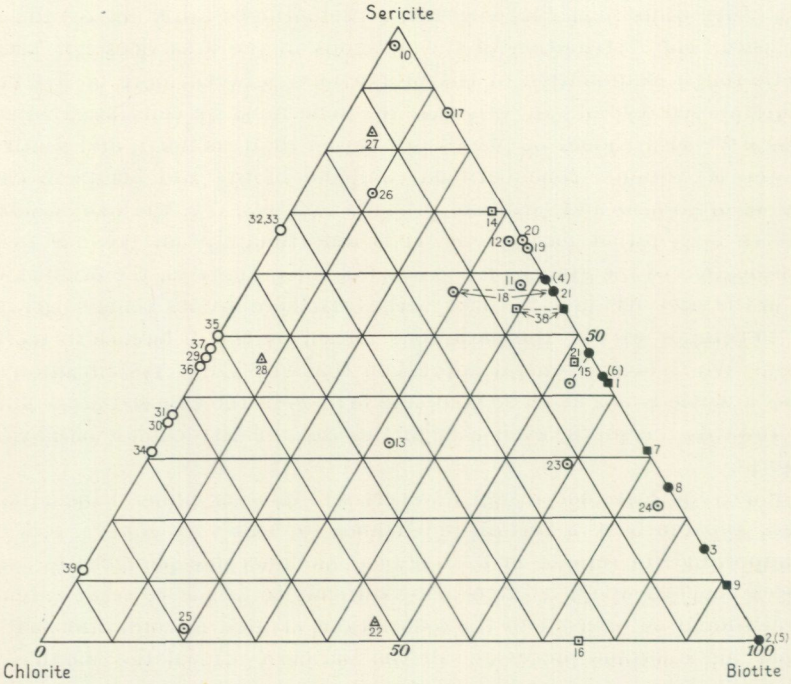


Fig. 7. Diagram illustrating the proportions of chlorite — sericite — biotite in rocks of quartzporphyry composition. Filled signs = complete biotite facies; open signs = complete chlorite facies, signs with a dot = transitional zone. The figures are the same as in fig. 6 B.

sericite side, rather far up towards the sericite corner. No. 9 is the only exception among the examples selected where the dot comes near the biotite corner. The great majority of dots, however, will be seen to fall even above 50 % sericite, while the corresponding projection points for the chlorite facies mainly fall immediately below 50 % sericite. The rocks still farther south, belonging to a still higher grade of biotite facies, show a distinct tendency to gather towards the biotite corner of the triangle.

According as the sericite may be presumed to have been formed in connection with the regional metamorphism, three metamorphic zones can thus be distinguished, which according to their mineralogical characteristics may be called the chlorite-sericite facies, the sericite-biotite facies, and the biotite facies (see fig. 6 B). In the middle one there are also types corresponding to biotite-chlorite facies or incomplete biotite facies. These names need not here be assumed to represent equilibria to the same extent as otherwise demanded when defining a certain facies association. The sericitization itself, whether from felspar or chlorite, as is evidently often the case, must definitely be accompanied by a certain transposition of material, so that in other words the chemical composition of the rock will be more or less changed during the course of metamorphism. The problems connected with the sericitization will be further discussed in connection with the treatment of the ores accompanying the mineralization (Chapter VII, E).

A small quantity of garnet occurs in samples Nos. 1 and 7, formed from biotite, judging by the microscopic observations. The localities where the observations were made do not allow a real mapping of the garnet isograde analogous with the construction of the biotite isograde, for instance, but it must suffice to establish the tendency towards the formation of a higher-grade association a certain distance from the isograde for complete biotite formation.

3. Summary.

The general tendency in the area indicates an increasing grade of metamorphism from north to south, and the lines that connect points with the same grade of metamorphism, the isogrades, will chiefly run WNW—ESE. The sketch-map of the regional metamorphism (figs. 6 A and B) is based on the extent to which certain mineralogical reactions have been realized, i. e. the change chlorite (+ sericite or microcline) → biotite in the rocks of quartzporphyry composition, and the change chlorite + calcite or epidote → hornblende in the greenstones. Isogrades have been drawn for points where these reactions first became noticeable and also for points where the change first becomes complete.

In cases when the points of observation are very sparse, the isogrades were drawn in such a manner for one of these mineral reactions, that they became as far as possible parallel to the isogrades for the other reaction. In order thus to be able to draw out the isograde for an initial biotite formation towards the east (towards point 39 in fig. 6 B), it is also necessary to make use of the courses of the isogrades within the corresponding area in fig. 6 A, where points 19, 20, 22, 24, and 26, supply better holds for the construction.

The maps show, however, that the middle zones, i. e. the areas for incomplete biotite formation and for incomplete hornblende formation, very often coincide. The transitional zone is considerably broader in the biotite-chlorite system than in the lime-hornblende system, and this is mainly demonstrated by the fact that the isograde for complete biotite formation is often somewhat farther south than the isograde for complete hornblende formation. It should be remembered, however, that this limit in the biotite-chlorite system is the one most difficult definitely to determine.

The isogrades for the initial hornblende formation and for the initial biotite formation, on the other hand, seem to coincide pretty closely, and here the differences are in many cases no greater than that they at least to a considerable extent might depend upon the different distribution of the points of observation in the two cases. The biotite in the hornblende-bearing greenstones always being found to be formed earlier than the hornblende, it might be expected that the biotite isograde would be slightly displaced northwards as compared with the hornblende isograde. On the other hand, it seems as if biotite began to occur in the tuffs richer in chlorite before signs of it are found in the rocks poorer in chlorite. This latter circumstance in itself indicates that also other factors but pressure and temperature may be of import-

ance for the mineralogical development. It has been stated that stress may have a certain influence on the formation of certain mineral parageneses (cf. Harker (*33*, p. 147)), and in these cases Eskola (*20*) considers stress mainly as a catalytic factor. An interpretation in that direction seems rather plausible in this case, as in the lowest metamorphic grades the mechanical deformation is very much more intense in rocks rich in chlorite than in those poor in chlorite. Such an interpretation might also be applied in a few cases where insignificant quantities of biotite have been observed in graphite-phyllite, completely outside the isograde for initial biotite formation.

It would appear clear from the above, however, that generally speaking the area can be divided into three main parts with reference to the regional metamorphism. The metamorphism in the southernmost area corresponds to the amphibolite facies according to Eskola's terminology, and probably also partly to the epidote-amphibolite facies. The occurrence of garnet formed from biotite in the southernmost parts of the quartzporphyry rocks furthermore indicates an increased grade towards the south, as well as the development of the association pyroxene—hornblende—microcline—(calcite) in greenstone in about the same metamorphic position. As already pointed out, this latter association indicates that when there is an excess of K_2O and CaO, a classification might be made into a high-grade association pyroxene—hornblende—microcline, and a low-grade one, i. e. biotite—calcite—hornblende. For the high-grade association the main deviation from the normal hornblende formation in the area would be that in this case also biotite had reacted with calcite, forming hornblende (or pyroxene).

In the northernmost part the associations mainly correspond to green schist facies according to Eskola's terminology. The middle zone, finally, which corresponds to the transition from green schist facies to amphibolite facies, is characterized by mineral parageneses indicating that the reactions used for the metamorphic map work have not been completed. What is characteristic for this zone is thus not the occurrence of certain mineral associations typical of a certain mineral facies, but instead the mixture of several types of facies.

The mentioned sporadic occurrence of plagioclase rich in An in areas characterized by low-grade metamorphism indicates that the metamorphism did not suffice to obliterate the non-equilibria in the lower grades, created during the volcanic period.

The occurrence of such a lack of equilibrium of course means certain deviations from the usual applications of the facies principles, which deviations are caused by differences in the conditions under which the different mineral parageneses were created. In the descriptions presented by Eskola and Vogt, the mineralogical development has been followed either in intrusive rocks or in sedimentary rocks. In neither case have mineral associations of such a character ever occurred as those found in the low-grade volcanites of this area. This difference in the primary conditions introduces a new factor which of course may be of great importance in certain cases for the associations

formed, and this is the different adaptability of different minerals to the metamorphic forces. Thus the minerals anorthite—epidote—calcite seem to form a series with an increasing power of reaction for CaO, or a series indicating a decreasing stability during the metamorphism. Ilmenite is another mineral that seems to possess considerable stability, judging by the experiences from this area. This is borne out by the fact that it is but in very few cases that any reasonable amount of titanite or leucoxen has been observed.

One problem now remaining to be dealt with is the connection between thermic metamorphism and granite intrusions. A recrystallization of minerals not partaking in the reactions runs parallel to the formation of new stable mineral associations. Little by little this recrystallization will obliterate the original textures and will produce in the rocks a general granular texture bringing to mind the Bergslagen leptites. In Bergslagen the recrystallization that gives rise to the leptite texture is considered to have initiated in a relatively early stage of the evolution, about contemporaneously with the advance of the older granites. Though this recrystallization is generally of a regional character, it is often intensified towards the contacts of these granites (see for inst. Geijer (*29*, p. 29) and Magnusson (*58*, p. 341)). The supercrustal rocks of the Malånäs area are now limited by granites some of which belong to an old group comparable with the oldest granites of Bergslagen, i. e. the large Jörn granite massive to the north-east, and some to younger granites corresponding to the Bergslagen Fellingsbro-Stockholm granites, forming large areas in the south. A look at the map discloses that here the thermic influence of the older granite has had no importance whatever for the regional metamorphism, and here the leptite-like texture has thus no connection with the emergence of the Jörn granite. The isotherms for the regional metamorphism quickly fall towards this massive. Certainly the contact areas towards the Jörn granite have not been thoroughly studied, but judging from isolated specimens its contact metamorphism is of a fairly local character, at least along the southern limit. A sample taken quite close to the contact (at Lillåberget) shows a fairly high biotite content, while samples 37 and 40, also quite close to the contact of the older granite show no signs whatever of biotite formation.

The isograde instead display a rather conspicuous conformity with the intrusives belonging to the younger granite generation, but also with the general course of the layers. If the experiences from this area alone were taken into consideration it would seem most natural to try to interpret the metamorphism as a contact metamorphism to the younger granites. According to A. Högbom these granites are often intimately connected with palingene phenomena, which increase greatly towards the south. In accordance with the "palingene" hypothesis on the formation and occurrence of these granites, the problem might just as well be expressed in such a manner that the occurrence of the granites is a result of the increase in the metamorphism towards the south. The regional metamorphism should thus be looked upon as an event in the general orogenesis and the approach of the isotherms as an indi-

cation of a displacement of the location deeper and farther into the geosyncline.

Such a point of view of course does not imply a great deviation from the interpretation of the metamorphism as a contact metamorphism, on the understanding that the palingene interpretation for these granites is accepted, and the metamorphism is then not confined to the contacts of certain granite massives.

VII. Ore Deposits.

A. Introduction, Terminology.

As already mentioned a number of sulphide ores occur within the mapped area. The more solid ores consist of solid pyrite or pyrrhotite ore bodies containing more or less copper and zinc. The zinc ores also contain some lead, although generally in fairly insignificant quantities. In most cases the wall rock is considerably altered. In addition to the solid ore bodies there also occur disseminated belts of no economical importance, but due to the wide area they cover, they may contain quite substantial quantities of sulphides.

The altered rocks rich in quartz that are often found around ore deposits, have long been termed ore-quartzites in Sweden and Finland. A prefix has been used to denote the mineral characteristic of the rock in question in addition to the quartz, e. g. cordierite-quartzite, sericite-quartzite, etc. In English literature there appears to be a tendency to give the term quartzite a genetic interpretation, making it cover rocks of only sedimentary origin. Lindgren (*53*, p. 745), however, used the term when reporting on Geijer's description of Riddarhyttan, and also in summaries of Russian literature (*62*) the term quartzite is used for metasomatically altered rocks. However, rocks which seem exactly to correspond to the ore-quartzites are usually called either schists, for instance sericite-schist, or we find the expressions sericitized rock, chloritized rock, silicified rock. The Swedish and Finnish conception of the term ore-quartzite covers these expressions. The characteristic feature in the development of the ore-quartzites is the destruction of the felspar of the original rock, and not the addition of certain definite elements or minerals. The increase in the quartz content of such rocks may be the result of an introduction of silica, though this need not be the case, and the unmistakable result of the alteration is still found to be the destruction of the felspar.

A classification of the rocks according to these principles was also made the basis of the mapping of the altered rocks, when the zone free from original felspar, the quartzite zone, was first denoted. Within this zone it was then possible to further classify the rocks according to their mineralogical or structural characteristics.

On account of the principles followed in the mapping work, it has proved most practical in this paper to use the term quartzite also for the altered rocks. In any case it is impossible to use the expression schist throughout, as some

altered rocks, e. g. at the Bjurfors ores, are absolutely massive, and it may also be questioned if this term can be used for chlorite-bearing rocks rich in quartz, without running the risk of misunderstandings. A detailed account of the mineralogical and textural characteristics of the different types of quartzite is given in the descriptions of the various ore deposits.

B. Mineralogy.

1. Gangue and Wall-Rock Minerals.

Garnet is fairly common in mineralized areas with high-grade alterations. It occurs mainly in chlorite-quartzite and chlorite -rocks, sometimes as idiomorphic crystals, but more commonly forming irregular spots or aggregates,frequently associated with minerals rich in lime. In the former case the individual crystals may, even under the microscope, seem comparatively homogeneous and free from inclusions. In most cases, however, garnet has been developed as poikiloblasts containing numerous inclusions of other minerals, mainly quartz. The garnet of the lime-free parageneses is normally bright red and seems to be an ordinary almandite. The garnets associated with lime-minerals are generally of a lighter colour and have a yellow-red shade.

In order to gain an idea of the type of garnet occurring in different associations, the specific gravity and the dimensions of the unit-cell have been determined for some different types. As chromium and manganese can no doubt be disregarded in this connection, the data mentioned give an idea of the approximate chemical composition. The data below refer to one garnet from a chlorite-quartzite at the Bjurträsk ores and to one from an altered quartz-porphyry at Bjurliden, intensely enriched with lime-silicates.

	Unit cell a_0	Sp. gravity
The Bjurträsk ores	11.56 ± 0.03	4.16 ± 0.02
Bjurliden	11.60 ± 0.03	3.84 ± 0.03

According to common combinations of the chemical properties of different garnets (*84*, p. 175), there exist continuous gradations between pure pyrope and pure almandite, on the one hand, and between pure grossularite and andradite on the other. In other words, Mg^{++} and Fe^{++}, on the one hand, Al^{+++} and Fe^{+++} on the other, may substitute each other entirely. Ca^{++} and $(Fe, Mg)^{++}$, however, can substitute each other only to a certain extent. According to Winchell each end-member can take up about 25 % of the other. C. H. Stockwell (*78*) has published a couple of diagrams showing the relations of the chemical composition of garnets to refractivity, specific gravity, and cell dimension. According to these diagrams the garnet from the Bjurträsk ores is an almandite, in which Ca^{++} replaces $(Fe, Mg)^{++}$ to about 10 %—15 %. According to the values mentioned the ratio Fe : Mg would be about 10 : 1. The values of a_0 indicate that also the garnet from Bjurliden belongs to the almandite-pyrope

series, as lime-garnets would require a considerably higher value. In the diagrams the data obtained correspond to a garnet in which Ca^{++} substitutes $(Fe, Mg)^{++}$, as far as the structure permits, i. e. to 20 or 25 %. The ratios Fe : Mg are about 1 : 1.

Gahnite. Spinel is found at the Bjurträsk ores and Bjurliden. In the former locality it usually occurs as irregular spots without any megascopical development of idiomorphic crystals. At Bjurliden, on the other hand, the mineral forms regular octahedrons, ranging in size from minute individuals to grains 3 or 4 mm in diameter. In thin section the colour is pale green to bright green. Numerous inclusions, mainly of quartz, are often seen, and may sometimes be so numerous that they entirely obliterate the outlines of the crystals.

The chemical composition of the spinel from Bjurliden is seen from the following analysis:

Analysis N:o 10.

Analyst: G. Assarsson.

	Weight-%	Mol.-%
Al_2O_3	55.71	51.72
Fe_2O_3	7.78	4.62
FeO	1.18	1.56
CaO	0.00	0.00
MgO	0.98	2.31
MnO	0.05	0.07
ZnO	33.95	39.72
SiO_2	0.26	—
Insoluble in $K_2S_2O_7$	0.32	—
	100.23	100.00

As will be seen from the analysis, the spinel is a gahnite. The slight percentage of SiO_2 in all probability consists of quartz, which occurs as minute inclusions and which thus cannot be completely separated. It can further be seen that the sum of the trivalent elements (in mol.-%) considerably exceeds the sum of the bivalent elements. Researches in the spinel-group, however, have shown that the form γ-Al_2O_3 can to a certain extent form solid solutions with $FeO : Al_2O_3$. According to Hägg and Söderholm (37) the solid solution may contain up to 67 mol.-% Al_2O_3, and thus the above-mentioned proportions are by no means remarkable.

Staurolite. Megascopically, staurolite has only been observed at Bjurliden, where it occurs in coarse quartzites, forming small brown spots. In thin section the mineral shows a distinct pleochroism:

γ bright yellow, α and β yellow-white.

The staurolite is generally found to contain very numerous inclusions. In such cases the idiomorphic form of the individuals cannot be clearly distinguished. In other cases, however, staurolite occurs as well-defined short prisms with a distinct (010)-cleavage and a vaguer cleavage parallel to (001).

Cordierite. True cordierite has been found only at the Bjurträsk ores. It is observed as porphyroblasts in chlorite-quartzites and also occurs in true cordierite-quartzites of the same type as in Bergslagen. These rocks play a very unimportant part, however. In the gedrite-bearing types the mean refraction of the cordierite is lower than the refraction of the quartz. The cordierites of the chlorite-quartzites show a weak pleochroism from a colourless to a faint yellow tint. The mean refraction is, in the main, higher than that of quartz. The mineral always forms porphyroblasts crowded with inclusions of quartz. The cordierites are, as a rule, relatively fresh and secondary alterations are of subordinate importance.

Andalusite occurs in chlorite-rocks and chlorite-quartzites at the Bjurträsk ores and Bjurliden. As a comparatively rare development it appears in pale red, idiomorphic prisms, 2 or 3 cm long, their vertical section being up to 1 cm^2. More commonly, however, the mineral forms irregular white spots in the green chlorite-quartzite groundmass. In thin section these spots are found to consist of andalusite individuals, enclosing large amounts of small rounded quartz grains. Occasionally the quartzcontent may exceed 50 % of the whole quartz-andalusite mass. The pale red andalusites, forming megascopically well-defined crystals, are also in thin section much more homogeneous than those occurring as irregular spots.

Chloritoid is found in small amounts in chlorite-quartzites and chlorite-rocks at the Bjurträsk ores and Ö. Högkulla. At the former locality the mineral forms bundles, about 1 mm thick, composed of thin plates, 1 × 10 mm. Megascopically, the chloritoid thus appears as black needles in a groundmass rich in chlorite (Pl. 23, a).

Pleochroism in thin section is very distinct: *α faint olive-green, β blue, γ faint green-yellow—colourless.* The normal to (001) makes an angle of 22° to γ, $2V_\gamma$ = = 57°—58°. Distinct (001)-cleavage is visible and has about the same development as the (110)-cleavage of the amphiboles. Twinning, parallel to (001) occasionally of a polysynthetic character, has been observed in several crystals.

Chlorite is one of the most abundant minerals formed during the sulphide mineralization of the country rocks. In most cases the chloriteminerals occur in so minute individuals that no exact optical determinations are possible. In the fine-grained aggregates, however, there are often found recrystallized areas, where chlorite of the same type as the surrounding fine-flaky generation has been developed as large flakes. Colour and pleochroism vary with the iron content of the mineral. The members richest in iron display a comparatively distinct pleochroism, the colour ranging from bright green to pale yellow-green. The types poorest in iron only display a faintly yellow-greenish tint. The substitution of the elements as well as the relation between optic properties and the chemical composition, are not sufficiently known to permit a determination of the exact composition on the basis of the optical properties. The main types of chlorites, however, may be determined when certain optical

data are known. Thus Winchell (*85*) has presented a diagram in which the chemical composition is brought into relation to refraction and birefringence On the basis of this diagram he has worked out a classification of the chlorite minerals. In Winchell's diagram the refraction and birefringence of chlorites

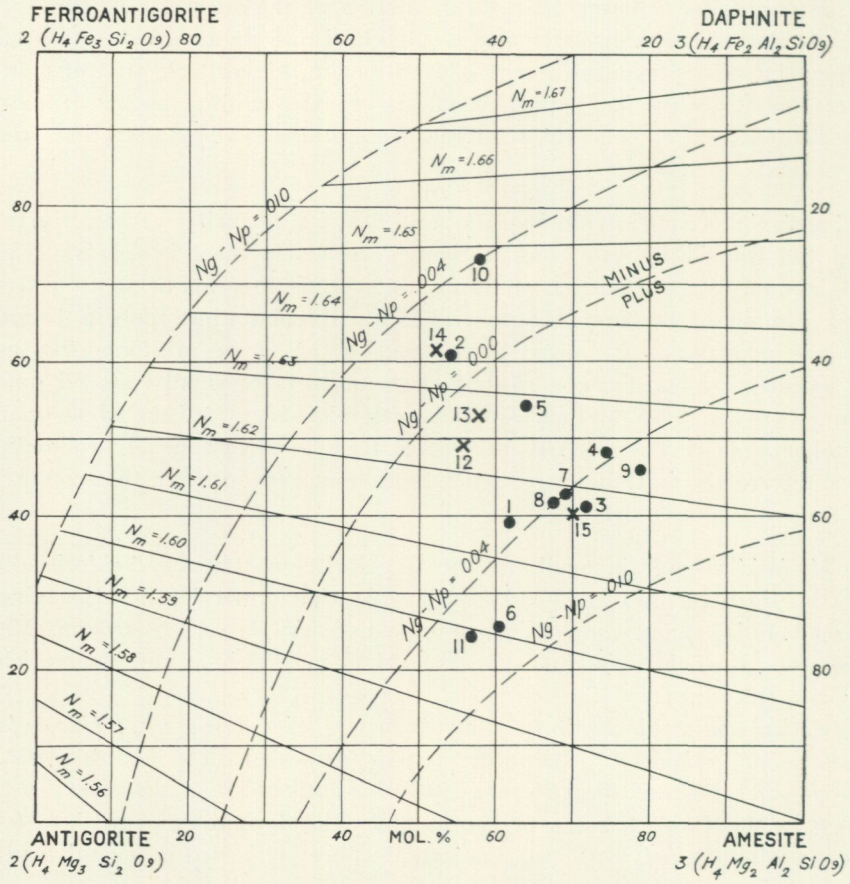


Fig. 8. Chlorites of the area plotted on Winchell's diagram. Filled circles = chlorites formed in the sulphide mineralization. Crosses = chlorites in greenstones (See Table 3).

from different places of the investigated area have been plotted (fig. 8). Though the dots in the diagram certainly do not always indicate the exact composition of the various types, the diagram does give a general survey of the chlorite types present. The distribution of the dots indicates a differentiation in members poor and rich in iron. Four types of chlorites from rocks belonging to the greenstoneseries have also been plotted, and show that there is no general difference in type between these latter and the chlorites of the sulphide mineralization. The variation in the composition of the secondary chlorites seems to be entirely independent of ore- and alteration types and also of the zoning around the ores and will consequently be of little importance in the discussion of the alterations.

Table 3.

Chlorites of the mapped area, plotted in fig. 8.

	Rock	Locality	Highest colour	Faintest colour
No 1.	Veined chlorite-quartzite . .	The Bjurträsk ores	Faint white-green	Yellow-white
2.	Chlorite-rock with plagioclase	»	Light grass-green	» »
3.	Chlorite-rock with plagioclase	»	Bright blue-green	» »
4.	Chlorite-quartzite with biotite bands	»	Light grass-green	» »
5.	Chlorite-quartzite with andalusite	Bjurliden	Light grass-green	» »
6.	Chlorite-rock with amphibole .	E. Bjurfors ore	Faint white-green	» »
7.	Chlorite-rock with plagioclase	»	Bright blue-green	» »
8.	Chlorite-quartzite	»	Faint white-green	» »
9.	Pyrite ore	»	Bluish green	» »
10.	Chlorite-rock with garnet . .	Ö. Högkulla	Bright grass-green	» »
11.	Chlorite-quartzite	Skäggträskberget	Yellow-white	» »
12.	Amphibolite	800 m N of the Bjurträsk ores	Bright blue-green	» »
13.	Amphibolite	S. of Norrliden	Light grass-green	» »
14.	Chlorite-greenstone with calcite	E. of Kotjärn	Faint white-green	» »
15.	Calcareous chlorite-rich tuff .	E. of Sandfors	Bright blue-green	» »

Biotite. In several cases, when biotite is found in the mineral assemblages formed in connection with the ore-formation, it is a remainder from an earlier mineralization stage, and has been formed contemporaneously with the generation occurring e. g. in normal quartzporphyries. In some cases, however, the mineral must in all probability belong to the sulphide mineralization stage, and is then both megascopically and microscopically of the same character as in the former case. The highest colour of biotite in thin section is dark brown and when forming large, uniform flakes, it has generally been developed as poikiloblasts enclosing more or less quartz (Pl. 13, b). In most cases numerous pleochroic haloes are found in these biotites, often arranged along the older planes of bedding or schistosity of the rock. In some cases, especially in the alteration parageneses rich in lime, the colour of the biotite is considerably paler than in the common types. The highest colour in an ordinary thin section is yellow-brown.

Colourless mica. More or less sericite is found in all areas where the mineralizing agents have been active. It usually occurs as fine-grained fibrous aggregates, but in several cases as well-defined large flakes. The larger crystals as well as the determinable individuals of the fine-grained aggregates are found to have values of 2 V_γ in agreement with those for common muscovite. In the specimens examined, 2 V_γ ranges from 38° to 42°. Some muscovite flakes, which replace biotite crystals, obviously contain a certain amount of iron, displaying as they do a very slight yellow tint in the highest coloured orientation. In these types 2 V_γ ranges from 36.5° to 38°.

In mineral assemblages rich in lime a colourless mica occasionally occurs, which seems to have a somewhat higher birefringence than common muscovite. As the optical angle is practically 0°, the mineral is in all probability *phlogopite*.

Plagioclase may be a constituent both of the altered rocks and of the ores themselves. It is, however, often difficult to decide whether plagioclase crystals were entirely formed in connection with the ore formation or if they may be looked upon as more or less changed relics of the pre-existent rock. In the main, it is possible to distinguish two different modes of occurrence in the alteration associations. Firstly, plagioclase forms extremely fine-grained, irregular aggregates, often intimately mixed up with quartz. Between crossed nicols the aggregates show an extremely irregular, flamy extinction. The very small size of the individual grains generally makes it impossible to determine the composition of the felspar by usual methods. Twinning and cleavage are generally absent and when they can be observed, they are often too indistinct to permit any exact optical determinations. It can be seen from the approximate estimation of the refraction, however, that this plagioclase is in the main very rich in anorthite, and even a cursory survey discloses considerable variations in composition also in the same thin section. Consequently exact determinations on individual grains are of little value, unless they are carried out on a very large scale. Determinations on those sparse grains where twinning or cleavage faces are well developed disclose the anorthite percentage in the main to range from 60 % to 90 %. In rare cases plagioclase of the same development has been found with an anorthite content of but 45 % An. A fine striation may comparatively often be observed in the anorthite-rich members of greater plagioclase crystals in the fine-grained mineral assemblage. Between crossed nicols a system of exceedingly thin twinning-lamellae parallel to the striation may be seen. Examinations of the striation in the U-stage prove that the lamellae are due to Pericline twinning, united according to the "rhombic section", and the striation visible between parallel nicols thus shows the composition faces.

In the altered assemblages plagioclase is also found in another development as large individual grains, also here often crowded with poikilitic inclusions. It is true that between this mode of occurrence and the fine-grained masses there exist continuous gradations, but generally they are easily told apart by microscopic examination. The inclusions of quartz are sometimes very numerous, sometimes they are entirely absent. In the quartzose rock-types inclusions are generally present, perfectly homogeneous crystals being extremely rare. When plagioclase forms porphyroblasts in pure chlorite-rocks, it occurs mainly as regular plates, flattened parallel to M, and the distribution of the quartz inclusions seems to be dependent on the quartz content of the surrounding groundmass. In chlorite-rocks, entirely free from quartz, also the plagioclase porphyroblasts, in fact, are absolutely homogeneous. Porphyroblasts in a quartz-bearing chlorite mass, on the other hand, always include about the same amount of quartz as does the groundmass. Polysynthetic twinning

is entirely absent in the pure chlorite-rocks and has been observed only in a single specimen of the plagioclase-bearing quartzose rocks. The composition of the plagioclase in the former type generally ranges from $Ab_{77}An_{23}$ to $Ab_{65}An_{35}$. In several cases the zoning is very pronounced, with an alternation between zones rich and poor in anorthite. The variation in the composition even of the same crystal may be quite considerable. The following determination for plagioclase from a felspathized chlorite-rock at the Bjurträsk ores exemplifies these variations:

Centre	32 % An
Middle zone	24 % An
Outer zone	29 % An

The poikiloblasts in the quartzose types of the altered rocks may be somewhat richer in anorthite, ranging to 60 % An. The same kind of zoning is observed in these types as that described above.

As has already been mentioned, polysynthetic twinning is absent in the types of plagioclase now referred to. On the other hand the outlines of the individual grains are extremely irregular and the diverse crystals often penetrate each other. Examinations in universal stage disclose that the adjacent individuals are sometimes in twinning orientation to each other. Pl. 15 a shows an example of such penetration-twins. When the twin-axis is plotted in a stereographic projection it lies on the Carlsbad-Albite curve and shows the composition $Ab_{55}An_{45}$. As will be seen in the figure, the shape of the composition-planes is very irregular and the planes do not strictly coincide with any crystal face.

In fig. 9 another twin is illustrated in which three different individuals penetrate each other. By an examination in universal stage and by plotting the orientation of α, β, and γ on a stereographic projection, the following twinning relation is found to exist between the individuals:

Individuals	*Twin-axis*	*Twinning law*	% *An as found from the curves*
1 : 2	⊥ (010)	*Albite*	57
1 : 3	[001]	*Carlsbad*	55
2 : 3	⊥ $\frac{[001]}{(010)}$	*Albite-Carlsbad*	58

The plagioclase has comparatively often been subjected to slight alterations, the introduced minerals being chiefly sericite and zoisite, in rare cases prehnite. In a few cases albitization has been observed, which may in places give rise to the occurrence of fairly pure albite in chlorite-rocks.

Amphiboles. Ordinary green hornblende is the most common member of the amphibole group though in all probability it often has a tendency towards actinolitic composition. In the diagram (fig. 5) the amphiboles more or less closely related to the sulphide mineralization have also been plotted. With

but one exception they seem to fit fairly well into the series of the greenstone amphiboles, being the members poor in iron in this series. The values of 2 V_a, however, seem to be comparatively small in relation to the values of refraction.

The members rich in iron appear megascopically as black needles in chlorite-quartzites or chlorite-rocks, which, owing to successive enrichment in the

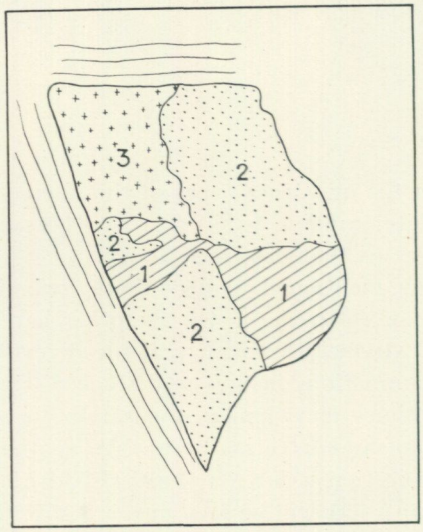


Fig. 9. Penetration-twins in plagioclase.

amphiboles, may grade into pure "skarn". The origin of amphiboles in close relation to quartz veins has also been observed. Megascopically the needles are either pale green and probably of a tremolititic character, or black, actinolitic. In thin section the highly coloured amphiboles, too, have a distinct needle-shaped habit. The colourless or slightly coloured types in the main consist of grains with irregular outlines and form fibrous masses.

The lime-free amphiboles, cummingtonite and gedrite, are found partly in the cordierite-rich quartzites, partly as alteration products of green hornblende in the greenstones. Quantitatively, however, they are of very little importance.

Epidote group. Owing to the alteration of plagioclase, epidote, clinozoizite, and zoizite are comparatively common. Generally, however, the minerals occur as fine-grained crystal aggregates, making exact optical determinations impossible in these cases. Only when associated with quartzites or chlorite-rocks, very rich in lime, is epidote found as large individual prisms.

Talc is found only at the Bjurträsk ores, where it occurs as a kind of groundmass in the hornblende "skarn" and forms fibrous, fine-grained aggregates. Detailed optical investigations cannot be made because of the small size of the individuals.

Orthite. In chlorite-rocks from the Bjurfors ores a mineral has been observed, which, according to the optical properties, is probably orthite or alteration products of orthite[1] (Pl. 15, b). The mineral forms minute prisms in the chlorite mass. The vertical section of the prisms is practically rhombic, the acute angle between the sides of the prisms being about 64°. The mineral is heterogeneous and shows distinct zoning. The centre consists of a pale yellow-brown mineral, with weak birefringence and large optic angle, character negative. The development of the mineral does not permit determinations in the universal stage. The next zone is highly brown, isotropic, and is in its turn surrounded by a thin marginal zone of a colourless mineral, displaying the optic properties of zoizite. Distinct pleocroic haloes are always found round the prisms. It would appear most probable that the two inner zones are different alteration-phases of orthite, while the marginal zone is true zoizite. Zoning of the same type has previously been described and illustrated, e. g. in the text-book of Rosenbusch-Wülfing (*66*, Table XXII, fig. 2).

Tourmaline is found at the Bjurträsk ores and at Bjurliden. In some localities it is megascopically visible, forming minute black needles in sericite-quartzite. In thin section the greatest amounts of tourmaline are found in a felspathized chlorite-rock from the Bjurträsk ores. Pleochroism is distinct:

ω *green-brown,* ε *pale yellow.*

Carbonates. The carbonates introduced together with the sulphides mainly consist of calcite. The contents of iron and magnesium are generally of subordinate importance. A pale yellow type was found to contain only 10 % FeO + MgO. Calcite may occur in the quartzose altered rocks as well as in ores, and occurs alone or together with quartz in the veins. As CaO in calcite at high temperatures reacts on the oxides of Fe, Mg and Al, amphibole being formed, the mineral-assemblages rich in calcite are found mainly amongst low-grade metamorphic associations.

Pale violet-blue *fluorite* was observed in one case in a quartz vein at Ö. Högkulla.

2. Ore Minerals.

Pyrite is one of the most common minerals among the sulphides. The pyrite crystals have a strong tendency towards idiomorphic development and very often attain a very distinct cubic habit. The original outlines of the crystals may, however, often be obliterated, mainly in consequence of corrosion or crushing. Large idiomorphic crystals are thus found to grade into aggregates

[1] The appearance of the mineral would seem to resemble that of the mineral that Goldschmidt (*75*, p. 416) calls epidote-orthite. However, as it is impossible to establish the optical data that, according to Goldschmidt, distinguish epidote-orthite from true orthite, and in view of the fact that the ordinary text-books do not differ between the two, the term orthite will here be used throughout to denote this type of mineral.

of small irregular-shaped fragments, owing to mechanic deformation. In the sequence of sulphides pyrite is one of the earliest minerals. Due to the great crystallization power of pyrite, the idiomorphic outlines do not always furnish proof of its age in relation to the surrounding minerals, but the replacement and breccia textures generally make the sequence quite clear. Pyrrhotite, sphalerite, chalcopyrite, and galena extensively replace pyrite, the two last-mentioned minerals, however, displaying a considerably stronger power of corrosion. The replacement often follows cleavage faces and cracks in the pyrite crystals. Sometimes traces of selective zonal replacement are observed, the remainders indicating the original shape of the crystals (Pl. 16, a). In other cases more irregular skeleton-like crystals are formed (Pl. 16, b, and Pl. 17, a).

Occasionally very regular pyrite cubes occur in a granular mass of sphalerite, chalcopyrite or pyrrhotite, which are not at all or only very slightly corroded by the adjacent sulphides. In some cases at least certain facts seem to indicate that this pyrite has been recrystallized from an earlier generation of pyrite, partly resorbed and fractured. In Pl. 30 b the earlier generation is seen as large grains with very irregular outlines. These grains give the impression of running apart in the sphalerite mass, forming first a multitude of minute well-defined cubes, which at some distance from the original crystals grow in size until they form the above-mentioned generation of larger, well-defined cubes.

In polished sections the pyrite is found to have the properties that generally characterize this mineral as regards colour, reflection power, and hardness. It is an interesting fact, however, that distinct anisotropic effects may very often be found in the pyrite crystals. It may even be questioned whether on the whole there exists any perfectly isotropic pyrite in the investigated area, and if so the cases where the anisotropic effects cannot be observed are due to a specific orientation of the grains. However it may be, a certain classification can easily be established, the pyrites of the Zn-ores being considerably more anisotropic than the pyrites of the Cu-ores. The greatest anisotropic effects are found in the pyrite from the sulphide zone of Österbäcken. In this locality the pyrite is present in intergrowth with arsenopyrite. On rotating the mineral between crossed nicols, distinct colour variations are observed, from yellow-brown to pale blue, thus making the individual grains visible.

Anisotropic pyrite has been described previously, and in this connection it is of great interest to refer to an investigation by Schneiderhöhn concerning these facts (*71*). He has shown that anisotropic pyrites from Upper Silesia always hold a certain arsenic content. It would seem most probable that the anisotropic effects in the pyrites of the Malånäs District, too, are due to the percentage of arsenic, since the visible arsenopyrite is always found to be enriched in the Zn-ores as compared with the Cu-ores. The Österbäcken mineralization is one of the parageneses richest in arsenopyrite.

Pyrrhotite is, second to pyrite, the predominant mineral among the sulphides. In the solid ores it mainly forms allotrimorphic grains. In the wall rocks it is occasionally found as plates with distinct outlines, the plates attaining a dia-

meter of 2 or 3 mm without any regular arrangement in the rock. In the Western Bjurträsk ore the mineral is observed in cavities as drusy, beautiful, hexagonal plates or bundles. As mentioned above, pyrrhotite replaces pyrite, but is itself replaced by chalcopyrite and galena with accompanying antimony minerals.

Pyrrhotite is relatively susceptible to mechanic deformation. In such cases irregular translation lamellae are first formed, having exactly the same appearance as the textures illustrated in the Schneiderhöhn-Ramdohr text-book (*72*, p. 135, fig. 60). Occasionally the lamellae may be broken, in which case the texture becomes very peculiar (Pl. 17, b). In a few specimens from Bjurliden thin lamellae have been found arranged parallel to (0001), a texture perfectly identical to the type shown in Schneiderhöhn-Ramdohr's text-book (*72*, p. 134, fig. 58). The development of this texture is explained as due to an immiscibility in the crystal. Whatever may be the cause, it is indubitable that in the present case the development of the texture is very closely connected with the mechanic deformation, as it is found only in specimens where the irregular translation lamellae are especially pronounced, and in several cases successive gradations between the two types of lamellae are observed.

Besides the formation of translation lamellae the deformation has another effect. Large individual grains are occasionally fractured and show a kind of undulatory extinction, recalling the traces of deformation in quartz. The intense crushing is in some cases followed by a complete recrystallization, which gives rise to entirely granular textures. Occasionally the recrystallization is accompanied by a very distinct uniform optic orientation of the individual grains over the whole polished section.

Sphalerite. With regard to its relations to adjacent minerals, sphalerite displays a distinct agreement with pyrrhotite. Mechanic deformation, however, does not affect this mineral as easily as pyrrhotite. In some cases deformation may cause a comparatively intense recrystallization.

Inclusions of chalcopyrite and pyrrhotite are generally found in the sphalerite crystals. Chalcopyrite in most cases forms minute rounded grains, pyrrhotite also occurs as well-defined staves or plates. These inclusions are in several cases arranged in lines, sometimes with irregular winding arrangement within the crystals or along the outlines of the separate crystals, sometimes with perfect orientation along the crystallographic directions of the sphalerite (Pl. 18, a). Such inclusions have been mentioned by several authors and Schneiderhöhn-Ramdohr's text-book (*72*, pp. 106—110) gives a general survey of the problem. There, however, it is chiefly the inclusions of chalcopyrite that are discussed. Attention is called to the fact that the lattices of sphalerite and chalcopyrite are much alike, this implying that mixed crystals may perhaps be stable between these components at higher temperatures. At lower temperatures these would probably unmix, and the blebs of chalcopyrite in sphalerite would in these cases be due to unmixing from a homogeneous phase. If this assumption is correct, it would be possible to use such inclusions as a geologic

thermometer. Experimental investigations carried out by Buerger (*6*) have shown that at higher temperatures sphalerite may to some extent take up chalcopyrite, and this chalcopyrite is unmixed as minute rounded grains at temperatures between 350° and 400°. Schneiderhöhn and Ramdohr, however, oppose the view that the texture in question should always be due to unmixing. They stress the fact that in several cases the chalcopyrite must undoubtedly have been introduced into the sphalerite, which is partly replaced. Synthetic experiments carried out by Schouten (*73*) show, too, that textures that are generally looked upon as due to some kind of unmixing, may often be formed by replacement. In the present investigation the above-mentioned textures in most cases seem to be due to an introduction of foreign substances into the sphalerite rather than to the unmixing of a homogeneous phase.

As regards the occurrence of the minute inclusions of pyrrhotite in sphalerite, the data concerning the crystal structure also in this case agree with the assumption that sphalerite may hold some pyrrhotite in solid solution. As the ionic radios of Fe^{++} and Zn^{++} are very much alike, these elements naturally substitute each other, at least to some extent, and it is a well-known fact that sphalerite generally has a certain iron content. However, microscopic results alone do not suffice to obtain reliable evidence as to the origin of the textures mentioned.

Chalcopyrite generally occurs as allotrimorphic grains. It replaces pyrite, sphalerite and pyrrhotite, but is itself corroded by galena. When abundant, the mineral is always associated with pyrrhotite. Twinning-lamellae are often found in the larger, single crystals and they frequently form several systems cutting across each other. When subjected to mechanic deformation the larger crystals are fractured and broken, the twinning lamellae disappear, and granular textures with equidimensional grains are formed.

Cubanite is only found in the Eastern Bjurfors ore, where it occurs as sharply defined lamellae in chalcopyrite. The predominant part consists of the modification called cubanite only by Schneiderhöhn and Ramdohr (*72*, pp. 360—367). In one polished section, however, the darker modification, cubanite II (*72*, p. 364), has been observed on the boundary between cubanite and chalcopyrite.

Valleriite very often occurs in the chalcopyrite, but always as exceedingly minute grains. It generally forms small worm-shaped individuals, in most cases clearly visible only when enlarged 500 times.

Bornite has been found only in two localities. In one case it appears in a quartz vein, closely associated with the mineralization of Skäggträskberget, forming grains visible to the naked eye and associated with chalcopyrite. In the other case it was observed in a polished section from Bjurliden as a minute grain associated with tetrahedrite.

Covellite has been found at one locality only (Önusberget), where it replaces chalcopyrite in a quartz vein. It is very probably of a supergene origin.

Arsenopyrite is very abundant and was never entirely absent in any of the deposits examined. Broadly speaking, two different modes of origin may be stablished. The arsenopyrite either forms idiomorphic crystals, appearing mainly as single individuals in a solid sulphide-mass, quartzite or quartz vein, or else it is enriched to more or less solid, separate masses, consisting of extremely fine-grained arsenopyrite aggregates. This fine-grained type probably represents a very early stage in the mineralization, as it is sometimes found to form angular inclusions in solid sulphide ore of other composition. Arsenopyrite of this type is occasionally replaced by other sulphides, but as a rule the corrosion is not very extensive. As to the relation between arsenopyrite and pyrite, the microscopic examination supplies no clear evidence as to the mineral sequence. Such textures are never met with as those dsecribed from Boliden by Ödman (*87*, Pl. II, 2), where the pyrite fills the interstices between the arsenopyrite crystals, though "drusy" textures resembling those illustrated by Ödman may occur, the interstices then, however, being filled with other minerals than pyrite. Intergrowths between pyrite and arsenopyrite have been observed in which both pyrite and arsenopyrite occur as inclusions in the other component. In most cases, however, the pyrite in such types seems to be the earlier mineral, and it frequently occurs as irregular-shaped grains, possibly due to corrosion, enclosed in the arsenopyrite.

When arsenopyrite appears as individual crystals in complex sulphide ores, it is often quite impossible to gain a clear idea of its age as compared with the surrounding minerals. In many cases a close association with the veinlets rich in galena can be shown, but because of the strong crystallization power of arsenopyrite, it nevertheless grows through other, earlier minerals. Thus crystal faces of large arsenopyrite crystals are frequently found to traverse the contacts between earlier sulphides. Arsenopyrite of this type is corroded chiefly by the lead minerals and to a certain extent by chalcopyrite.

Galena is present in the majority of the zinc-bearing ores but great quantities never occur separately. It seems to be the last mineral in the sequence of crystallization of the sulphides and displays a considerably higher degree of mobility than the other minerals. A series of antimony-minerals is found in association with galena, and because of the close relationship between these minerals and galena and their independent appearance, they constitute a very specific mineral group. The particular textures and the paragenetic associations of the lead-copper-antimony minerals have previously been described by the author (*27*), and these problems will consequently be discussed but summarily in the present paper.

The galena is usually very fine-grained, the individual crystals of the separate veinlets attaining only in rare cases a diameter of 1 mm. In silicates where the cleavage is very pronounced, galena is occasionally introduced along the

cleavage planes (Pl. 18, b). Other sulphides are generally very extensively replaced, and among the minerals mentioned galena seems to be the mineral which to the largest extent replaces the earlier sulphides.

Tetrahedrite is the commonest of the antimony minerals associated with galena. Under the microscope its colour is olive green, and as the mineral is perfectly isotropic it is apparently a common copper-antimony tetrahedrite, in all probability with a certain silver content. Generally it appears as rounded grains in galena, sometimes displaying embayments of corrosion towards the galena. In specimens especially rich in tetrahedrite, regular intergrowths are often found between galena and tetrahedrite (Pl. 19 c and 20 a). The proportions between the different components, however, may often vary quite considerably even within the same polished section. In most cases the author has received the impression that such intergrowths are due to a simultaneous crystallization of the two minerals.

Bournonite is found chiefly as intergrowths with galena, and in this case the proportions between the components are very much alike in the diverse specimens. The mineral has about the same shade of colour as tetrahedrite though it is somewhat paler. The anisotropic effects are weak but distinct, making the outlines of the individual grains visible between crossed nicols. In many cases the polysynthetic twinning characteristic of bournonite can be observed, sometimes forming two systems of lamellae traversing each other at right angles.

Jamesonite[1] and *boulangerite*[1] have both been observed, and may also occur in the same polished section. The minerals are strongly anisotropic and reflection-pleochroism is very distinct. According to Schneiderhöhn and Ramdohr (*72*, pp. 404 and 411), jamesonite displays greater differences in colour when compared with galena than does boulangerite. As the impression of colour, however, is highly dependent on the adjacent minerals, it is impossible in each separate case to decide which of the two minerals is present. In a few polished sections, when a comparison with specimens of true jamesonite has shown the mineral examined to be jamesonite, there have been observed cleavage planes, perpendicular to the elongation of the crystals. In one of these polished sections translation lamellae have also been found, closely resembling the corresponding translation lamellae in pyrrhotite. Polysynthetic twinning lamellae have been observed in one case.

[1] According to a personal communication from Dr. O. Ödman, Professor P. Ramdohr of Berlin and Dr. Ödman have established the occurrence of a new mineral belonging to the boulangerite-jamesonite group at Boliden. With the aid of X-ray methods J. Hiller (*33*) could identify the various components in the lead-antimony sulphides, and by using these methods it was possible to determine the occurrence of the mineral both in certain German ore deposits and at Boliden. An article on the subject, by Ramdohr and Ödman, is just in print. In a lecture given by Ödman at the Mineralogical Society in Stockholm, he gave an account of the microscopic characteristics of the new mineral which are closely related to the characteristic properties of boulangerite and jamesonite. For this reason I must in the following make a reservation for the determinations jamesonite and boulangerite, as there may be a third mineral present. The only thing that can be said definitely is that a Pb-Sb-sulphide is present.

In contradistinction to bournonite and tetrahedrite, these minerals never occur as regular intergrowths with galena, but generally as homogeneous, uniform, elongated crystals. In some cases galena may be found within the otherwise homogeneous crystals, but it then forms narrow streaks along the cleavage planes with an irregular distribution in the crystals.

Geocronite has been found at Bjurliden only, where it occurs in a separate, narrow quartz vein, rich in galena. Under the microscope the mineral is easily identified. Its reflection-power is approximately the same as that of galena. When directly compared with galena the highest colour has a faintly greenish tint. The anisotropic effects are approximately as distinct as in jamesonite or boulangerite. A pronounced polysynthetic twinning in most of the geocronite crystals and the very weak reflection-pleochroism, however, prevent confusion with these minerals. The type of twinning is fairly similar to the twinning in bournonite. Geocronite is conspicuously corroded by galena and is intersected by veinlets of bournonite and galena.

Pyrargyrite is by no means rare in the mineral assemblages rich in silver, but it always occurs as exceedingly minute grains with very irregular outlines towards the adjacent minerals. The colour is greyish blue and between crossed nicols red internal reflection colours are clearly visible. It is not possible to decide on the basis of the microscopic data, whether the mineral is proustite or pyrargyrite, but as it is always found in association with the parageneses rich in antimony and in several cases appears to have been formed by the breaking down of tetrahedrite, it is in all probability a pyrargyrite.

Gudmundite, FeSbS, is a very common mineral in the assemblages, rich in antimony, but it never occurs in so large individuals as to permit a chemical analysis. The mineral seems to be relatively common in certain parageneses of the Skellefte District. Thus Ödman mentions gudmundite both from Boliden (*87*, p. 130) and Holmtjärn (*88*, p. 99). Probably it is relatively common also in other ore districts, where it may have been overlooked due to its great resemblance to arsenopyrite. Recently Ramdohr has found gudmundite also at Sulitelma (*65*, p. 280). The optic properties of the mineral are on the whole identical with those of arsenopyrite. The reflection-pleochroism seems to be somewhat more distinct for gudmundite than for arsenopyrite, but the most striking difference of diagnostic importance is with regard to hardness. The resistance to polish is considerably lower for gudmundite than for arsenopyrite and agrees far better with that of pyrrhotite. In fact gudmundite is somewhat harder than pyrrhotite, though the difference is not so marked as to cause any pronounced relief even when subjected to comparatively intense polishing.

In some cases gudmundite occurs as idiomorphic crystals, either forming single grains or in aggregates or bundles of well-defined needles. Though the mineral in the development mentioned often is directly surrounded by pyrrho-

tite, sphalerite or gangue, it is also in these cases closely associated with galena-veinlets rich in antimony minerals. Gudmundite occurs comparatively often along the contacts between pyrrhotite and tetrahedrite. The textures strongly suggest that the origin of this type of gudmundite is due to corrosion of pyrrhotite by the antimony-bearing ore solution, tetrahedrite and gudmundite being formed almost contemporaneously. In these cases very regular intergrowths between gudmundite and pyrrhotite often occur (Pl. 19, b).

Gudmundite is also formed by the replacement of bournonite by galena in which case it occurs in the bays in the corroded bournonite but is entirely surrounded by galena. It then has the shape of ramiform crystal aggregates. Some chalcopyrite and pyrrhotite is generally also present in this type (Pl. 19, a). In very rare cases, finally, gudmundite is doubtlessly a product resulting from the breaking down of tetrahedrite, when it forms intergrowths with chalcopyrite and pyrrhotite.

Stannite is of great paragenetic interest, though it has been observed only in two polished sections from Ö. Högkulla. As an analysis has proved the presence of small quantities of Sn also at Bjurliden, which mineralogically closely resembles Ö. Högkulla, the mineral is in all probability present also in that deposit, even though it has not been observed microscopically. The mineral is perhaps not very rare in the Skellefte District as Ödman mentions the mineral both from Boliden (*87*, p. 141) and Holmtjärn (*88*, p. 99).

In the stannite-bearing specimens the mineral is always very intimately connected with the veinlets rich in galena and antimony minerals. However, there seems to exist a certain relationship also between sphalerite and stannite. Sphalerite is sometimes distinctly replaced by stannite, and sometimes stannite may also occur as minute inclusions in the sphalerite grains. These inclusions are of the same shape and size as e. g. the above-mentioned chalcopyrite inclusions. Under the microscope stannite displays a colour somewhat similar to that of tetrahedrite, though it is slightly darker and has a more brownish shade. When enlarged 1,000 times a large number of minute yellow points can be seen, which probably consist of chalcopyrite. In larger grains a distinct twinning may sometimes be observed.

Bismuth is comparatively common in the mineral assemblages rich in lead, even though it always occurs in exceedingly small quantities. It occurs chiefly as minute rounded grains, distributed without any regular arrangement in galena or in the accompanying antimony-minerals (Pl. 20, a). In exceedingly rare cases bismuth has evidently been in solution even after the crystallization of galena, and then fills cavities between the galena cubes or is arranged along cleavage planes of the galena.

Electrum (?). In an intergrowth of galena and bournonite from Ö. Högkulla there occur minute grains of a mineral with an exceedingly high reflection power. The individuals do not even attain the size of the bismuth grains (cf.

Pl. 20, a). As the mineral seems to be harder than galena and never displays the yellowish tarnish characteristic of bismuth, the mineral is probably electrum. The percentage of silver being comparatively high, the percentage of gold, on the other hand, very low, the mixture no doubt contains fairly much silver. At Bjurliden a similar mineral is found, occurring as minute inclusions in geocronite.

The occurrence of the secondary minerals native *copper* and *sulphur* in insignificant quantities has been mentioned by A. Högbom and Eklund.

Marcasite or marcasite-like minerals are common supergene alteration products of pyrrhotite. In most cases the minerals in question seem to be identical with the mineral mentioned in the text-book of Schneiderhöhn-Ramdohr as a marcasite-like alteration product of pyrrhotite (*72*, p. 139, fig. 62), rather than with typical marcasite. The anisotropic effects are often very distinct and make it possible to distinguish the isotropic members of the alteration products, which may be classified as secondary pyrite. The alteration can be traced along cracks and cleavage planes in the pyrrhotite (cf. *72*, p. 139, fig. 62), but has also a tendency to form zonal textures (Pl. 20, b).

Magnetite is widely distributed both among the silicates and in the solid ores. In chlorite-quartzites and chlorite-rocks it often appears as idiomorphic octahedrons. Under the microscope the outlines of the individual grains, however, look rather irregular, because of the abundance of inclusions of other minerals. When occurring together with the sulphides, magnetite forms more or less rounded grains. Perfectly idiomorphic outlines and octahedron cleavage are but rarely seen under the microscope. In many cases small grains of pyrite, sphalerite, pyrrhotite, and even chalcopyrite are enclosed in otherwise homogeneous crystals. Sometimes these inclusions may be due to the introduction of sulphides in the magnetite. This is no doubt true of chalcopyrite, which is often found to attack the borders of the magnetite grains to a certain extent. The pyrite, on the other hand, in all probability represents true inclusions, as they are very often found concentrated in the centres of the magnetite crystals (Pl. 21, a), and in one case a band-like arrangement of the inclusions has been followed across the individual magnetite crystals, which in this case are probably porphyroblasts.

When subjected to mechanic deformation the magnetite crystals are intensely crushed, the sulphides then being introduced along the fractures. Even when they are definitely later than the magnetite, the sulphides do not attack the magnetite chiefly by replacement, the result of the attack mostly being a normal brecciation.

Ilmenite is a common constituent both of the silicate and the sulphide parageneses. It generally forms minute rounded or elongated grains. In rare cases the mineral is found as narrow lamellae in magnetite. At Bjurliden, however,

ilmenite is observed in a peculiar development. In some specimens very rich in pyrrhotite ilmenite occurs as staves or minute elliptical grains, which generally form a comparatively regular intergrowth with pyrrhotite (Pl. 22, a). Between crossed nicols the ilmenite individuals seem to have the same optic orientation within certain areas. In most cases also the pyrrhotite displays a uniform optic orientation within the same areas, but there are exceptions, when the ilmenite lamellae are found to cut across the contacts between pyrrhotite crystals with different optical orientations. Furthermore, the orientation of

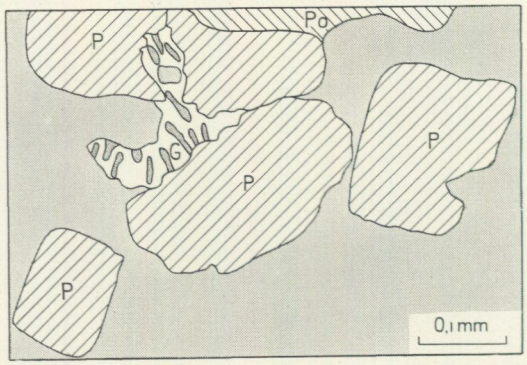


Fig. 10. Pyrite (P) is corroded by galena (G) containing small parallel staves of ilmenite (darker grey). Po = pyrrhotite. Light grey = gangue.

the ilmenite lamellae may sometimes change even within a homogeneous pyrrhotite crystal. In other cases ilmenite of the same appearance may occur in a mixture of sphalerite and pyrrhotite, and occasionally the lamellae or the orientated group of grains are even found to cut across the boundaries between these two minerals (Pl. 22, b). Finally ilmenite may occur as intergrowth with galena. Galena containing orientated lamellae of ilmenite is also found to corrode an otherwise idiomorphic pyrite crystal (fig. 10).

The origin of these textures is not very easily elucidated. As the formation of orientated intergrowths is often thought to be due to contemporaneous crystallization, this probability must first be taken into consideration. The fact, however, that the ilmenite lamellae occur in different minerals and furthermore in minerals belonging to considerably different stages of mineralization, does not confirm this assumption, at least not in all cases. It must be borne in mind, however, that selective replacement by the late minerals may, to a certain extent explain these textures. When the ilmenite occurs in galena, the texture is probably due to selective replacement, the earlier embedding mass being wholly replaced by galena, the ilmenite being left intact. The importance of selective replacement of this kind has been recognized by several authors, and on the basis of synthetic experiments C. Schouten (*73*) has stressed the great importance that in certain cases may be attached to phenomena of this kind among sulphide minerals.

If the galena had replaced some other mineral, leaving ilmenite intact, the

intergrowths with pyrrhotite and sphalerite might be expected to be of the same origin. It might then be supposed that some mineral often found to occur in intergrowths of some kind or other with ilmenite had been present from the beginning, but that it had subsequently been entirely replaced. The minerals that might be suspected are magnetite and hematite. The arrangement of ilmenite lamellae in the pyrrhotite intergrowths, however, makes an original intergrowth with magnetite very improbable, as there can be found no traces of the octahedron arrangement characteristic of the titaniferous magnetites. The other mineral mentioned, hematite, is never found as large individual grains in parageneses of the type in question, whether at Bjurliden or elsewhere, and for this reason a development of the texture from a hematite-ilmenite intergrowth seems highly improbable. When occurring together with pyrrhotite, the ilmenite lamellae show a tendency to arrangement parallel to (0001) in the pyrrhotite. If this is true, the sphalerite intergrowths may perhaps have been formed by selective replacement of pyrrhotite + ilmenite. The age relations between pyrrhotite and sphalerite, however, are not quite clear in all cases, and in addition there are features indicating that the ilmenite was not originally fixed together with the sulphides. Large grains of ilmenite are in fact found in association with mica, which is extensively brecciated and replaced by pyrrhotite and sphalerite. When they get into contact with the sulphides these large ilmenite grains are disintegrated into minor grains of exactly the same shape and size as those in the intergrowths. This development would correspond to the above-mentioned corrosion and disintegration of large pyrite crystals, when there are formed a large number of minor, distinctly idiomorphic cubes. The recent minor ilmenite grains, however, may be orientated along certain crystallographic directions in the replacing sulphides. Later replacements of these sulphides may give rise to intergrowth-like textures with any of the late minerals with a great reaction power. The above considerations thus lead back to the assumption that the ilmenite lamellae were developed at approximately the same time as the crystallization of the pyrrhotite, possibly also of the sphalerite, even when ilmenite is originated during an earlier stage of mineralization.

Rutile is comparatively rare and seems mainly to occur in the parts of the ores that are rich in zinc. It appears as diminutive rounded grains, usually directly embedded in sphalerite.

Hematite occurs only in close association with ilmenite. At Ö. Högkulla it has been observed only in one specimen from a slightly altered porphyry, where it forms irregular grains together with ilmenite. At Bjurliden and the Bjurträsk ores there have been observed some minute light spots in a few ilmenite grains, which owing to their mode of occurrence have been presumed to consist of hematite segregated from the ilmenite.

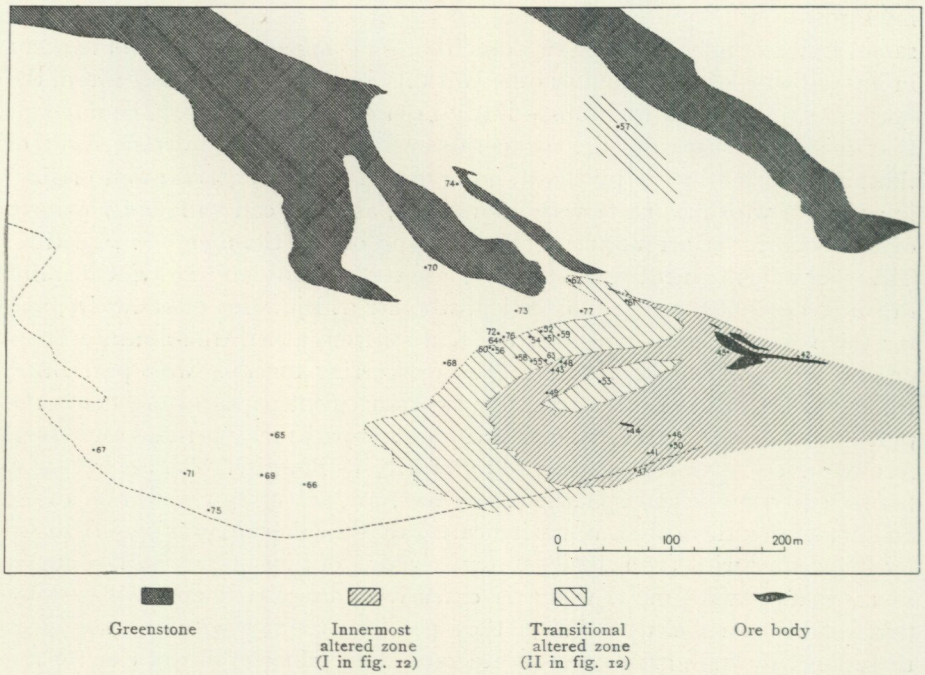


Fig. 11. Sketch-map showing the zoning of altered rocks around the Bjurträsk ores. The dots represent localities for volumetric analyses presented in fig. 12. The fine broken line = the boundary against the quartzporphyry lava bed.

C. Description of the Ore Deposits.

1. The Bjurträsk Ores.

a. Location, Shape, Tectonic Features.

These ores, which are situated about 3 km N of Bjurträsket village, have been examined by means of several trenches. The principal ore, situated in the eastern part of the mineralized area, is a complex pyrrhotite-pyrite ore with varying zinc content, cupriferous portions also occurring, but only occasionally. WSW of this ore body there is a minor copper ore which has been examined by means of a shaft, 12 m deep, and a small drift. The shape and extension of the larger ore body is shown in Pl. 34, and fig. 11 gives a view of the broad zoning of the alteration, partly founded on the results presented in fig. 12.

The dip of the eastern ore is generally 50° to the south. As there are no drill holes and as no underground work has been carried out, its extension in depth is not known. The minor western ore dips 60—65° to the south, the main axis of the ore pitching about 45° WSW, thus in a direction approximately coinciding with the linear structure and the axes of the small folds in the rocks of the surroundings. Also the poor disseminations are found to be orientated along the same direction of the linear structure.

Within the area around the Bjurträsk ores the magnetic vertical intensity was measured by S. Werner with a Schmidt-type magnetometer. These results

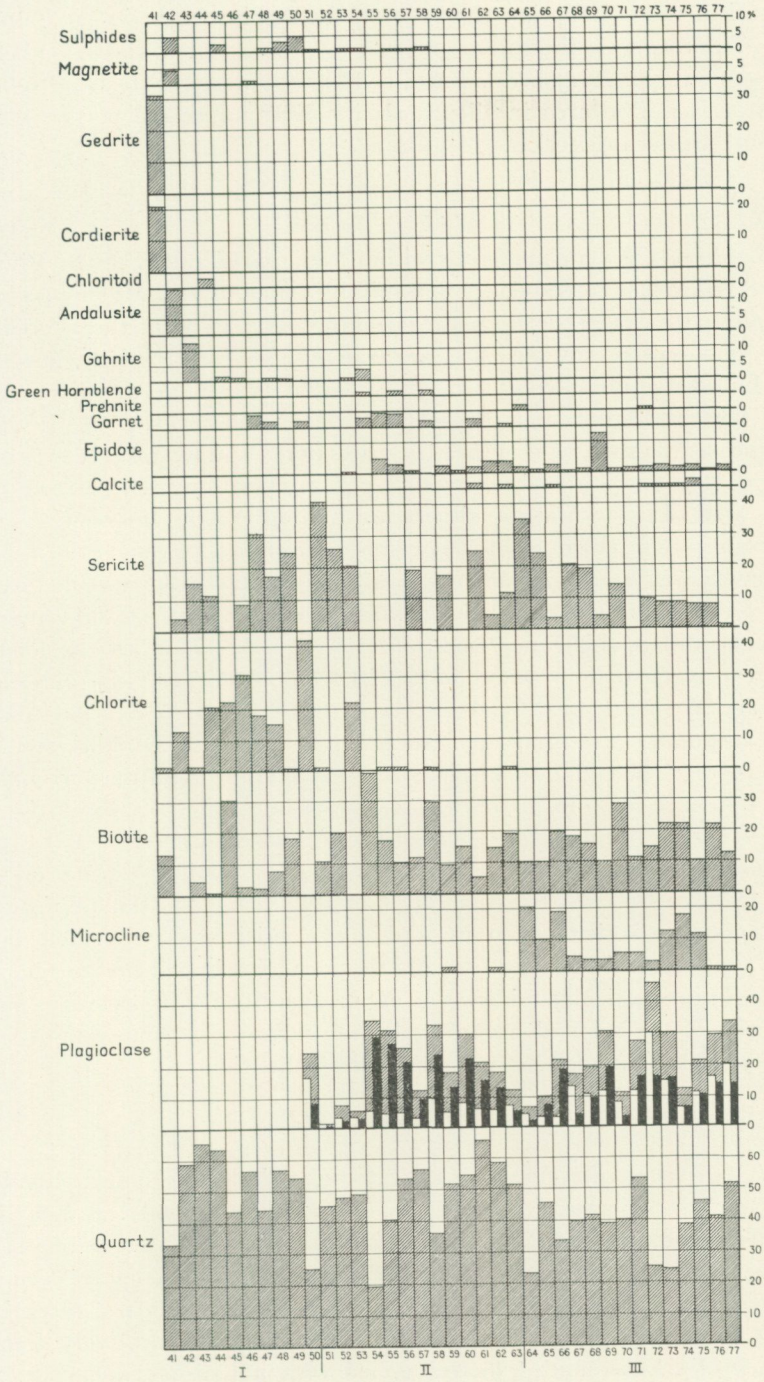


Fig. 12. Mineral composition of more or less altered rocks around the Bjurträsk ores, in volume per cent. The situations of the analysed specimens (Nos. 41—77) are shown in fig. 11. For plagioclase: filled columns = anorthite; open columns = albite.

also confirm the assumption that the ore bodies in the main pitch towards WSW. The magnetic indications may also be followed towards WSW, even after the quartzporphyry bed has attained a north-westerly strike. This means that the mineralized area in all probability dives under the porphyry in the west-south-western direction.

b. *Altered Rocks.*

The outcrops are very numerous within the area W and N of the Bjurträsk ores, and this area is consequently well suitable for an investigation of the zoning of the altered rocks, especially as regards the outer parts of the altered area. The most intensely altered parts are generally covered by drift, but thanks to the knowledge obtained through trenches, it is possible to gain a general idea of the distribution and character of the altered rocks.

A glance at the map reveals that the rocks north and west of the ores chiefly consist of agglomerates of quartzporphyry composition. The larger, homogeneous beds of greenstone are situated on the north side, the continuous bed of quartzporphyry on the south side of the altered area. Minor beds of quartzporphyry as well as of greenstone may be found, however, also in the more intensely altered areas, it thus being possible to study the effect of the alteration on rocks of different chemical compositions. On the whole the agglomeratic structure is very well preserved also within those parts of the outcropping area N and W of the ores that have been affected by the alteration, and it is but in exceptional cases that this structure has been entirely obliterated. The linear structure coinciding with the axes of the small folds of the surroundings, has been observed also in the mineralized areas, and is, especially in the types rich in sericite, even more pronounced there than elsewhere.

On the basis of the occurrence of micas and chlorite minerals a megascopical classification of the felspar-free rocks, Group I in fig. 12, can be made into chlorite-quartzite, sericite-quartzite, and biotite-sericite-quartzite. Within each of these types several sub-types may further be defined according to the occurrence of certain particular minerals of minor quantitative importance. Fig. 12 is a survey of the mineral assemblages in a number of thin sections of the main rock types, founded on volumetric determinations.

Chlorite-Quartzites.

Chlorite-quartzites with garnet in their most typical development are found close to the eastern ore and also south of the western ore body. A megascopic examination discloses the garnets in a bright or darker green groundmass. The size of the garnets as a rule ranges from 1 or 2 mm to 2 cm in diameter. Generally the garnets are heterogeneously distributed in the groundmass, often being arranged in streaks. An interesting feature is the comparatively frequent occurrence of small rounded quartz grains with a bluish opalescence, their appearance being exactly the same as the appearance of the quartz phenocrysts of the quartzporphyries. In this case we are thus faced with a meta-

somatic replacement of the groundmass and the plagioclase phenocrysts, the quartz phenocrysts being left entirely intact.

Under the microscope the groundmass is found to consist of a fine-grained mixture of *chlorite* and *quartz* with more or less *sericite*. The flakes of chlorite and sericite are fairly uniformly orientated, thus giving rise to a distinct schistosity. While quartz and chlorite are found to have a very uniform distribution in the groundmass, sericite is often concentrated in spots or streaks, and is most probably of a later origin than chlorite. As a rule *biotite* is also present, though always in small amounts. It forms larger flakes than chlorite and sericite, and the flakes often tend to be arranged perpendicularly to the planes of schistosity.

Garnet appears as large poikiloblasts, very irregular in shape. Their idiomorphic outlines have been more or less obliterated by the great amount of included minerals, quartz being the predominant mineral among these inclusions.

The *residual quartz phenocrysts* are generally fairly well preserved. The mechanic deformation causes slight fracturing and undulatory extinction. When the deformation becomes more intense the phenocrysts are broken down into aggregates of minor grains. The outlines of the groups, however, clearly indicate the original phenocryst. Opaque minerals are always present in varying proportions. *Sulphides* and *magnetite* are prominent, *ilmenite* being somewhat rarer.

Felspathized chlorite-quartzites and chlorite-rocks are found in close association with the solid ores. The felspathization is found mainly in the types richest in chlorite, which due to a decrease in the quartz content grade into comparatively pure chlorite-rocks. Members of this kind appear close to the western, minor ore body, where tabular *plagioclase* occurs in a dense groundmass which megascopically seems to consist almost entirely of *chlorite*. *Garnet* has been observed in a similar rock-type from a trench situated in the direction of the strike from this locality. Occasionally the plates of plagioclase attain a size of 1 × 2 cm but generally they are considerably smaller. The individual plagioclase crystals may be so abundant that the rock assumes the structural appearance of normal porphyrite.

Close to the eastern ore the felspathization is also comparatively pronounced. Thus there have been found extremely coarse chlorite-rocks as minor inclusions in the solid ore, containing idiomorphic *garnets* up to 3 cm in diameter, *plagioclase* of the same size, *magnetite*, and in rare cases *andalusite*. Andalusite may in this case form well-defined, idiomorphic, pale red prisms of about the same size as plagioclase. When andalusite becomes more abundant, garnet is generally lacking and magnetite becomes comparatively plentiful.

In the groundmass rich in chlorite, the minute grains of *quartz* and ore minerals, in this case chiefly *ilmenite*, are often found in a band-like arrangement traversing the plagioclase-poikiloblasts, and when garnet is present the band-like arrangement may be found to traverse that mineral, too. The groundmass is mainly built up of chlorite with minute grains of quartz. Small amounts

of *apatite, epidote,* and *zircon* may also be found. In one specimen *tourmaline* was comparatively plentiful (about 0.5 vol-%). It appeared as minute prisms irregularly distributed both in the chlorite mass and in the plagioclase poikiloblasts.

It was mentioned above that andalusite-bearing quartzites are sometimes found close to the eastern ore. In the most abundant type felspar is lacking, magnetite on the other hand being very plentiful, and the rock may be characterized as *magnetite-andalusite-quartzite.* Megascopically, *magnetite* forms conspicuous porphyroblasts in the groundmass, where, furthermore, the plentiful occurrence of white, irregular spots gives rise to a very characteristic appearance of the rock. Under the microscope the spots seem to consist of *andalusite* poikiloblasts crowded with inclusions of *quartz.* In some cases the quartz represents more than 50 % of the quartz-andalusite mixture. The spots are often found to form zones round the magnetite grains, and there seems to be a very close relationship between the origin of magnetite and andalusite. Colourless mica occurs as separate flakes, formed distinctly later than the chlorite, but also as fine-grained, fibrous *sericite,* which replaces the andalusite, too, along the cleavage planes.

Sulphides are fairly abundant and examinations of polished sections disclose *pyrrhotite* to be predominant. The origin of sericite seems to be very closely associated with the crystallization of the sulphides, at least in some cases. *Arsenopyrite* has also been observed, occasionally in fairly great amounts and always forming well-defined idiomorphic crystals. Faintly yellowish *staurolite* has been observed in a specimen rich in andalusite, and then appeared as irregular poikiloblasts distinctly later than the andalusite.

Magnetite forms large octahedrons with numerous inclusions of quartz. In polished sections *ilmenite,* too, could be established, which, in the shape of small staves, is comparatively regularly distributed in the groundmass. When enlarged about 1,000 times, minute spots with a high reflecting power became visible in the ilmenite, these spots presumably consisting of *hematite* segregated from the ilmenite.

Gahnite-bearing chlorite-quartzites are rather common within the altered area. Similar to the garnet, gahnite is often arranged in streaks and spots. It may be found in close association with *garnet,* but the two minerals often occur separately from each other, when we find an interchange of garnet-rich and spinel-rich schlieren. The gahnite-bearing chlorite-quartzites are generally of a brighter colour than the other types mentioned, this being due to the greater content of *quartz* and *sericite* in the groundmass. Gahnite is also found in pure sericite- or sericite-biotite-quartzites.

Under the microscope the groundmass of the gahnite-bearing chlorite-quartzites has the same appearance as the groundmass in the types mentioned above. In thin sections gahnite is bright green, and the individual grains enclose large amounts of rounded quartz grains. *Biotite* is abundant, the in-

dividual flakes mainly being orientated perpendicularly to the schistosity. Sometimes the mineral seems to have been formed simultaneously with the sulphides. Thus sulphide grains are found, the outlines of which are covered with biotite. In one case biotite was observed on one side, chlorite on the other side of the same sulphide grain. The chlorite was of the same type as that occurring in the surrounding groundmass, but formed a large, individual flake close to the sulphide.

Gahnite is also a common constituent of *biotite-banded chlorite-quartzites* appearing to the south of the major ore. Megascopically this rock may be characterized as a chlorite-quartzite with an interchange between chlorite-rich, chlorite-poor, and biotite-rich schlieren. Even megascopically the biotite flakes show a tendency to becoming arranged either perpendicularly or parallel to the planes of schistosity. In thin sections this tendency is very distinct, as large uniform biotite poikiloblasts, sometimes with numerous quartz inclusions, occur, sharply cross-cutting the schistose chlorite-quartz groundmass.

The *gahnite* forms irregular porphyroblasts, elongated parallel to the direction of schistosity. Small amounts of *clinozoizite* and *zircon* are found. The occurrence of zircon may — apart from its appearance in well-defined grains — also be inferred from the appearance of numerous pleochroic haloes, arranged in rows parallel to the planes of schistosity. These rows become particularly conspicuous in the biotites (Pl. 13, b). In one type small needles of *anthophyllite* have been observed, often arranged in rosettes.

Sulphides and quartz of a more coarse-grained, granular development replace mica and chlorite and form spots entirely free from the ferro-magnesia minerals. The shape of these spots sometimes supports the opinion that they originated as pseudomorphs on the traverse biotite porphyroblasts.

Chloritoid-bearing chlorite-quartzites are found in rare cases among the samples taken from the trenches. Megascopically, chloritoid forms elongated bundles of a needle-like appearance in the groundmass. Under the microscope *sericite* is found to be a comparatively abundant constituent. In this case sericite is enriched in schlieren consisting of almost pure sericite together with minute grains of ore minerals, partly *ilmenite*, partly *pyrrhotite* and excessively fine-grained *arsenopyrite*. Both the minute flakes of mica and the ore minerals display a peculiar winding arrangement, probably caused by a rotary movement. In the thin sections chloritoid is found to be solely associated with these schlieren of sericite and is formed distinctly later than the sericite. The minute ore grains, however, had no part in the formation of the chloritoid, but may be observed forming the same winding rows traversing the chloritoid porphyroblasts as in the sericite mass (Pl. 21, b).

Cordierite-Quartzites.

Cordierite-quartzites of the same type as are described from central Sweden and Finland in connection with metasomatic alterations have been found in one of the prospecting trenches. The groundmass of this rock is more coarse-

grained than in the surrounding quartzites and *cordierite* and *gedrite* are both visible to the naked eye. The mineral composition will be seen from No. 41, fig. 12. The *biotite* is dark brown and forms comparatively large, irregular flakes with numerous pleochroic haloes. Gedrite has been developed as well-defined needles penetrating the other minerals.

In one case cordierite was also found in chlorite-quartzite, forming a poikiloblast about 0.5 cm in diameter. The inclusions are fairly uniformly distributed and consist mainly of quartz.

Sericite- and Sericite-Biotite-Quartzite.

Pure sericite-quartzite, which is generally a very common result of the alteration in the Skellefte District, is of subordinate importance in the area here in question. Boulders of strongly schistose altered quartzporphyries very rich in sericite are found in the southern trenches, indicating the occurrence of rocks of this kind along the southern border of the altered area. A relatively massive sericite-quartzite with some *gahnite* and minute, black *tourmaline*-needles also occurs in the southernmost outcrops north of the eastern ore. In this latter locality the original rock no doubt belonged to the agglomerates, the agglomeratic structure, however, having been entirely obliterated by the intense recrystallization.

The chlorite-free quartzites generally contain a certain amount of *biotite*, which in these cases forms irregular streaks in the rock. *Garnet* and *spinel* may be found in these rock-types, too.

Altered Rocks with Incompletely Altered Felspar.

Groups II and parts of III in fig. 12, include those rocks that have been distinctly affected by the mineralizing solutions but in which the alterations have not lead to the development of felspar-free quartzites and which consequently represent a less complete change. The late felspathization in some chlorite-quartzites, mentioned above, is a process which is generally easily recognizable in the investigations and which gives rise to rock-types which need not be confused with the incompletely altered rocks of group II.

Group II in fig. 12 shows the composition of rocks constituting a transitional zone between the pure quartzites and the unaltered or very slightly changed rocks. The limit between groups II and III has been determined by the content of alkali felspar, and rocks which according to the volumetric analyses contain less than 10 % alkali felspar have thus been placed in group II, rocks exceeding this value are in group III. This classification is founded on the assumption that in the earlier stages of alteration, the change was essentially due to the disintegration of the alkali felspar.

The alterations in those marginal zones tend to develop in two different directions. On the one hand *sericite-rich quartzose types* are formed, on the other we find rocks in which the essential change from the original composition is indicated by the abundance of lime-rich minerals. This latter type of alter-

ation is mineralogically demonstrated by the presence of *An-rich plagioclase, epidote, garnet,* and occasionally *hornblende.* In some cases An-rich plagioclase and sericite are found in the same thin section, but in the majority of cases the two types tend to occur separately. This differentiation, however, never results in the development of continuous areas of one type or the other on so large a scale as to be mapped. On the contrary, an irregular, intimate alteration between the two forms of alteration can generally be established.

The development of plagioclase in these mineral assemblages was mentioned when discussing the individual minerals. When it occurs in fine-grained, granular masses, associated with quartz, its evolution may be studied under the microscope. The first trace of alteration is the appearance of numerous inclusions of quartz in the original phenocryst, the composition of plagioclase at the same time growing richer in An. When subjected to stronger alterations the outlines of the phenocryst are gradually obliterated, the extinction grows flamy and irregular. Sometimes recrystallization takes place, when comparatively pure streaks of An-rich plagioclase are formed.

In a few specimens from parts which have been only slightly affected by the alterations, *microcline* is found, either as a constituent of the fine-grained groundmass associated with quartz and plagioclase or as irregular phenocrysts. In the latter case, numerous minute, rounded quartz grains are enclosed, and the texture greatly resembles the appearance of the poikilitic plagioclase phenocrysts.

A special development of microcline has been observed in two of the thin sections examined in which small amounts of *prehnite* have also been found. Here, microcline forms narrow lenses in biotite orientated parallel to the cleavage planes. The cleavage plane itself is visible even within the microcline lens as a fine line. Similar textures have been described and pictured by Hjelmqvist (35, figs. 1 and 2), in which case, however, prehnite appears along the cleavage planes in biotite. In the thin sections from the Bjurträsk ores prehnite forms irregular grains, generally, however, very closely associated with biotite. This last-mentioned mineral has furthermore been more or less altered to *chlorite* in the prehnite-bearing rocks.

The sericitization may under the microscope be followed from a slight infiltration of *sericite* in the groundmass to rock-types in which sericite is a predominent mineral. In the latter case the distribution is generally very heterogeneous and sericite often forms streaks or spots, sometimes conspicuously penetrating and brecciating other minerals. When present in the sericitized types the *biotite* is often earlier than the sericitization and is then a remainder of the pre-existing biotite generation. Often, however, the biotite flakes are arranged very regularly perpendicular to the planes of schistosity. This texture suggests that at least part of the biotite has been fixed after the development of the schistosity, which is always found to be closely associated with the origin of the sericite. These questions, however, will be considered in greater detail in a following chapter (cf. p. 159).

In the slightly altered types, which are situated outside zone II, under group

III in fig. 12, the formation of muscovite directly from biotite has been observed. Thus, small remainders of the primary biotite may be found in large muscovite flakes, both minerals having the same optic orientation.

Greenstone and Amphibole Skarn.

The greenstones within the altered area have been changed far less than the rocks belonging to the quartzporphyry series. It is true that rather considerable quantities of *sulphides* have been introduced, but *plagioclase* as well as *hornblende* seem to have been left perfectly intact in spite of this sulphide invasion. Possibly a certain amount of *quartz* has been introduced and sometimes *chlorite* is comparatively abundant in the groundmass, but whether or not this chlorite originated through an alteration of amphiboles cannot be decided. However, a straight alteration from common hornblende to *cummingtonite* can be established in several cases, evidenced by a discolouration of the points of the amphibole needles.

In other cases the mineralizing solutions give rise to a comparatively intense *biotite* formation. The microscopical textures reveal that biotite must have originated after hornblende, which, occasionally, is distinctly replaced. *Garnet* has been observed in this type, too. It appears as small idiomorphic crystals with a comparatively homogeneous distribution in the rock.

Amphibole skarn occurs in the eastern, large ore. Megascopically, the rock may be described as a fibrous mass of light green *amphibole* needles and in some respects it closely resembles certain types occurring in the sulphide or iron ores in middle Sweden. A microscopic examination reveals needles of hornblende in a groundmass chiefly consisting of *talc* with subordinate bright green *chlorite*, arranged in spots or streaks. Two types of amphibole occur, one faintly bluish green, the other quite colourless. As even slight variations in colour within individual crystals indicate that the mineral is not entirely homogeneous, the optic data below are in this case comparatively unreliable.

	γ	α	$2\,V_\alpha$	$c : \gamma$
Colourless amphibole	1,636	1,612	74°	11°
Slightly coloured amphibole	1,647	1,624	83°	16°

These optical data indicate that also the colourless amphibole belongs to the hornblende series and is not associated with the cummingtonites, as would be expected when considering the common relations within the greenstones. It must be considered remarkable, however, that decreasing values of refraction are accompanied by a decreasing optic angle. This implies that in the diagram of the relations between refraction and optic angle (fig. 5) the coloured amphibole lies outside the belt that includes the main amphibole types of the investigated area.

c. *Ores.*

The Eastern Ore.

Main Types and Relations to the Wall Rocks.

The main ore, as a whole, has a rather complex composition, but also here we find certain more or less well-defined types. In parts the western portion of the ore may be looked upon as *pyrite* ore. The grains are generally 0.5—1 mm but often attain 2 mm. In its purest portions *sphalerite* and *pyrrhotite* are of very insignificant importance. Generally these minerals occur irregularly distributed in the pyrite mass, but occasionally a regular interchange has been observed between sphalerite-free pyrite layers and pyrite-poor layers rich in sphalerite. When this development occurs the layers appear to follow the boundary towards the wall rock.

The main part of the ore has been developed as solid *pyrrhotite* ore with an irregular *sphalerite* content. Iron- and magnesium-rich silicates, such as *chlorite* and to a smaller degree *hornblende*, may be present, and when these minerals become more abundant, transitional types to the disseminated ore types appear. To the naked eye *pyrite* is entirely absent in most cases, but locally the mineral may form cubic "phenocrysts", 2 or 3 cm in diameter. In certain places sphalerite may be enriched and thus give rise to extremely zinc-rich ore types. In some specimens of the solid, zinc-rich ores we find rounded quartz grains of exactly the same type as the phenocrysts in the quartzporphyries which strongly emphasizes the metasomatic origin of the ore.

Chalcopyrite is occasionally found in the pyrrhotite masses, and this mineral may in places be so plentiful that the ore may be characterized as copper ore. Judging from the available material the highest percentage of copper is confined to more or less disseminated ore types, in which chalcopyrite and pyrrhotite penetrate dark chlorite masses.

The eastern part of the ore consists of pure fine-grained pyrrhotite enclosing numerous, sometimes rounded fragments of iron- and magnesium-rich silicates.

A characteristic feature of the Bjurträsk ore is that *galena* has never been observed in the available material from the ore itself, either in megascopic or microscopic examinations. In a few specimens from trenches, however, situated within the altered area but outside the solid ore, galena has been found as small cubic crystals in narrow quartz veins penetrating sericite-quartzite.

Arsenopyrite, too, has been found in a similar development. In one of the polished sections arsenopyrite has certainly been observed in one single grain, but megascopically the mineral has not been observed within the ore. Some of the quartzites in the surroundings, however, are found to contain arsenopyrite, occasionally as comparatively rich disseminations.

As regards the gangue minerals, *quartz*, *chlorite*, *biotite*, *sericite*, and sometimes *hornblende*, may be megascopically visible. After microscopic examination *plagioclase* and *epidote*, the latter in small amounts, can be added to this list.

When the present investigations were made, the contact between the solid

ores and the wall rock was not exposed so as to give a clear view of the contact relations. From available material and previous descriptions, however, it seems that the solid ores are generally rather sharply separated from the wall rock, though disseminated types may occasionally cause successive gradations.

Special Mineralogy.

Microscopic examinations reveal that also in this case *pyrite* is the first sulphide mineral to crystallize. It generally occurs in crystals with idiomorphic outlines against *pyrrhotite*, *sphalerite*, and *chalcopyrite*. These latter minerals may replace pyrite, but in the majority of cases the corrosion is comparatively slight at the Bjurträsk ore. Sphalerite and pyrrhotite generally form rounded or irregular-shaped grains and the textures do not give any clear evidence as to the mutual age relations.

In sphalerite, rows of minute pyrrhotite grains are common, but without attaining any pronounced orientation along the crystallographic directions, as is often the case elsewhere. Chalcopyrite is also present in sphalerite, forming minute blebs. Generally speaking, the sphalerite in the present deposit contains much smaller quantities of foreign minerals than in the other sphalerite-bearing deposits within the mapped area. Pyrrhotite has often been partly changed into *"secondary" pyrite* or *marcasite*.

Chalcopyrite appears in the majority of the polished sections examined and, when fairly abundant, distinctly replaces the sulphides of iron and zinc. In chalcopyrite we sometimes find *valleriite* forming minute worm-shaped grains.

Magnetite has been observed in all of the polished sections examined and forms more or less rounded grains enclosing minor particles of pyrrhotite, sphalerite, and occasionally also chalcopyrite. In some cases magnetite is associated with the gangue minerals but generally the individual magnetite crystals appear separately in the sulphides.

Ilmenite occurs in minute, rounded or elliptic grains, but is widely distributed and is present in most of the specimens examined. The probable occurrence of *hematite* as minute segregations from ilmenite in a coarse-grained chlorite-quartzite has already been mentioned in the description of the altered rocks.

The dense pyrrhotite ore forming the easternmost part of the ore body, displays quite a different texture from the ore types mentioned above. Pyrrhotite in this case forms small equidimensional grains, which between crossed nicols appear as a pronounced granular texture, resembling the texture of recrystallized leptites. The scanty sphalerite grains of this type are often crushed and are arranged in a kind of flow-texture. The texture as a whole thus produces the impression of being due to mylonizing with accompanying recrystallization of previously formed minerals.

Sulphur and Metal Contents.

Within the zink-rich parts of the ore we find zinc contents between 14 % Zn and 17 % Zn. In this case the analysed sections are generally 1—2 m in

width; in one case a high-grade section attains a width of 4 m. On the whole, however, the zinc content is considerably lower even in the parts considered as zinc ore, and within the analysed portions contents varying between 4 % and 6 % Zn predominate. Ore types rich in copper are as a rule extremely poor in zinc. The copper content may in one case be as high as 3.5 % on a width of 0.5 m, but within large continuous parts the content is considerably lower. Thus the values 1.4 % Cu and 0.4 % Zn are found in a section 3.5 m wide. The content of sulphur varies between 30 % and 45 %, a section 8 m wide containing 41 % S. Determinations of As, Ni, Au, and Ag, were performed on average samples but gave negative results. As, Ni, and Au could not be established at all and there were only traces of Ag.

The Western Ore.

The western ore is a disseminated copper ore as is seen from an average analysis of the outcropping area: 10 % S, 2.9 % Cu, 1.2 gr/t Au, 20 gr/t Ag. The sulphides appear in dark chlorite-rich quartzites or chlorite-rocks. Under the microscope the following minerals are observed: *chalcopyrite, pyrrhotite,* partly altered into *secondary pyrite, sphalerite, arsenopyrite, valleriite,* and *ilmenite.* The mutual relations of the minerals are the same as in the eastern ore. As regards arsenopyrite, however, it must be pointed out that this mineral appears only in the gangue minerals, and then as minute idiomorphic crystals often arranged in rows or in minor irregular aggregates.

2. Bjurliden.

a. *Location, Shape, Tectonic Features.*

The Bjurliden ore is situated 2 km W of the Bjurträsk ores in a geological *milieu* in many respects similar to the area in which the Bjurträsk ores occur. The ore was first investigated by means of prospecting trenches and three drill holes; later, parts of the ore were exposed by removing the drift.

The general direction of strike is about E—W, the dip is 60° to the south, but as regards the directions of the main ore axes there is some uncertainty. The results from the drill holes may, however, be combined with the known outcrops of the ores, indicating axes pitching 20°—30° towards WSW. As the linear structure of the surrounding rocks and the fold axes are in the same direction, it would seem most probable that this direction is actually the direction of the ore axes. The shape and extension of the ore will be seen in Pl. 34.

b. *Altered Rocks.*

The altered rocks at Bjurliden are to a large extent of the same type as at the Bjurträsk ores. The chemical composition of the country rocks is very much alike at both localities though structurally there may exist some differences, as quartzporphyries are more common at Bjurliden and agglomerates

predominate at the Bjurträsk ores. At Bjurliden the tuffitic rocks are generally stratified, and one greenstone bed and one limestone layer are found in these rocks.

The more intensely altered quartzporphyry appears in the foot wall of the ore and forms a bed parallel to the larger quartzporphyry bed in the hanging wall. The last-mentioned bed is comparatively unaltered and the alteration here causes but a slight sericitization of the plagioclase. The stratified or massive tuffitic rocks in the hanging wall are also comparatively little altered. Small amounts of a light green *hornblende* are found in the lime-rich bed. Close to the eastern part of the ore there occurs *andalusite-spotted quartzite* of exactly the same type as the corresponding type at the Bjurträsk ores. A certain amount of *biotite* is found also in this case, sometimes enriched in streaks in the quartzite. The biotite flakes are often orientated perpendicularly to the planes of schistosity. Pure *biotite-rock* occurs at the contact of the ore to the hanging wall. In the solid ore there are also found narrow enclosed parts of bedded tuffs which have changed to pure *sericite-quartzites* or to *coarse-grained spinel-* and *garnet-bearing quartzites* with *biotite* and *muscovite*.

The alteration of the greenstone occurring close to the ores is of about the same grade as at the Bjurträsk ores. Thus, besides a certain enrichment of *sulphides*, the only change from the normal development is a slight alteration of hornblende to *cummingtonite*. One specimen of *garnet-bearing hornblende-quartzite* has been found, apparently an alteration product of greenstone close to the contact with the ore.

Though the alterations are generally more pronounced in the foot wall, there have been found massive rocks belonging to the quartzporphyry series which seem to have been rather resistant. In the eastern part of the ore the plagioclase of these rocks may be preserved even at a distance of one metre or two from the ore-contact. *Tourmaline*, *garnet* and *arsenopyrite* are visible to the naked eye. Close to the ore, however, the rock has changed to a *coarse-grained quartzite* with *biotite* and *muscovite*.

The best survey of the character of the alterations is obtained by examining the variations in the types developed from the quartzporphyries which may be assumed to have had a relatively constant original composition. In the less altered parts of the northern quartzporphyry bed the conditions correspond almost exactly to those prevailing in the outer zones of the area around the Bjurträsk ores. The only difference is that calcite is more common at Bjurliden than at the Bjurträsk ores. The lower part of fig. 21, p. 152, is a survey of the mineralogical variations in drill hole 2 from unaltered porphyry to a poor pyrrhotite ore occurring N of the main ores. As regards the mutual relations of the various minerals to each other there is nothing of importance to add to the description of the corresponding parageneses in the altered area around the Bjurträsk ores. The altered types specific to Bjurliden are coarse staurolite-, gahnite-, and andalusite-bearing quartzites occurring in the foot wall of the main ores, and further quartzporphyries which are extensively enriched in lime-rich minerals.

Gahnite-bearing sericite-biotite-quartzite. This type occurs in the immediate vicinity of the northernmost ore lenses, and partly within those lenses. From types slightly disseminated with sulphides there are successive gradations into comparatively solid ores which are also gahnite-bearing. The quartzites are as a rule fairly coarse-grained; in most cases it is however possible to identify the *residual quartz phenocrysts*. The gahnite generally forms regular octahedrons which may have a diameter of up to 1 cm. In some cases relatively pure sericite-quartzites occur, but generally there is an admixture of more or less biotite.

Under the microscope the *biotite* is found to form large uniform flakes, as a rule fairly free from inclusions. Colourless mica occurs partly as fine-grained masses, partly as large flakes of *muscovite*. The gahnite is found to have crystallized distinctly later than sericite and biotite, but is replaced by sulphides, and there often seems to exist a very intimate relationship between the formation of gahnite and the deposition of sulphides. In one case a solid ore has been observed to contain an inclusion consisting of spinel-quartzite with *bytownite* forming fine-grained aggregates and *anthophyllite* in the form of large, homogeneous needles.

Staurolite-quartzite could only be studied in specimens from one of the old prospecting trenches and in some boulders obviously from the same zone. Megascopically this type appears as a coarse quartzite in which the recrystallization has progressed so far that it is not always possible to distinguish the original phenocrysts of the quartzporphyry. One type rich in *chlorite* and one rich in *biotite* have been observed. In both of these types pale red *andalusite* is visible to the naked eye in the form of small irregular spots, small brown *staurolite* grains, *gahnite* as well as idiomorphic crystals of *magnetite* and *arsenopyrite*. The latter may have a diameter of up to 1 cm. The mineral composition in two thin sections appears from the following volumetric analyses:

	Specimen No. 94	Specimen No. 95
Quartz	58	67
Andalusite	23.5	—[1]
Staurolite	8	8.5
Biotite	7	4
Chlorite	—	11
Gahnite	1.5	—
Magnetite	0.5	5.5
Sulphides (Arsenopyrite predominant)	1.5	4

Under the microscope the *biotite* is found to be of the normal brown type with abundant pleochroic haloes. In some cases the *zircon* grains themselves may be observed. The *chlorite* is light green and clearly replaces biotite in sample 2.

Andalusite forms large poikiloblasts with extremely irregular outlines and with a highly varying content of quartz inclusions. There exist all gradations

[1] In the hand specimen but not in the thin section.

from cases where quartz dominates andalusite to entirely homogeneous grains of andalusite. Biotite is sometimes found as irregular remainders in the andalusite grains (Pl. 24, a).

Staurolite, like andalusite, occurs in irregular poikiloblasts and clearly replaces both biotite and andalusite. In the chlorite-bearing specimen the staurolite grains have a strong tendency to assume idiomorphic crystal habit.

Gahnite, finally, occurs in very irregular grains and seems to have been formed later than even the staurolite.

A type, found in boulders only and evidently closely associated with the above-mentioned rocks, is a chlorite-quartzite representing a type of alteration still more enriched with iron. There thus occurs an altered quartzporphyry in which the groundmass consists almost exclusively of a coarse-grained chlorite in which the quartz phenocrysts still remain. *Magnetite* is also found, forming octahedrons with diameters up to 1 cm. In these coarse chlorite-quartzites there is often an abundant dissemination with *arsenopyrite* which also occurs in large idiomorphic crystals.

Quartzporphyries with lime-silicates are quantitatively very insignificant, but are of a certain interest from a genetic point of view. The best information regarding the occurrence of this type is obtained from the outcrops in the easternmost part of the outcropping area. Hornblende-rich schlieren up to one dm thick are found in the quartzporphyry and in this case they appear as fairly distinct veinlets, sometimes clearly cutting across the schistosity in the porphyry. On the other hand, these veinlets may also be said to have a metasomatic character, since the quartz phenocrysts of the porphyry are visible in the mass, in the same frequency as in the adjacent porphyry itself. Such an occurrence represents, as it were, a transitional type between replacement in the usual sense of the word and the development as normal veinlets. A carbonate vein has obviously penetrated the porphyry, the temperature being so high as to enable the lime to react with the wall rock, lime-silicates thus being formed. Similar schlieren have frequently been found in the drill holes, in which cases also *calcite* is often observed.

Under the microscope those parts of the skarn-schlieren which are poorer in hornblende have been found to consist of abundant quantities of *quartz* and *plagioclase*, the latter occurring in aggregates of round, equidimensional grains with irregular optic orientation. These aggregates often seem to brecciate the quartz mass. The plagioclase is very rich in anorthite, the composition of the examined specimen being $Ab_{10}An_{90}$. Fine lamellae according to the Albite and Pericline laws are common.

The *hornblende* is light green and forms large poikiloblasts with abundant inclusions of both quartz and plagioclase (Pl. 24, b). *Biotite* occurs partly in minute flakes uniformly distributed in the rock, partly in large flakes including small *zircons*. These large biotites also grow through the hornblende crystals.

Garnet is not uncommon and seems to have been formed in close connection with the crystallization of the sulphides. *Staurolite* occurs, too, in single grains.

The following order of crystallization can be established with a reasonable amount of certainty: plagioclase → hornblende → biotite → garnet → pyrite.

c. *Ores.*

Main Types and Relations to the Wall Rocks.

Several types of ore appear at Bjurliden. Thus, there is often found a differentiation into pure pyrrhotite ore with an insignificant content of other sulphides, and *pyrite ore* in which pyrrhotite is less conspicuous or entirely lacking. In the zinc-bearing portions the *sphalerite* occurs together with *pyrrhotite* in a fairly uniform distribution throughout the sulphide mass, whereas in the types rich in pyrite there is often found a more or less typical band-like structure, layers of pyrite and sphalerite alternating with each other. *Arsenopyrite* may sometimes be found in the solid ore types, generally in the form of idiomorphic crystals uniformly distributed in the sulphide mass. Though this mode of occurrence is the most frequent, true solid arsenopyrite ore of the extremely dense type has been observed in one case. It is exceedingly fine-grained and of approximately the same dense type as the solid arsenopyrite ore occurring at Boliden and in several other deposits in Västerbotten. At Bjurliden this solid arsenopyrite ore is intensely brecciated by the solid pyrite-sphalerite ore and occurs as small irregular fragments in it. *Galena* and *antimony minerals* are further megascopically visible. These are apt to occur together in schlieren in the solid ore. Sometimes similar schlieren rich in galena are found in the quartzite adjacent to the solid ores, in which case they occur in the form of well-defined veinlets and often cut across schistosity and stratification. As a rule arsenopyrite in idiomorphic crystals, up to 1 cm, also occurs in association with such schlieren. In the frequent cases where quartzite is enclosed in solid sphalerite-pyrite ore, most of the galena has been precipitated in the quartzite inclusions. In some cases *chalcopyrite* has been observed in the solid pyrrhotite ore, associated with hornblende-chlorite-rocks.

The relatively pure pyrite ores are as a rule fairly even-grained, the size of the grain being 0.5 to 1 mm. In a small part of the ore there occur types with grains 2—3 mm. The grains of the sphalerite-banded pyrite ores as a rule display greater variations, ranging from 0.2 to 1 mm.

Quartz seems to be the predominant gangue mineral in the comparatively solid ores. Especially in the northern ore lens there are often found round quartz "eyes" of the same character as the phenocrysts in the quartzporphyry. These have thus obviously been preserved, the groundmass of the porphyry having been replaced by the sulphides. *Biotite* and, to a smaller extent, *chlorite* are enriched especially in the pyrrhotite ores, while also *sericite* occurs in the pyrite ores, where, in certain cases, it entirely outweighs the ferriferous mica minerals. In one case round fragments of pure biotite-chlorite-rock have also been observed. *Gahnite* and, in rare cases, *garnet* occur here and there. *Plagioclase* (andesine—labradorite) is fairly common. It obviously belongs to a com-

paratively late stage of the mineralization, and under the microscope it is found to replace e. g. biotite. *Hornblende* has been observed, but is quantitatively of very subordinate importance. *Calcite* sometimes occurs, partly uniformly distributed in the sulphide mass, partly in the form of small lenses. In the calcite-bearing specimens quartz generally decreases in quantity. On the other hand *epidote* has also been found in these types.

All gradations are found from the comparatively solid ores to the poor disseminations. In general, however, the contacts of the solid ores parallel to the strike are fairly sharp, whereas in the direction of the strike the ore bodies successively grade into sulphide-free quartzite via disseminations. Further there are often portions where pure quartzite layers, one or two cm thick, alternate with solid pyrite bands. This development is especially conspicuous in the pyrite-rich ore types, the quartzites generally being light in colour owing to a high content of sericite or felspar. In such a type consisting of fine-grained pyrite in sericite-quartzite, *gahnite* has been observed as small beautifully idiomorphic crystals arranged in quite regular rows. Locally this type contains a *porphyritic pyrite ore* in which pyrite cubes up to 0.5 cm are embedded in the otherwise extremely fine-grained pyrite mass, which also contains well preserved quartz phenocrysts.

Special Mineralogy.

In addition to the opaque minerals visible to the naked eye, *viz. pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena, boulangerite*[1] or *jamesonite*[1], and *magnetite*, another series of minerals is disclosed in the microscopic examination. Antimony, especially, seems to have stimulated the mineral formation, and the mineral group of which antimony is an important constituent is found to contain a large number of various minerals. Thus we find the following minerals containing antimony with additional quantities of copper and lead: *tetrahedrite, bournonite, jamesonite, boulangerite*, and *geocronite*. The lead-copper-free Sb-minerals *gudmundite* and *pyrargyrite* have also been observed. *Bismuth* has been found in several specimens but always in minute quantities. The minerals *valleriite, bornite* and *hematite* have also been found in isolated specimens but in very insignificant quantities, and finally the two oxides *ilmenite* and *rutile* have been observed.

The three minerals that are so very predominant, i. e. *pyrite, pyrrhotite*, and *sphalerite*, are generally present in the majority of the investigated specimens. In specimens of extremely pure pyrrhotite or sphalerite ore, pyrite may, however, be entirely lacking. Completely pyrrhotite- and sphalerite-free types have been found among the sericite- and gahnite-bearing pyrite ores. In one specimen of this type sphalerite has been observed, however, but in this case entirely free from pyrrhotite, which is very uncommon. However, *marcasite* is also present in this specimen, it thus being probable that pyrrhotite previously existed but has been subjected to secondary alteration. The sphalerite in this

[1] Cf. p. 80.

specimen further seems to have a tendency to spread out of the pyrite mass proper and be precipitated together with mica in the comparatively mica-rich portions of the ore. The pyrite in these specimens displays an extremely irregular grain and gives the impression of having been intensely mechanically deformed (Pl. 25, a).

Otherwise, the pyrite grains are generally surrounded by a pyrrhotite-sphalerite-mass towards which they often present idiomorphic boundary-lines. The pyrite crystals are occasionally replaced by pyrrhotite and sphalerite, but generally the corrosion phenomena that can be observed microscopically in this ore deposit are comparatively insignificant. It is also possible to establish a marked difference in the relations of sphalerite and of pyrrhotite to pyrite, the former mineral having a greater power to replace the individual pyrite grains than the latter. Megascopically we can sometimes find how the pyrite grains are surrounded by a border of sphalerite, and the same thing is also found in detail on microscopic examination. In this case the sphalerite penetrates the pyrite crystals along the cleavage planes, corroding them to a certain extent. On the other hand, it is found that pyrite grains lying directly in the pyrrhotite mass sometimes show no signs of having been corroded.

The age relations between sphalerite and pyrrhotite are difficult to determine merely on the basis of the textures observed microscopically. Generally the relations between the two minerals display what are usually termed "mutual boundaries", these usually being regarded as evidence of simultaneous crystallization. According to van Schouten's investigations (*73*), similar textures may, however, also be formed by replacement. In the present case also the close association in the mode of occurrence indicates an intimate relationship between the two minerals, though it should be observed that the sphalerite in many cases shows an evident association with the distinctly late galena. In such cases there also occur textures which might suggest that the sphalerite, at least sometimes was really crystallized later than the adjacent pyrrhotite.

The sphalerite forms rounded or irregular grains, either comparatively homogeneous or with abundant inclusions of pyrrhotite in the form of staves or small rounded grains. Generally, the inclusions are regularly arranged in sinuous rows. The tendency to arrangement according to the main crystallographic directions of the sphalerite is usually slight, though it may occasionally be fairly distinct.

The pyrrhotite generally forms large uniform plates with rounded or irregular boundary-lines. A common characteristic of this deposit is that in most cases the pyrrhotite grains show distinct traces of mechanic deformation in the shape of frequent translation lamellae (Pl. 17, b). This translation may in places grade into the fine striation mentioned before, it thus being possible to find structures exactly resembling those illustrated in the textbook of Schneiderhöhn-Ramdohr (*72*, p. 134, fig. 58, and p. 135, fig. 60).

This deformation seems to have overtaken practically the whole sulphide mass. In narrow belts, however, there does occur a more intense crushing, the large pyrrhotite grains being crushed and divided into a number of small,

equidimensional grains. This results in an even-grained pyrrhotite mass which between crossed nicols displays a very marked granular texture and in which the individual grains may also show a marked uniform optic orientation. In these cases, the sphalerite grains are also disintegrated, but not to the same extent as the pyrrhotite, and textures are found of the kind illustrated in Pl. 30, a (from Ö. Högkulla).

Arsenopyrite is present in the majority of the investigated specimens but generally in small amounts as isolated crystals scattered in a groundmass of pyrrhotite or sphalerite. In its most common development it forms idiomorphic crystals up to 2 or 3 mm. In many cases all grain sizes are found, down to 0.01—0.02 mm. Owing to the great power of crystallization of arsenopyrite, however, it is not possible to use the idiomorphic crystallographic habit to establish the age of the mineral in relation to its surroundings. There are cases in which the mineral is obviously later than both pyrite, sphalerite, and pyrrhotite, when it grows as idiomorphic crystals across the outlines of these minerals. As mentioned above, there is often an enrichment of arsenopyrite in the late schlieren rich in galena, the mineral, however, being highly corroded by the lead-copper-antimony minerals. In these cases part of the arsenopyrite is apt to migrate from the galena veinlets proper and to be crystallized in the immediately surrounding quartzite or in the older sulphide mass. In such cases the paragenetic association affords evidence of the origin of arsenopyrite in a late stage of the mineralization. On the other hand, it is sometimes found how arsenopyrite grains are distinctly corroded by sphalerite and pyrrhotite. Finally, there are cases when fragments consisting of fine-grained arsenopyrite exclusively, are included in complex zinc-rich ores. This arsenopyrite was thus formed before the crystallization of the zinc-iron sulphides had begun. These results thus show that arsenopyrite is a decided "Durchläufer"-mineral which may be formed during very different stages of the deposition of the sulphides.

Chalcopyrite is quantitatively very subordinate in this deposit. It is true that it occurs in the majority of the specimens investigated, but in most cases there are but insignificant amounts. On the whole, it is possible to distinguish three modes of occurrence, between which, however, no sharp limits can be drawn.

Thus the mineral occurs together with pyrrhotite in the relatively pure pyrrhotite portions, and in this paragenesis it may be locally enriched, chalcopyrite dominating pyrrhotite. Pyrrhotite is more or less replaced, and when pyrite and sphalerite are present also these minerals are strongly corroded by the chalcopyrite. The relation to pyrite indicates that the chalcopyrite replaces that mineral to a far greater extent than pyrrhotite and sphalerite.

Another mode of occurrence is the presence of the above-mentioned small chalcopyrite blebs in sphalerite. Finally chalcopyrite is found in intimate association with the parageneses rich in lead and antimony. Then it crystallized comparatively late in relation to the minerals belonging to this paragenesis, too, and galena is the only mineral that, with certainty, has been found to replace it.

Of the other antimony-free copper minerals *valleriite* and *bornite* have been observed. Valleriite has been found in one single specimen and then as minute worm-like grains in chalcopyrite blebs in sphalerite. Bornite has also been found only in one single specimen and seems there to be an alteration product of tetrahedrite.

Galena is relatively common in the zinc-rich portions of the ore but it never occurs in large quantities. The association with copper-lead-antimony minerals is so general at Bjurliden that it has not been possible to find galena in any of the polished sections investigated without some antimony mineral being found at the same time.

Galena seems to be the latest sulphide to crystallize and it very beautifully replaces all earlier minerals, including the antimony minerals. Also under the microscope it is found to form veinlets or schlieren in the other sulphide mass. In the mylonized and recrystallized ore types galena often occurs as a fairly regular net-work of veinlets in the pyrrhotite (Pl. 25, b). As in these cases the adjacent sulphide ore, not subjected to mylonization, does not contain any considerable amounts of galena, the introduction of galena must have occurred after or in close connection with the deformation. This mode of occurrence thus proves that the mechanic deformation of the ore is directly associated with the actual ore formation.

In its relation to the gangue minerals galena displays a very high mobility and is sometimes pressed into mica or hornblende along the cleavage planes (Pl. 18, b).

Tetrahedrite is the most common antimony mineral occurring in the galena. In the majority of the galena-bearing polished sections, tetrahedrite is occasionally found in the galena, either as small rounded, more or less corroded grains or as real intergrowths with the galena (Pl. 20, a). The rare galena schlieren that are entirely free from tetrahedrite also lack all traces of chalcopyrite, and it is thus possible that the formation of tetrahedrite is to some extent adjusted by the amount of copper of the mineral-forming solutions.

Bournonite is the most common mineral in this paragenesis, next to tetrahedrite. This mineral is also apt to form intergrowths with galena.

Both *jamesonite*[1] and *boulangerite*[1] probably occur, though in several cases it has been impossible to determine even under the microscope which of the two minerals is present. Cleavage at right angles to the longitudinal direction has sometimes been observed, which, according to the text-book of Schneiderhöhn-Rahmdor (*72*, p. 404), is characteristic of jamesonite. The jamesonite has occasionally also been found to contain translation lamellae of about the same type as the corresponding lamellae occurring in pyrrhotite. In contradistinction to tetrahedrite and bournonite, jamesonite and boulangerite occur chiefly in homogeneous elongated crystals entirely free from galena.

The third pure lead-antimony mineral observed in this deposit, *geocronite*, has only been found in a few lead-rich quartz veinlets, where, however, it forms relatively large, uniform grains.

[1] Cf. p. 80.

The mutual relationship of the different lead-copper-bearing minerals suggests that they are closely related to each other with respect to the sequence of crystallization. The pure lead-antimony minerals, however, seem to be the first to crystallize in this group. In the geocronite, for instance, there are found veinlets of bournonite with galena which brecciate and replace this mineral. Jamesonite and boulangerite are replaced by bournonite + galena or tetrahedrite + galena.

The relations between bournonite and tetrahedrite are not quite clear. In some cases homogeneous tetrahedrite grains have been clearly replaced by bournonite-galena intergrowths, in other cases tetrahedrite-galena intergrowths are formed, when a lead-bearing solution corrodes bournonite. Occasionally there is a beautiful zoning with jamesonite or boulangerite in the centre surrounded first by a zone of bournonite + galena, then by a zone of tetrahedrite + galena, and finally, outermost, by pure galena.

The mineral *gudmundite* occurs in close association with the minerals described above. It is very common in the antimony-bearing parageneses and has been observed in all specimens where other antimony-bearing minerals occur in relatively large amounts, but always as minute crystals. In rare cases gudmundite is found as idiomorphic crystals in the gangue minerals or in complex sulphide masses near the contacts of lead-antimony-bearing veinlets. This mode of occurrence displays the largest isolated crystal needles, which, however, are never more than about 0.5 mm long. More frequently, however, gudmundite is formed when the antimony-bearing solutions replace pyrrhotite, in which case it often occurs on the contacts between tetrahedrite and pyrrhotite, very beautiful intergrowths with pyrrhotite often being formed (Pl. 19, b).

The skeleton-like development, too, has often been observed, when the gudmundite is entirely surrounded by galena, and when its formation is clearly associated with the replacement of bournonite (Pl. 19, a). Finally, gudmundite is also found as a direct product of disintegration of tetrahedrite, occurring together with chalcopyrite.

Pyrargyrite has been found in extremely minute quantities in several ore types rich in antimony. Generally it should be regarded as a disintegration product of antimony minerals rich in silver. It is thus found on fissures in the geocronite-bearing types, in which case fissure-fillings of pyrargyrite occur both in the geocronite and in the galena, and often traverse the contacts between these two minerals. However, it is more commonly found in association with tetrahedrite, and in some cases it is possible to establish the formation of a mixture of chalcopyrite, pyrrhotite, gudmundite, and pyrargyrite owing to the disintegration of homogeneous tetrahedrite grains.

Bismuth is the only native element of a primary nature that has been observed with absolute certainty. It generally forms small rounded inclusions in the galena. They may have a size ranging to 0.025 mm, but are usually considerably smaller. Occasionally bismuth shows a tendency to fill the cavities that are often formed between the cubes of galena. The mineral may

thus have remained in solution, even after the crystallization of the galena. In the galena-bournonite veinlets brecciating the geocronite individuals we may observe, under very high magnifications, small specks of a mineral with an extremely high reflection power, which mineral seems to be harder than galena, and consequently cannot be bismuth. Owing to the insignificant size of the grains it is not possible to make any exact determinations; *electrum* or possibly *dyscrasite* may be suspected.

Marcasite and *secondary pyrite* are the only minerals found in the microscopic examination of the ores that, in all probability, were formed by supergene alteration. Pyrite is here much more common than marcasite. The two minerals partly appear parallel to the cleavage planes (0001) in pyrrhotite (cf. Schneiderhöhn-Ramdohr, *72*, p. 139, Fig. 62), partly as irregular garlands with a certain zonal arrangement, marcasite and gangue forming alternating zones.

According to information received from A. Högbom and J. Eklund the earlier investigations also disclosed *native sulphur* as an alteration product of pyrite ore.

Of the oxide minerals *magnetite* predominates quantitatively. It may occur in large or small, generally rounded grains, either associated chiefly with the gangue minerals or appearing within the sulphide mass itself. The individual grains occasionally show traces of cataclastic deformation, but no replacement by the sulphide minerals can be established with certainty. In two or three cases small rounded inclusions of pyrrhotite, pyrite, and sphalerite, have been observed. As, however, magnetite must to a large extent have been formed in connection with the alterations in the silicate rocks, part of the magnetites occurring in the sulphide mass may be regarded as porphyroblasts.

Ilmenite is fairly common and has been observed in most polished sections of solid ore. In one single case this mineral has also been observed as small lamellae in magnetite. In some specimens rich in pyrrhotite ilmenite has been found as staves or small oval grains in a fairly regularly orientated intergrowth with the mass of pyrrhotite (Pl. 22, a), which mode of occurrence has already been discussed in the survey of the minerals (see page 84).

Rutile has been observed in a few specimens only, as minute round grains. It occurs partly in zinc-banded ores rich in pyrite, partly in ores very rich in zinc, in the latter case scattered in the sphalerite.

Hematite, finally, has been observed in ilmenite as very minute spots visible only when magnified 500 ×. This mode of occurrence is of a certain interest, however, as it may be used as a temperature indicator under certain conditions, indicating a relatively high formation temperature for the ilmenite (cf. *72*, pp. 543—547).

Sulphur and Metal Contents.

The metal contents in the deposit vary quite considerably. The pyrite ores may contain up to somewhat more than 40 % S, but generally the contents range from 30 to 35 % S. In sections two or three m. wide, the zinc content

may amount to 12—17 % Zn; a mean for the whole zinc-bearing portion of the ore is probably about 7 % Zn. The values of the analyses of lead vary quite considerably, which might be expected from the irregular distribution of the galena. The average content may be estimated at 0.5—1 % Pb. In a few analysed sections there are, however, 2—3 % Pb. The determination of Co and Ni in some samples showed that these elements are very sparse (0.00 % Co, 0.05 % Ni). Bi sometimes occurs, 0.01—0.02 %. The contents of gold and silver vary on the whole with the lead contents so that in the sections relatively rich in lead there generally occur Ag contents of 100 to 250 gr/t. In one case more than 800 gr/t Ag was found, but this sample also had the highest Sb content (0.07 %), and as a correlation of the results of microscopic examinations and chemical analyses seem to indicate that the silver is contained chiefly in the antimony minerals, the Ag content mentioned is easily explained. The gold contents are generally low and only exceptionally amount to a few gr/t. In one of the samples richest in silver determinations of platinum have also been carried out, four different samples of the same material, however, yielding values ranging from 0.5 gr/t to 12 gr/t. It is further of a certain interest that small amounts of tin have been found in one of the specimens richest in lead.

3. Snåttermyran.

About 3 km E of the Bjurträsk ores there are some minor electrical indications which have been investigated by means of two drill holes and a number of prospecting trenches. The indications were found to have been caused chiefly by disseminations surrounded by extensively altered rocks. The trenches are no longer accessible, the following description being based on older material and the information that may be gained from the drill holes.

The altered rocks from this area so closely resemble the corresponding types from the Bjurträsk ores and Bjurliden that a detailed description in most cases is unnecessary. Thus, quartzporphyry has been changed into a coarse-grained *sericite-quartzite* with very marked linear schistosity. In the hanging wall there are generally found *chlorite-quartzite* types, and nearest the ore *chlorite-rock* occurs containing large *magnetite* octahedrons, thus the same type as occurs in the Bjurträsk ores close to the ore in the eastern part. Together with the light quartzite there has been observed a *bytownite-rich quartzite* with abundant amounts of *epidote* and *calcite* and carrying *actinolitic hornblende* as small rosettes in the groundmass.

The character of the sulphide mineralization is best seen from the results of the drill holes. It is not at all so extensive as at Bjurliden and the Bjurträsk ores, and in general there are only found disseminations of *pyrite* and *pyrrhotite* in sericite-quartzite. A more solid ore lens about 1 m. thick has, however, also been intersected by the drill holes. This lens consists of a complex *pyrrhotite-pyrite-sphalerite* ore with a slight galena content.

Under the microscope some *chalcopyrite* and a few small tetrahedrite grains are observed together with the galena. Small irregular grains of *pyrargyrite*

have also been found in one specimen — a remarkable fact, as the silver content is not especially high. In addition, *arsenopyrite* and *gudmundite* have been observed as small idiomorphic crystals.

4. Low-grade Disseminations in the Eastern Part of the District.

Poor sulphide disseminations with attendant alterations of the silicate rocks occur in several places. Generally these have the character of narrow but relatively continuous belts of sericite-quartzite or chlorite-quartzite containing more or less sulphides. The most interesting of these mineralized areas is a belt that runs about 500 m N of the Bjurträsk ores and parallel to the marked zone of schistosity through the eastern part of the Malånäs District. This mineralization can be followed, partly in outcrops, partly as magnetic or electrical indications between them. In the best exposed areas there occur quartz-porphyries transformed into chlorite-quartzite and sericite-quartzite. The altered rocks display a very distinct linear schistosity and are always somewhat crumpled. The content of quartz-phenocrysts is considerably higher in the intensively altered rock than in the unaltered porphyries. The individual phenocrysts are sometimes flattened and partly dissolved, in which case there is formed a type that might be termed veined chlorite-quartzite, and which contains coarse quartz as veinlets. In these types there have been observed some peculiar textures which may contribute to explaining the origin of the crumpling of the rock. Under the microscope there are in fact sometimes observed quartz grains which have obviously been subjected to plastic post-crystalline bendings (Pl. 26, a.). The quartz axes to a certain degree have the same optical orientation, the variations in the orientation of the axes being only caused by the bending of the quartz strip (see fig. 13). The centre parts of the strips in some places consist of absolutely clear quartz, while the quartz in the corresponding margins have been crowded with finely divided sericite, but both types have the same optical orientation. It may be assumed that the clear quartz was formed by the recrystallization of the crowded types, perhaps due to the action of circulating solutions. The structure as a whole may have originated in the following manner. When subjected to deformation the quartz grains are intensely elongated, in which case fissuring may also take place. In a later stage, when the bedrock, owing to the introduction of the solutions with an attendant intense formation of sericite and chlorite, will behave more plastically during the deformation, the fissure planes formed earlier may also be crumpled. The advance of the solutions along such fissure planes more or less contributes to the recrystallization of quartz, the recrystallized quartz attaining the same optic orientation as the quartz forming the walls of the fissure. These plastic movements are obviously the same as the movements causing the crumpling, observed even megascopically in these chlorite-quartzites. The sericite is arranged between the bent quartz limbs in complete agreement with the examples of paracrystalline folding illustrated by Sander (67, pp. 269—270, Figs. 145 and 146).

Chlorite-free, entirely white sericite-quartzite occurs in narrow belts with relatively sharp boundaries to the chlorite-bearing types. Under the microscope these rocks are found to consist of quartz and sericite only, the latter with a strongly marked parallel arrangement.

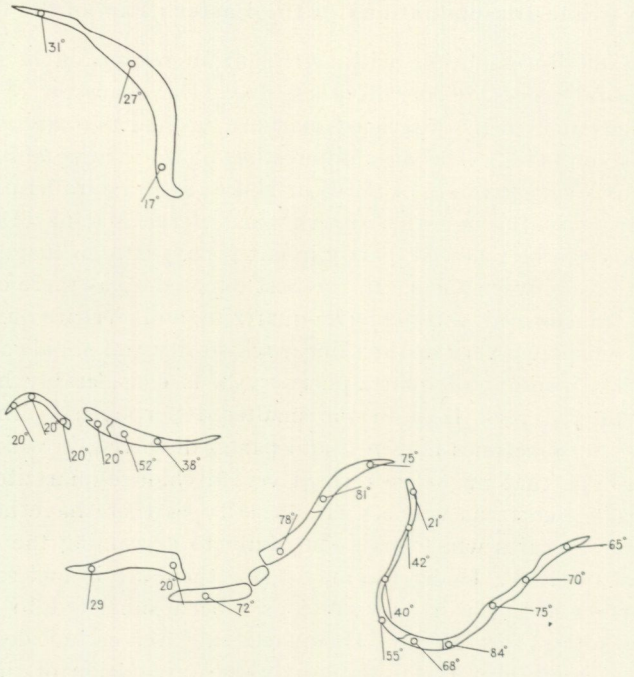


Fig. 13. Orientation of the optic axes in bent quartz grains in chlorite-sericite-quartzite (cf. Pl. 26, a)

Other sporadic, mineralized zones, which occur both S of the Bjurträsk ores and N of the last-mentioned belt, provide no further important data bearing on the problems regarding the alteration of silicate rocks.

5. The Bjurfors Field.

The Bjurfors ore field is situated immediately south and south-west of Örträsk village about half-way between Ö. Högkulla and Bjurträsk. This field, which has a length of 900 m, is usually considered to comprise three different ore bodies, which according to their mutual location have been called Eastern Bjurfors, Middle Bjurfors, and Western Bjurfors.

The Eastern Bjurfors Ore.

a. *Tectonic Features.*

This ore, which, economically, is the most important one in the group in question, can be characterized as a pyrite ore with varying copper contents. No other metals in quantities to be of economic value are present. On account

of its location and general character, this ore has been examined quite thoroughly by the practically complete removal of the overburden, by shafts and by means of drifts and crosscuts at the 30 m level below the rock surface, and finally by drill holes in order to supplement the information gained. Thanks to these investigations we are safe in saying that the shape of the outcropping ore body is almost completely known. Pl. 35—36 show the form of the ore and the distribution of the altered rocks in the best-known sections through the ore body. The main axis of the ore is, on an average, practically horizontal, but in detail it presents slight undulations. This causes the intersection of the ore with the surface to be fairly large, as the undulations of the axis lead to a repetition of corresponding parts of the ore in different parts of the exposed area. The depth of the ore, on the other hand, is slight, and dependent upon the extension of the ore at right angles to its axis. The contacts and the band-structures in the ore usually dip 50°—70° S. In the easternmost part of the exposed ore, all signs indicate a pitch of the axis of 25°—30° WSW. Fragments and quartzite beds also display a tendency to be orientated in this direction. In the middle part it is difficult to obtain definite proofs of the pitch of the axis. Enclosed fragments and quartzite beds here often stand southwards, and occasionally we find a tendency towards the development of a linear structure in the same direction. The curve of the thickest of the quartzite beds running straight through the ore thus has occurred along an axis pitching about 60° SSW. At the sharp southward curve of the northern ore contact, however, we find that the ore contact and also minute folds in neighbouring chlorite-rock have an axial direction pitching 25° SE—ESE. In the westernmost part it is impossible to obtain definite proofs of the direction of the axis on the basis of observations made in the outcrops, but upon combining these observations with the results from the westernmost drill hole, it can be established that as far as it is possible to speak of a true axial direction, it must also in this case pitch to the WSW.

The corresponding tectonic features are very much clearer at the 30 m level, where the lower contacts of the ore can be studied in detail. In the easternmost part we find fold-axes pitching 20°—35° WSW. Between the third and fourth crosscut E of the crosscut from the shaft we find an axial depression and in the second crosscut to the east we find a very distinct axial direction pitching 30° ESE. In the westernmost part, finally, the tectonic features are more indistinct, but the fact that the ore does not extend farther westward at the 30 m level than at the surface certainly shows that if we here, too, are to count with axial directions pitching westwards, the ore cannot be supposed to extend in this direction for any very considerable distance, but must in such a case soon wedge out and disappear.

Usually we find the planes of schistosity fitted into the structures described above, and particularly at the 30 m level the sulphides are often found to form very pronounced bands or stringers orientated along such planes of schistosity. Occasionally, however, we find a fairly marked direction of schistosity abruptly crossing ore stringers and older axial directions. This secondary schistosity

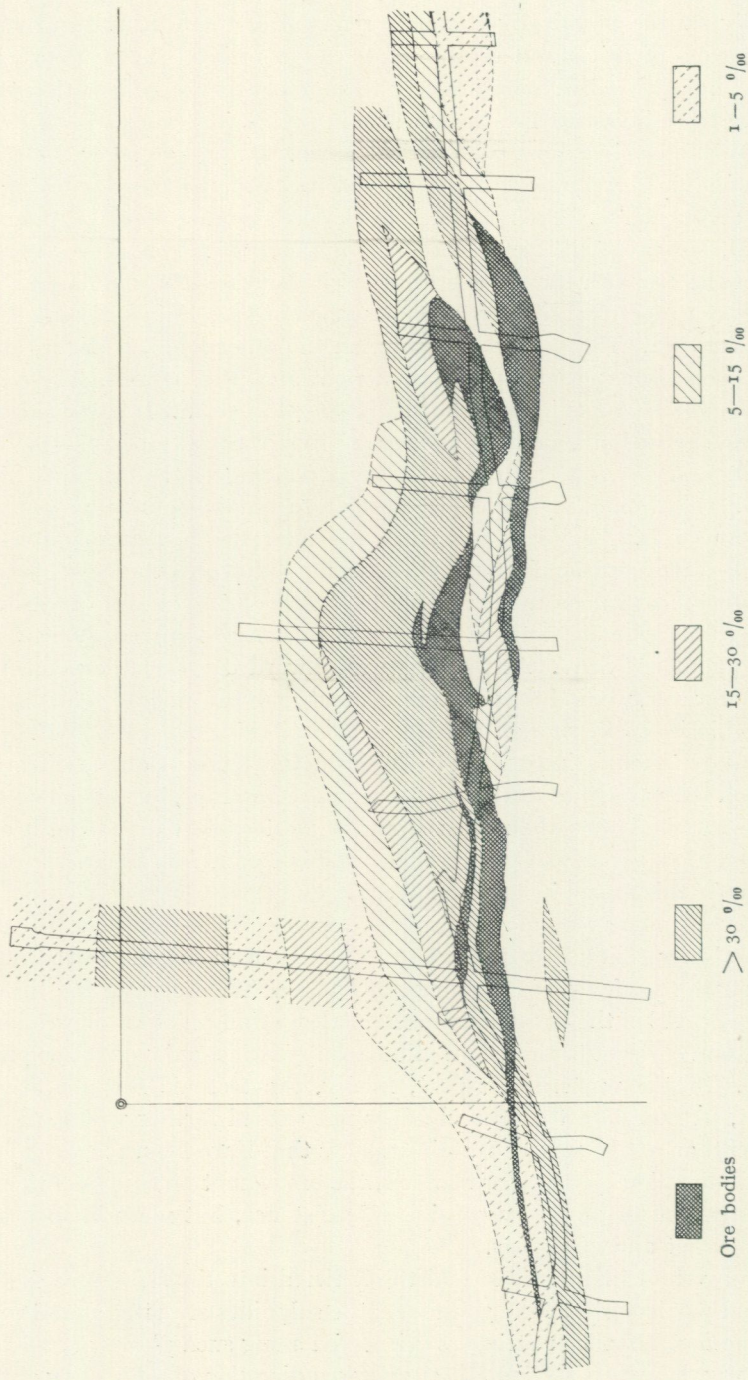


Fig. 14. The distribution of quartz of vein type at the 30 m level, Eastern Bjurfors ore. The quartz content has been calculated in ‰ of rocks in the respective sections.

occurs in the foot wall of the ore and is most clearly developed at the 30 m level in the easternmost parts. The strike is generally parallel to the ore contacts or the pyrite stringers; the dip is steep towards the north or is vertical. Such a steep schistosity occurs also in the western part of the exposed ore, intersecting the axial direction pitching moderately ESE.

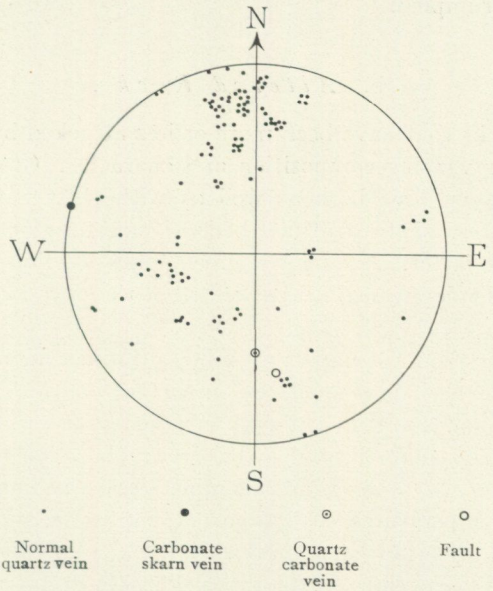


Fig. 15. Stereographic projection of quartz and calcite veins at the 30 m level, Eastern Bjurfors ore. (Projected on the upper hemisphere.)

In this ore faults are of no importance at all for the main tectonic features. In isolated cases dislocations of a few metres along steep east-west lines are found. Such faults have only been found in the foot wall of the ore. However, fissures without dislocations have evidently been of fairly great importance during the late stages of the deformation, which is apparent from the abundance of quartz veins. The frequency of the quartz veins thus constitutes an approximate measure of the intensity of the fracturing. Fig. 14 gives a summary of the frequency of quartz veins at the 30 m level calculated in per mille of rock within certain sections of the individual drifts or crosscuts where the occurrence of quartz is fairly uniform. It will be seen that the introduction of quartz is greatly intensified towards the ore in the foot wall side. The deviation from this rule in the western part of the 30 m level is due to the fracturing there mainly being localized to the massive chlorite-quartzite, which is less apt to be deformed plastically during the deformation than the other rocks. Fig. 15 shows a summary of the directions of the most important veins. As will be seen from the illustration there is a decided maximum for directions dipping steeply northward. The veins belonging to this generation always turn out to be younger than the more irregular ones, among which we find at least a tendency, as

far as the larger ones are concerned, to become orientated along lines running north—south. A certain variation in the appearance and composition can also be established between the two different generations, the younger veins being pure quartz veins, usually forming absolutely linear fissure-fillings, while the earlier generation of veins sometimes may contain calcite and skarn, and are often somewhat crumpled.

b. *Altered Rocks.*

The country rocks that have been more or less attacked by the ore solutions have had a rather varying composition and character. Greenstones alternate with quartzporphyry lava beds as well as with their more or less bedded pyroclastic derivates. Interstratified beds of limestone are also found in association with the latter. Among the greenstones we find representatives of the normal hornblende-greenstones as well as of the pure albite-chlorite-greenstones.

Chlorite is by far the most important mineral formed in the wall rock during the mineralization. Sericite is much less important and pure sericite-quartzites are rather uncommon. Pure chlorite-rock in which quartz is of very subordinate importance, is fairly common, and in this type black hornblende needles are not infrequent. On the other hand, all minerals are lacking that are characteristic of higher temperatures, such as garnet, cordierite, andalusite, staurolite, etc. On the basis of certain structural variations, a classification of the chlorite-quartzites has been made on the maps, Pl. 35—36, into schistose chlorite-quartzite, veined chlorite-quartzite, and massive chlorite-quartzite.

Schistose chlorite-quartzite. The most common development is the schistose chlorite-quartzite, in which *quartz* and *chlorite* are the main components. *Biotite* generally occurs, though in very small quantities, and also more or less *sericite*. As was the case with the corresponding altered rocks from the Bjurträsk ores and Bjurliden, the latter mineral has a certain tendency to gather in spots or schlieren of a more or less brecciating character. When the altered rock consisted of quartzporphyry, the quartz phenocrysts are still retained in this stage of metamorphism.

Veined chlorite-quartzite. In some cases *quartz* and *chlorite* are separately enriched in schlieren, and the schlieren-structure is megascopically visible. Altered rocks of this kind appear mainly in the foot wall. A great part of the quartz appears to be added to the rock and the quartz schlieren are often directly connected with the abundant, more separate quartz veins. Megascopically, too, these types display an extremely irregular distribution of the individual minerals. The chlorite does appear in the form of small flakes, comparatively uniformly distributed also in areas richer in quartz, but is mainly enriched in schlieren, which are either arranged along the planes of schistosity or along lines running obliquely towards these planes. In

the chlorite schlieren regenerated *plagioclase* has occasionally been observed, having a composition corresponding to basic oligoclase. In other cases there occur fairly sharply delimited *sericite* spots, which give a strong impression of being sericitized plagioclase crystals. Accessory *apatite*, *titanite*, and *zircon* have been observed.

Massive chlorite-quartzite. Megascopically some of the chlorite-quartzites display a more massive structure and can often be told apart from the previous group also thanks to their occurrence. A rather uniform magnetite impregnation is also characteristic of this type of alteration, imparting to the rock a characteristic dotted aspect. This type occurs in the quartzite bed running straight through the ore and also in the chlorite-quartzites bordering on the solid ores in the north. In many cases the massive chlorite-quartzite seems to have been formed directly from the albite-chlorite-greenstones. The first stage in the alteration is then seen in the magnetite dots mentioned above, at the same time as a certain secondary addition of quartz can be established.

Under the microscope we find the *chlorite* to be fairly uniformly distributed, forming small flakes, which also here, however, show a certain tendency towards a parallel arrangement. *Biotite* also occurs in small flakes and in certain instances it can distinctly be seen that it has replaced the *magnetite* very beautifully (Pl. 26, b). Minerals of the *epidote*-group appear in small granular aggregates; *hornblende* and *titanite* may also occur in some types.

Along the northern contact of the ore in the western part of the exposed area we find biotite-banded chlorite-quartzite, being of a certain value for an understanding of the formation of some of the band-structures. The biotite there occurs in narrow stringers, 2—3 cm apart (see Pl. 23, b). The band-structure is so regular that one would first feel inclined to interpret it as a residual structure of some original bedding. That this cannot be the case, however, is evident from the fact that there occur a swarm of biotite layers of exactly the same character, but in this latter case sometimes pyrite-bearing, which cuts the more prominant banding. Here we are thus more likely faced with a biotite invasion along the fissure-planes, which penetrate the rock in swarms, in one direction or the other.

Sericite-quartzite. As already mentioned pure sericite-quartzites are of rather minor importance in the Eastern Bjurfors ore. Sections rich in *sericite* appear in the veined quartzite types N of the ore body, but not to such an extent nor so continuously as to be separated in the mapping. S of the ore body, however, we find more typical sericite-quartzite belts. It is remarkable that these quartzites present very sharp boundaries towards the surrounding chlorite-quartzites. In one instance we thus find a sericite-quartzite bed three metres wide, on both sides sharply bounded by highly schistose chlorite-quartzite, which in turn grades into normal schistose and veined chlorite-quartzite.

Chlorite-rock and skarn. Pure chlorite-rocks in which *chlorite* greatly dominates the *quartz* is a fairly common result of alteration in the Eastern Bjurfors ore. Although transitional types from chlorite-rocks to chlorite-quartzites of course may be found, the boundary is usually comparatively distinct, and it is generally not very difficult — even on so small a scale as 1 : 800 — to follow the different belts of chlorite-rock. Small lenses of chlorite-rocks which it has been impossible to indicate on the map, certainly do appear also in the areas mapped as veined chlorite-quartzite.

As will be seen in the map of the 30 m level and the cross-sections, Pl. 35—36, chlorite-rock generally appears close to the ores or as direct continuations of them. The types more or less directly associated with the ores, usually display a very marked linear schistosity, chlorite forming comparatively large flakes. Another development consists of more massive types forming a fine-grained chlorite mass with some quartz. As was the case in the massive chlorite-quartzites, we here often have very regular *magnetite* dots. In a number of cases these altered types rich in chlorite seem to have been formed from rocks fairly rich in iron and magnesia, whose original character has thus contributed to the creation of extreme altered rocks. On the other hand quartzporphyry rocks can also have been changed into massive chlorite-rocks, for small bluish quartz "eyes" are sometimes found in the chlorite mass, which in all probability should be interpreted as residual quartz phenocrysts.

The dense chlorite-rocks are often felspathized, and clear *plagioclase* plates can then be observed fairly uniformly distributed in the chlorite mass. Under the microscope the plagioclase crystals are found to be fairly zonal, but lack inclusions. In one specimen their composition varied between $Ab_{74}An_{26}$ and $Ab_{67}An_{33}$. In one of the zonal grains the kernel had the composition $Ab_{67}An_{33}$, and the shell $Ab_{69}An_{31}$. An introduction of *chlorite* and *sericite* or *albite* arranged along the cleavage planes in the crystals could occasionally be observed. In one specimen where also the groundmass was rather highly sericitized, the kernels of the plagioclase plates were almost completely altered, the remainder consisting of albitic plagioclase.

Sometimes the chlorite plates display a certain flow structure around the plagioclase plates, indicating that movements occurred also after the formation of plagioclase. In addition, chlorite has not infrequently been recrystallized in the spaces behind the large plagioclase crystals. On the other hand, instances fairly often occur when the plagioclase crystals quite distinctly have grown across the schistosity.

Under the microscope *biotite* can be observed in the shape of small, scattered grains, but often as larger flakes in the spaces behind large plagioclase crystals. As is the case in the chlorite-quartzites, however, biotite also displays a tendency to originate at the expense of magnetite. A decided enrichment of biotite was thus observed at the contact between plagioclase and magnetite grains. Furthermore the magnetites are replaced in the same manner as illustrated in Pl. 26 b, but in this case biotite is usually not formed immediately, but we find instead an isotropic, yellowish brown mass, probably some iron

hydrate. In association with this brown mass we occasionally find *calcite* and *pyrite*.

In one case *titanite* occurs in fairly abundant quantities, then often forming margins around *ilmenite* grains. There also occurs a mineral, always surrounded by pleochroic haloes, which in all probability should be considered as decomposition products of *orthite*, cf. Pl. 15 b and p. 75.

In some types of chlorite-rocks we find dark *hornblende* needles irregularly penetrating the chlorite mass. These types usually appear in the foot wall of the ore near the ore contact. Under the microscope the hornblende needles are found to grow through the chlorite mass as well as through the sparser biotite. The hornblende seems to belong to the same series as the common greenstone hornblendes. Colour and pleochroism:

α light bluish green
β light green
γ pale yellow—colourless

$\alpha = 1.618$, $\gamma = 1.643$, $\gamma - \alpha = 0.025$
$2V_\alpha = 75°—76°$ $\quad c : \gamma = 18°$

Numerous small spots consisting of equidimensional, small quartz grains were observed in one of the hornblende-bearing types. A small ilmenite grain is often found in the middle of each quartz aggregate. This relationship is beyond doubt, even though every ilmenite grain in the thin section is not surrounded by such quartz, and quartz spots also occur in which no ilmenite can be observed. The quartz spots appear in the chlorite mass as well as in the hornblende needles. Pure hornblende skarn occurs locally. Calcite, some quartz, and sometimes *phlogopite*, have also been observed in this mass.

Quartz and carbonate veins. As already mentioned we here find an abundance of quartz veins. These veins usually contain *quartz* only, sometimes with a little *chlorite*, and here and there some *pyrite*. The mineralogical variation is greater in the *carbonate*-bearing quartz veins, where the lime has reacted more or less with the wall rock, forming lime-silicates. In addition this group comprises types rich in pyrite, forming gradations to the solid ores.

The most important carbonate-bearing veins are found at the 30 m level as well as in outcrops in the westernmost part of the ore. In the latter *hornblende* occurs as isolated needles or arranged in rosettes. In some cases we also find lumps of hornblende skarn. Megascopically the hornblende is usually light green, but at the 30 m level there are also dark hornblendes, often associated with the lighter types. In thin sections the lighter hornblende is practically colourless, while the darkest type becomes pale green. Hornblendes of the two types occurring in the same thin section have the following optic properties:

	$2V_\alpha$	$c:\gamma$	$\gamma - \alpha$
Colourless hornblende	85°	20°	0.030
Light green hornblende	76°	17°	0.025

Phlogopite, too, is often found in the veins rich in lime and hornblende and forms fine-grained aggregates or larger uniform individuals. In rare cases there are calcareous veins in which hornblende or mica are entirely lacking, calcite and quartz appearing in practically equal proportions.

c. *Ores.*

Main Types.

The greater part of the ore consists of a more or less *cupriferous pyrite ore*. In certain sections we find a pyrite ore relatively poor in copper which also forms large connected parts. The pure pyrite ore is usually fairly even-grained, the grains varying in size between 0.1 and 0.4 mm. *Chalcopyrite* and *pyrrhotite* can always be seen megascopically, although in these types only as quite small, individual grains. *Quartz* and, not infrequently, *chlorite* are other minerals megascopically visible as streaks or marked stringers.

The individual grains in pure pyrite ores that are particularly rich in chlorite, are usually larger, and grains with a diameter of about 1 mm are often predominent. An increase in the amount of pyrrhotite and chalcopyrite produces complex ore types, in which the mutual proportions of the minerals present all feasible variations. In ore types rich in pyrrhotite but poor in copper the pyrite often appears as irregularly porphyritic grains, usually with a tendency towards cubic habit but very often of a quite irregular shape. This porphyritic pyrite usually appears in sizes of from 1 to 3 mm.

The commonest type of the extremely complex ores shows a marked schlieren-structure, heterogeneous as far as the size of the grains is concerned. Chalcopyrite and pyrrhotite form veinlets in the pure pyrite sections, the pyrrhotite having a certain tendency to form veinlets of a distinctly brecciating character. Such veinlets are often parallel to the chlorite stringers previously mentioned, but occasionally cut them. The chalcopyrite is often enriched towards the pure pyrrhotite veinlets, and in some cases it may also appear as small, separate schlieren, but usually it occurs as a more diffuse dissemination. Sometimes we find a distinct zoning in the narrow veinlets, a central stringer of pyrrhotite being surrounded by fairly pure chalcopyrite. According as chalcopyrite appears as more separate veinlets, these latter often intersect distinctly older band-structures. In these types pyrite forms either porphyritic, more or less idiomorphic crystals, or appears as quite dense schlieren or lenses together with gangue minerals. The sizes of grain in these fine-grained pyrite masses are usually from 0.01—0.03 mm. The dense pyrite schlieren are in all probability the result of a mechanic deformation of an already crystallized sulphide mass. As they also are very closely associated with the veinlets of chalcopyrite

and pyrrhotite one receives a general impression that the precipitation of the chalcopyrite and pyrrhotite is connected with or immediately superceded by a rather considerable cataclastic deformation. In such types as well as in the purer pyrite ores there often occurs *magnetite* in megascopically visible quantities, either as isolated grains or in rarer cases enriched in small streaks and lumps.

Certain parts of the ore are developed as high-grade copper ore with 7—10 % Cu. They are often very regularly porphyritic types, in which idiomorphic pyrite crystals (1—2 mm) are uniformly distributed in a groundmass of chalcopyrite and more or less pyrrhotite. In the types richest in chalcopyrite where the analysed sections contain 10—12 % Cu, the chalcopyrite is often coarser and the quantity of pyrite decreases. Ore types rich in copper often contain fairly considerable quantities of calcite, the latter appearing either as small, irregular aggregates or occasionally as small, real inclusions, rounded or angular. Calcite sometimes reacts with chlorite, forming *hornblende*, which occurs as black scattered needles in types rich in copper.

In certain parts of the copper-rich ore layer at the eastern point of the ore, the carbonate mass can dominate the sulphides, hornblende appears, and types are found of exactly the same character and appearance as in the carbonate-sulphide mass occurring as veins in the westernmost part of the ore (see the map, Pl. 35). As all gradations from the abundantly calcareous ores to the solid ores are found in the eastern part, while the western part presents examples of gradations between the same type and normal calcareous quartz veins, the field relations here provide very good proof of the intimate genetic relationship between solid ore and veins.

In a few cases — in the central part of the ore and at the westernmost point — *sphalerite* is megascopically visible. It there appears in pyrite ores that are extremely poor in copper, and a tendency towards band-structures is usually found, bands one cm wide, rich and poor in sphalerite, interchanging. Quantitatively, however, this form of development is of very little importance.

Finally, solid ores have also been observed, consisting of a very fine-grained, complex sulphide mass, often rich in copper, with plenty of rounded fragments of quartz, chlorite, and carbonates.

In the wedging out of the solid ores in the direction of strike, downward as well as in the horizontal plane, there usually occur disseminated types, often developed in chlorite-rock. According as such types of ore constitute the wedging out of pyrite ores rich in copper, the sulphide minerals in the disseminated part consist principally of chalcopyrite and pyrrhotite, making also these disseminations relatively high-grade copper ores. Low-grade pyrite disseminations, however, also occur to a fairly large extent, and this is particularly true of the 30 m level in the foot wall of the main ore. Occasionally we also find *sphalerite* here, and *galena* in small quantities has been observed in quartz schlieren. Usually the sulphides in the disseminations are gathered in schlieren or stringers which according as the disseminated rock displays a decided schistosity, help to create intensely linear structural types. In the mas-

sive chlorite-rocks and in quartzites rich in chlorite, however, the pyrite usually appears in the form of extremely regular, small, cubic crystals, evenly distributed in the rock.

Special Mineralogy.

As a result of the microscopic examination, the list of minerals was supplemented with a number of species over and above those already found megascopically, *viz.*: *arsenopyrite, cubanite, valleriite, gudmundite, ilmenite, rutile,* and the supergene minerals *marcasite* and *secondary pyrite*. The mutual relations of the different minerals seem to agree completely with the conditions ruling for the deposits earlier described, for which reason only a few textural characteristics typical of this ore will be dealt with in greater detail. With regard to the relation of the sulphide minerals to the gangue minerals, here, as well as earlier, the former generally seem to have been formed later than the latter. For pyrite, however, it is difficult only from the observed textures to obtain definite proofs in one direction or the other, as pyrite usually appears as idiomorphic crystals in the gangue, even when it is definitely later than neighbouring minerals. On the other hand, irregularly-shaped grains are sometimes found which almost seem to be corroded by gangue minerals, but it is so difficult to interpret these textures that no definite statements can be made either way or other.

In the pure pyrite ores, *pyrite* forms skeleton-like aggregates, the individual crystals being of a fairly uniform size. There is always a certain amount of *chalcopyrite* and *pyrrhotite* in the spaces between the individual pyrite grains. The dense pyrite schlieren just mentioned consist of extremely small crystals in gangue mass, but they are generally practically free from other sulphide minerals. Pl. 27 a shows the contact between such a fine-grained form and the "normal" ore. If the proportion of pyrite is very high in these dense schlieren, very peculiar skeleton-like developments occur, which often greatly resemble certain replacement textures.

When occurring in abundant quantities, sphalerite as well as pyrrhotite and chalcopyrite very extensively replace pyrite, but it should be noted that the chalcopyrite seems to possess a considerably greater corrosion power than pyrrhotite and sphalerite, which, moreover, may themselves be greatly replaced by chalcopyrite. The replacement of pyrite often results in extremely peculiar textures. In some cases the replacement is only the result of a uniform corrosion, giving rise to decided corrosion bays in otherwise idiomorphic crystals; in other cases the decomposition follows cracks formed by mechanic deformation or takes place along cleavage faces in the crystal (Pl. 27, b). Examples of a selective replacement of certain zones of the pyrite crystals are very often found, the original crystal habit being apparent from narrow remainders in the homogeneous chalcopyrite mass (Pl. 16, a). However, it is generally not possible to observe an arrangement of the remainders that is so regular and conspicuous as the one illustrated in Pl. 16 a, but extremely

irregular pyrite skeletons are formed instead, filled with chalcopyrite and more or less pyrrhotite (Pl. 16, b).

In the copper-rich ores where the pyrite, megascopically, seems to appear as uniform, idiomorphic crystals in a groundmass of chalcopyrite, rather varying textures are found upon microscopic examination. In some cases the pyrite crystals are but slightly corroded, in other cases the grains bounding directly on the chalcopyrite are greatly replaced, while the pyrite grains that have been more or less protected by gangue minerals display idiomorphic forms. Sometimes the replacement of these types also appears to be closely connected with a recrystallization of pyrite, for large pyrite crystals or aggregates are broken up by the chalcopyrite and instead of them we find a number of small, decidedly idiomorphic crystals.

Pyrrhotite as well as *chalcopyrite* usually form large, uniform grains and in the majority of cases show no signs of mechanic deformation. Twinning lamellae are thus generally retained in chalcopyrite, and in pyrrhotite we hardly ever find even a sign of translation-lamellae. Mylonized and secondarily recrystallized chalcopyrite-pyrrhotite ore may occur locally, showing decidedly granular textures. Such textures thus appear in the dense ore previously mentioned containing small, round fragments of gangue minerals, a type of ore whose parallel has already been described from both Bjurliden and the Bjurträsk ores. Such a granular development is also found close to gliding planes of an entirely local character, and it is characteristic that such forms are apt to appear in the immediate proximity of veinlets of pure pyrrhotite.

Sphalerite usually occurs in most of the specimens, but nearly always in very insignificant quantities. It is only in the pyrite ores poorest in copper that it is entirely lacking. In most cases the mineral forms small, irregular, corroded grains in the chalcopyrite. In the ore types richest in sphalerite it forms large, homogeneous grains with a rather insignificant amount of enclosed chalcopyrite and pyrrhotite. These latter minerals are, what is more, of very minor importance in these types. Where sphalerite appears in large, uniform grains in copper-rich parageneses, there is, however, an abundance of small chalcopyrite blebs arranged according to the crystallographic directions of the mineral. In such cases it is fairly probable, however, that the chalcopyrite is later than the sphalerite and has been introduced into it.

Cubanite has sometimes been observed in the copper-rich ores, in the shape of regular lamellae here and there. The modification called cubanite II in Schneiderhöhn-Ramdohr's text-book has been found in one instance in the contact between ordinary cubanite and chalcopyrite. The pyrrhotite in the specimen that was richest in cubanite often had a peculiar appearance, occurring there as quite narrow vermicules on the contacts between chalcopyrite grains (Pl. 28, a). Exactly similar textures are described by Stevenson (77, p. 445), who interprets the pyrrhotite vermicules as secondarily separated from the chalcopyrite. The fact that they appear here in the parageneses richest in cubanite may support such an interpretation, and as cubanite in the form of lamellae is usually considered to have been formed by the disintegration of

originally uniform grains, the chalcopyrite should in these cases already at the time of its formation have contained an excess of iron sulphide.

Valleriite often appears in the chalcopyrite as extremely small, worm-shaped grains, in many cases visible only upon being enlarged 500 ×. It is remarkable that the mineral has been found also in the latest fissure-fillings, which consist of almost absolutely pure chalcopyrite without other sulphides.

Galena is extremely rare. It has been observed in quite small grains in one of the specimens from the pyrite ores rich in sphalerite, but is more generally associated with the post-sulphide veins, or with ore types closely related to them. Galena has thus been found in the quartz-rich schlieren in the disseminated area at the 30 m level, in the large pyrite-bearing carbonate vein in the western part of the exposed ore, and in the type of ore that in the easternmost section partly grades to types of the same kind as the vein mentioned.

Arsenopyrite also appears very scantily, and considering the general character of the Västerbotten ores it can be said that the scarceness of arsenopyrite is the most characteristic feature of the Eastern Bjurfors ore. Small, isolated arsenopyrite grains have been observed in but very few specimens of the solid ore. It is of great interest, however, that arsenopyrite occurs in much greater quantities in the sulphide-carbonate vein in the western part of the ore than in any of the specimens of the other types.

Here the mineral appears in the form of idiomorphic, extremely small (on an average 0.01 mm) crystals, often enriched in groups, and always lying together with the carbonates. Arsenopyrite is never found in direct contact with the fairly abundant chalcopyrite or pyrrhotite. *Gudmundite* has also been found in the same sample in a couple of grains of the same size as the arsenopyrite. The occurrence of these minerals, shows that there was a clear tendency in this ore so extremely poor in antimony and arsenic, towards an enrichment of the small quantities of these elements in the last stages of the mineralization.

Magnetite is without comparison the most important oxide mineral, and is present in nearly all of the specimens examined. It occurs in the sulphide mass as well as together with gangue minerals. It generally forms rounded grains. Pyrite inclusions are very common, pyrrhotite and sphalerite (see Pl. 21, a) are rarer. The significance of these inclusions has already been discussed in the general survey of the minerals (p. 83), and the most probable interpretation undoubtedly is that pyrite and, in most cases, also pyrrhotite and sphalerite, represent true inclusions. Generally the outlines of the magnetite grains display no distinct signs of corrosion caused by the sulphides, but chalcopyrite sometimes appears distinctly replacing. However, its corroding influence upon magnetite is much less pronounced than upon pyrite, and in a mixture of pyrite and magnetite it can be seen how the former mineral is selectively and intensely replaced while the latter remains fairly intact. It will be seen from the above, however, that magnetite in its present appearance must be assumed to belong to the sulphide stage. As, however, there are many examples of magnetite development in a fairly early stage of the alteration of the silicate rocks, it

would be reasonable to assume that the present magnetite generation is a recrystallization product of earlier magnetite, and that the magnetite crystals with abundant inclusions should be looked upon as a sort of porphyroblasts.

Ilmenite has never been observed in the solid ores, but appears together with the silicates in specimens of disseminated ore types. As is usually the case, it forms small, rounded grains scattered in the silicate mass. *Rutile* has been found in a similar development in a specimen of the zinc-rich pyrite ore, in an ore rich in pyrite but poor in copper, and finally in quartz schlieren rich in pyrite.

Supergene alteration of pyrrhotite in *marcasite* or *secondary pyrite* has been observed in a few cases, but is generally of no great importance here. The texture and general appearance does not differ from the cases described from Bjurliden. According to verbal information from A. Högbom, insignificant quantities of *native copper* have also been observed in the form of a film in fissures.

A microscopic examination of the gangue minerals from the different types of ores in many cases discloses *plagioclase*, in addition to the megascopically visible minerals, *chlorite*, *sericite*, *quartz*, and *calcite*, already mentioned. In the specimens examined the anorthite content varies between 30 and 45 %. The plagioclases are usually developed as uniform grains with abundant inclusions of chlorite, mica, and quartz, and in many cases they are highly disseminated with pyrite. Sometimes only insignificant remainders appear of a practically destroyed plagioclase generation. These small plagioclase remainders are often much richer in An than the better preserved types. *Phlogopitic mica*, too, is often found in ore types rich in lime. Finally, fairly abundant quantities of *epidote* have been found in some cases.

Sulphur and Metal Contents.

The exposed ore is estimated at 250,000 metric tons with 2.4 % Cu and 31 % S. This ore, however, includes certain sections consisting of comparatively pyrite-free chlorite-quartzite or chlorite-rock, which probably constitute at least 10 % of the entire quantity of ore. The actual sulphide ore would thus contain an average of 2.7 % Cu and 34.5 % S. As already pointed out the copper contents vary quite considerably, but the sections with a copper content of from 8 to 10 % are not very large. In the eastern part of the ore, however, it is safe to figure with a continuous part amounting to about 50,000 tons with at least 4 % Cu.

An analysis intended to represent the average content of the outcropping area is given below, and shows the contents of still further elements:

	Weight-%	Mol.prop. × 1,000
S	35.9	1,119.8
Fe	40.6	727.1
Cu	2.65	41.7
Zn	0.10	1.5

	Weight-%	Mol.prop. × 1,000
Pb	0.00	0.0
As	0.07	0.9
Sb	0.02	0.2
Co	0.06	1.0
Ni	0.00	0.0
Sn	0.00	0.0
Se	0.021	0.3
SiO_2	8.58	142.9
Al_2O_3	1.56	15.3
CaO	1.83	32.6
MgO	2.46	61.0
Na_2O	0.3	4.8
K_2O	0.0	0.0
CO_2	3.0	68.2
$H_2O^{+105°}$	1.52	84.4
$H_2O^{-105°}$	0.50	
	99.17	

Relations to the Wall Rocks.

Thanks to the rather completely exposed area of outcropping ore and the underground work at the 30 m level, this ore provides a very rich material for the study of the relations of the ores to their wall rocks. Important information can be secured regarding the processes by which the ores have obtained their present form and location. As will have been seen from the preceding description the exposed ore consists largely of a solid cupriferous pyrite ore with chlorite stringers, and with a small quantity of quartz. The ore body also contains continuous beds of massive or somewhat schistose chlorite-quartzite. Included fragments of the same rock are also found here and there, often arranged in rows parallel to the strike, an arrangement indicating that they probably constitute broken parts of formerly continuous beds. Such fragments may be strongly elongated, but are usually more or less rounded. Shape and size will be seen from the map, Pl. 35. Inclusions with a diameter of about one metre have been observed at the 30 m level, both elongated ones, forming "rods" in the ore, and almost spherical fragments. The contacts of the solid ore with such inclusions as well as with the similar foot-wall quartzite in the outcrop is absolutely sharp and covered with a thin chlorite film. The chlorite stringers follow the contacts of the fragments with great fidelity.

In some cases, however, the ore solutions appear to have strongly attacked and more or less dissolved the quartzite. In the direction of strike massive chlorite-quartzite is thus found to be corroded and transformed into chlorite stringers. Sections with an abundance of chlorite stringers usually occur between the individual fragments in the rows of fragments.

Although the contact of the solid ore parallel to the strike is usually perfectly sharp, conditions are entirely different where the ores wedge out, which is best illustrated by two examples from the exposed area. Fig. 16 shows solid pyrite ore with chlorite stringers in contact with massive chlorite-quartzite.

The gradation from chlorite-quartzite into ore has the following appearance along the direction of strike. First we find a network of intersecting cracks in the quartzite. They are filled with chlorite, increase greatly in number towards the ore, when the chlorite mass also increases and pyrite begins to appear together with the chlorite. We thus find a sort of transitional zone which can be defined as a kind of breccia with more or less rounded fragments

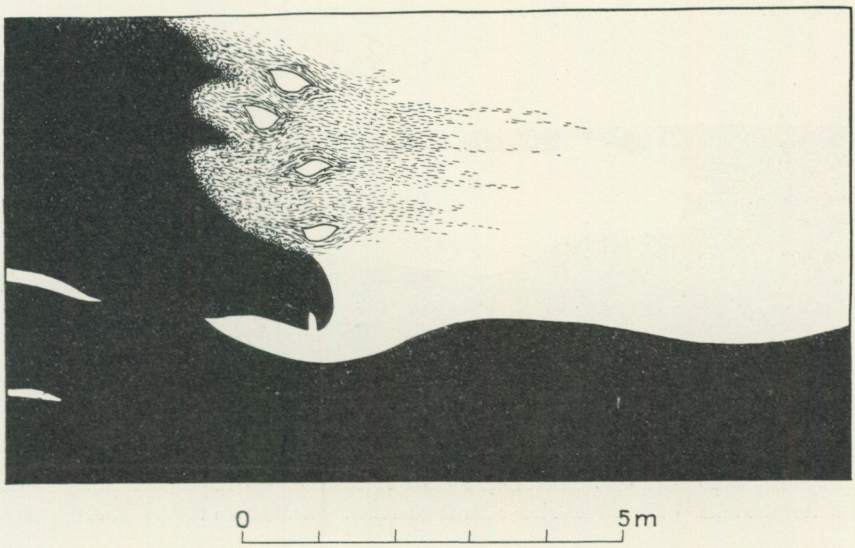


Fig. 16. Contact relations between massive chlorite-quartzite (white) and solid cupriferous pyrite ore (black). Shaded part = chlorite-rock. Outcrop from the Eastern Bjurfors ore.

of massive chlorite-quartzite in a chlorite mass with disseminated pyrite. Due to a great increase in the pyrite content and due to the fact that the fragments of chlorite-quartzite decrease in number, the breccia, in a transitional zone of one or two metres, changes into solid pyrite ore. This detail discloses, however, that the chlorite stringers often found in the solid ore directly in the strike of beds of massive quartzite, cannot in such cases be interpreted as a residual structure occasioned by the silicates being replaced by sulphides, as we find that a similar parallel structure is entirely lacking in the original rock. It would seem more probable that the arrangement of the chlorite as stringers in the sulphide mass should be looked upon as a kind of fluidal structure, originated in connection with movements during the formation of the ore minerals. As already mentioned the chalcopyrite veinlets often intersect the chlorite bands. Highly mobile solution phases thus existed at the time of the development of these bands, and at that stage the whole mass was thus probably still rather mobile.

Another example intended to illustrate how the sharp contacts between solid ore and chlorite-quartzite originated is shown in fig. 17. The upper limit of the ore is perfectly straight and can be traced into the chlorite-quartzite as a marked joint line. A narrow, solid pyrite stringer penetrates the quartzite for

some distance along the fissure, but is soon pinched out in an insignificant chlorite streak (at the right in fig. 17). The sharp contact of the ore with the quartzite is thus in this case due to a fracture towards which the ore solutions have deposited their material. It is not possible in this case definitely to decide to what extent the formation of space in the precipitation of the ore takes place by replacement of chlorite-quartzite or by pushing aside the walls

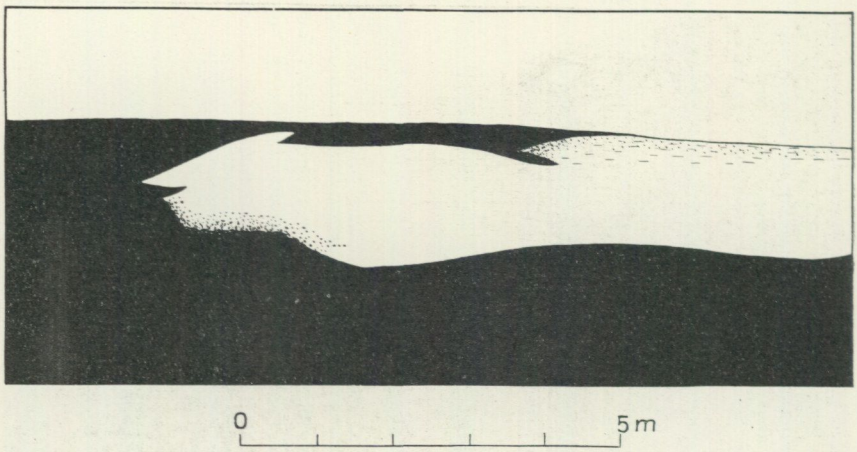


Fig. 17. Contact relations between massive chlorite-quartzite (white) and solid pyrite ore (black). Small irregular lines = marked schistose chlorite-quartzite. Outcrop from the Eastern Bjurfors ore.

of the fissure; this question will be discussed in greater detail further on. According as fractures intersect each other there are of course possibilities for the detachment of fragments, and the conditions illustrated in fig. 17, with the intruding pyrite vein in the upper part of the illustration, might be looked upon as a first step towards the complete detachment of a quartzite fragment.

Fig. 18 shows the contact conditions as they appear in the walls of a crosscut in a locality from the 30 m level. We find here a sort of "boudinage" structure, the chlorite-banded ore representing the highly plastic phase, while the chlorite-quartzite remains rigid and chiefly reacts to the deformation by fracturing. The still plastic pyrite mass is pressed into the chlorite-quartzite along the fissure planes, and here a differentiation can be observed, the outermost points being enriched in chalcopyrite, and the fissures emanating from them are usually filled with quartz. A similar differentiation has been described by Ödman at Boliden (*87*, p. 142), where chalcopyrite separates from solid pyrite ore and appears in cracks in adjacent sericite-schists. A differentiation of the same type is indicated by the occurrence of quartz-schlieren in the larger fragments enclosed by ore. Such quartz veins very often contain coarse chalcopyrite, but usually lack pure iron sulphides. The veins usually stop at the solid pyrite ore, but in some cases they can also be followed a distance into it, a circumstance showing that they could not have been formed before the

deposition of ore. The most feasible explanation of this phenomenon presumably is that the quartz veins are segregations from the more solid ore in the same way as is the case in fig. 18. That illustration also shows an example of how inclusions are formed. If the pyrite »intrusions» occurring there become larger and intersect each other, quartzite of the same character as that in the fragments will be detached.

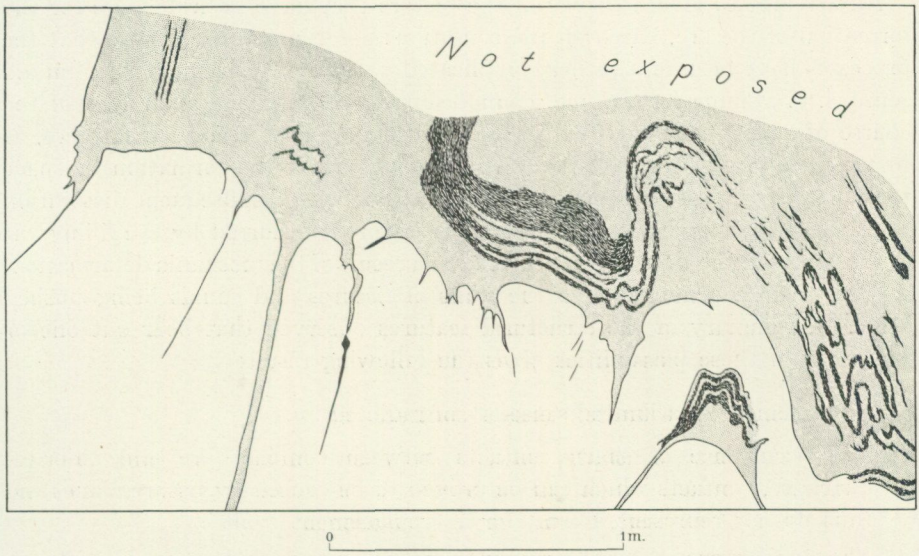


Fig. 18. Contact relations between massive chlorite-quartzite (white) and solid cupriferous pyrite ore (grey) with schlieren of chlorite (irregular small lines). At the points of the ore quartz-filled fissures (black). Eastern Bjurfors ore, 30 m level.

A true ore breccia with round or oval fragments of chlorite-quartzite in a solid, copper-rich pyrite mass, has been observed at the 30 m level. That this is no replacement breccia in the ordinary sense of that term is apparant from the fact that the planes of schistosity of the fragments are sometimes differently orientated, for which reason the individual fragments must have been moved from their original location during the introduction of ore. It may also be pointed out that the adjacent chlorite-quartzite gives an impression of being more highly chloritized than the fragments in the breccia.

Although sharp contacts between compact pyrite ore and comparatively pyrite-free chlorite-quartzite have thus been established in several places also at the 30 m level, such contacts are not of the same quantitative importance here as in the outcropping area. Ores interbanded with chlorite-quartzite and chlorite-rock occur to a great extent, and may grade either into more solid pyrite ores or into sulphide-free quartzite. Similar conditions exist at the eastern point of the outcrop, excepting, however, the solid middle layer rich in copper, which the whole time forms a delimited solid ore. The impression is thus created that the more pronouncedly banded types of ore represent the pinching out of the solid ores, whether horizontally or vertically.

It has already been pointed out that the chlorite stringers may originate by the ore solutions partially dissolving massive chlorite-quartzite, when the banding should be interpreted as a sort of fluidal structure. The experiences from the 30 m level show that also the band-shaped interchange of different rocks helps to form similar structures, certain rocks being attacked more than others or being more intensely penetrated by the ore solutions.

An attempt to give a survey of the factors that have been decisive for the formation of the ore, based on the conditions described above, shows that the processes have been of a rather complicated nature. Replacement in a limited sense, i. e. volume for volume, cannot supply a complete explanation of the course of events connected with the origin of the ores. The question here, as in practically all such cases, will be to what extent the formation of space took place by means of a purely chemical attack with a subsequent dissolution of the pre-existing silicates, and to what extent it occurred by the filling out of the spaces in the country rock formed as a result of the mechanic deformation, and by their widening due to the walls of fissures and canals being pushed aside. A summary of the structural features observed that bear out one or the other of these possibilities gives the following result:

A replacement in a limited sense is contradicted by:

1. The occurrence of sharp contacts between compact ore and chlorite-quartzite, contacts which can be proved to be caused by fissure planes and thus do not represent a limit for a "replacement front".
2. The appearance of band-structures in the ore which have no parallel in the rock supposed to be replaced, and the fact that these band-structures conformly follow the contacts of the fragments in the ore. That such structures nevertheless are directly connected with the actual deposition of the sulphides is borne out by the fact that chalcopyrite is often found to be crystallized after the development of the chlorite bands.
3. The appearance of the quartzite beds in the solid ore mass. Sharp curves in one bed have no parallel in a quartzite bed in its immediate proximity. It is difficult to combine such a structure with the assumption that the ore minerals in their present location merely replace previously existing quartzite.
4. The occurrence of true ore breccia, where the linear structures of the inclusions are differently orientated.

The following factors may be considered to indicate a replacement or at least a certain chemical activity by the ore solutions:

1. The occurrence of disseminated and pyrite-streaked chlorite-quartzites, which by the increase of the sulphide content successively grade into solid ores.
2. The directly observed structures indicating a dissolution of a number of fragments and their replacement by ore with abundant chlorite stringers.

According to these observations it would thus seem undeniable that a dissolution of the silicates has been of some importance, but even when the sulphide mass must be considered largely to have been gathered in its present location, it has had enough mobility to behave purely intrusively and to form such structures as for instance the ore breccia mentioned and fissure-fillings of ore emanating from the solid ore, e. g. in fig. 18. In addition it is characteristic that in all cases where the ore is palpably "intrusive", it consists of pyrite with abundant chalcopyrite.

Conclusions Regarding the Origin of the Ore.

Referring to the facts stated above, the sequence of events, as interpreted by the author, can be summarized as follows. The metals have probably advanced as a sulphide solution, the ore space in the first place being orientated along the faintly undulating primary fold-axis. The arrangement and precipitation of the sulphides seem also extensively to have been dependent on the purely mechanic deformation to which the country rock was subjected. The changes must thus be conceived as having been superseded by a fairly intense fracturing of the more or less massive original rocks (cf. fig. 16) or by a foliation of the stratified rocks. The rounded fragments should probably be looked upon as portions which for one reason or other were detached and escaped a more intense mechanic crushing.

Stage 1 would thus represent the advance of the sulphide solution, when a certain dissolution of silicates occurs with a simultaneous crystallization of pyrite. There occur movements in the still mobile sulphide mass, mainly in the shape of differential movements parallel to the contacts of the ore and parallel to the original fold-axis. Judging from curves in quartzite beds, etc., these movements seem usually to have had the direction illustrated by system No. 1 in fig. 19. Incompletely resorbed chlorite here forms stringers, already crystallized pyrite is mylonized, etc. The linear structures created certainly become dependent upon the outlines of the harder rocks, which form inclusions in the ore, but their general tendency is to become practically perpendicular to the main fold-axis.

Stage 2 is represented by the deposition of more abundant quantities of pyrrhotite and chalcopyrite. The chalcopyrite sometimes occurs in the shape of small veinlets, whose direction indicates that they are "Fiederspalten" in relation to the chlorite stringers in the pyrite ore. There are also sharply crosscutting, well-defined pyrrhotite veinlets, from which chalcopyrite spreads and replaces older minerals.

Owing to the crystallization of a large part of the pyrite, the liquid phase remaining is gradually enriched in copper, and these ore solutions rich in copper seem to have a certain tendency to become pressed out and precipitated along the contacts with the quartzite beds. A zonal structure is often indicated, parts richer in copper forming an outer zone around solid pyrite bodies, poor

in copper. The copper-rich solid ores are often very rich in lime, and among them we find gradations into

Stage 3 which is represented by the older vein generation. To this stage belong the lime-chlorite-chalcopyrite vein in the outcrops, the lime-skarn vein at the 30 m level, and the older quartz veins, whose directions on the whole coincide with those of the two first-mentioned veins. It is characteristic for

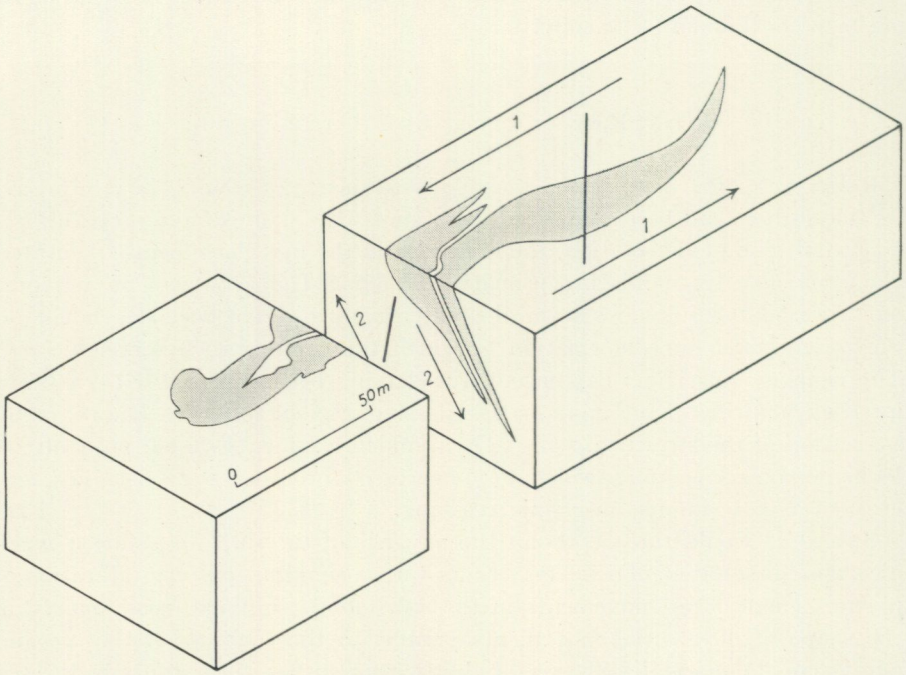


Fig. 19. Block diagram of the Eastern Bjurfors ore. The arrows indicate the probable differential tensions in different stages of the evolution.

these veins that they are to a certain extent crumpled. This produces the impression that the system was not quite rigid at the time of their formation. The direction of the veins is what would be expected of a "Fiederspalten" system to the differential stress illustrated by the arrows 1 in fig. 19.

Stage 4 is represented by the later quartz veins, whose predominant direction is parallel to the longitudinal direction of the ore, and which dip steeply northward. This system comprises the fissures that open as a result of a "subsidence" of the ore, the system as a whole being rigid. The differential stresses are then completely changed and are illustrated by the arrows 2 in fig. 19. In connection with this "subsidence", the vertical or steeply northward schistosity would then also be formed, which in several places has been observed to intersect ore streaks and ore contacts.

The Middle Bjurfors Ore.

This ore has been examined exclusively by means of drill holes from the surface, the ore having been intersected 20—35 m and 60—80 m below the surface. The ore consists of more or less solid pyrite beds with a slight content of zinc (Pl. 37). Due to the difficulty to make reliable correlations between the different levels, no definite statement can be made regarding the exact dip of the ores. Measurements of the magnetic vertical intensity with the Schmidt-type magnetometer indicate a dip towards SW of the magnetic field. On the other hand, the results of the drill holes make it seem more probable that at least the main axes of the individual ore bodies are orientated slightly more southward. In any case we are here faced with steeper and probably more uniform linear structures for the individual ore bodies than were found at the Eastern Bjurfors ore.

a. *Altered Rocks.*

Here, as was the case at the Eastern Bjurfors ore, the alteration of the rocks bounding on the ores has been rather extensive. The same types of original rocks seem to have occurred to a great extent, and the altered types are also very similar. We thus find *veined chlorite-* or *chlorite-sericite-quartzites* in the foot wall on the eastern part of the ore and east of the ore bodies, of exactly the same type as the corresponding types described from the Eastern Bjurfors ore. In the hanging wall there are mostly pure *sericite-quartzites*, and this is particularly the case in the western part of the altered area. Here we thus find the same tendency in the distribution of chlorite-free and chlorite-bearing quartzites as in the eastern ore, *viz.* that the chlorite-quartzite generally appears under the ore, while the pure sericite-quartzites occur above the ore. A boundary-line between chlorite-bearing and chlorite-free quartzite types can be drawn on the map, even though this line of course is not sharply marked. As a matter of fact chlorite increases successively from the pure sericite-quartzites, and isolated beds of pure sericite-quartzite can also be found in the chlorite-bearing parts. The boundary-line drawn on the map is thus a limit between on one side an area where chlorite and sericite appear together, and on the other an area where chlorite retires completely. Curiously enough this limit does not conform with the stratification and schistosity, but cuts them at an oblique angle (see the map of ores and altered rocks, Pl. 37).

The sericite-quartzite in the hanging wall of the ore occasionally alternates with quartzite, containing frequent *calcite* schlieren, when, however, instead of sericite we find a pale brown *biotite*. In these types we also find *plagioclase* rich in anorthite in the form of irregular, often elongated poikiloblasts. Pale green *hornblende* has also been observed in isolated cases. This seems to be older than the calcite and is to a certain extent replaced by it.

Greenstone, hornblende-bearing as well as pure chlorite-albite-greenstone, is very common. As was the case in the western ore, it is often more or less changed into a type with frequent magnetite dots, *massive chlorite-quartzite* or

pure *chlorite-rock*. The latter is sometimes intensely felspathized. It may seem strange, however, that in one place a greenstone bed is absolutely unaffected by the alteration, in spite of its being surrounded by greatly altered chlorite-quartzite, developed from quartzporphyry rocks, while the corresponding bed a distance away has changed to chlorite-rock, without there being any sign of an increase in the grade of alteration in the surrounding rocks. The explanation of this difference in the alteration of the greenstones is still an open question. One explanation may be that the permeability has been of decisive importance for the solutions and this in turn would depend upon the mechanic deformation to which the different parts of the bed in question have been subjected. An interesting illustration of how freakish is the alteration, is found upon examining two specimens from the greenstone bed between the two thickest ores in drill hole No. 2, one taken close to the ore contact, the other from the middle of the greenstone bed. A megascopic examination of the rocks discloses in neither case any other signs of alteration but that the rock is crowded with spots of *magnetite*. Under the microscope they both prove to consist of typical chlorite-albite-greenstones, the albite developed as well-defined laths. *Ilmenite* and *titanite* occur in fairly abundant quantities. In the specimen taken from the ore contact, however, *quartz* is more plentiful, and small spots of pure chlorite mass are also found, which evidently has completely replaced the albite in these areas. We are thus faced with an example of an origin of chlorite-rock on a small scale, which leads to the development of quite irregularly distributed chlorite spots in the remaining albite-chlorite mass. It is very interesting that the mineral which has been observed in other chlorite-rocks and which is surrounded by pleochroic haloes also occurs here and there in these chlorite spots, which mineral has been assumed to be *orthite* or decomposition products of orthite. With reference to the alteration of the greenstones it should also be mentioned that in the hornblende-bearing types we often see how the chloritization also includes the hornblendes.

b. *Ores.*

Main Types.

A description of the types of ore in the Middle Bjurfors ore can of course not be as complete as the one of the Eastern Bjurfors ore, the results from the Middle Bjurfors being accessible only from the drill holes. The greater parts of the investigated ore beds consist of *pyrite*, occasionally with abundant *sphalerite*. The ores are developed as solid ores and as disseminations with practically equal parts of sulphide and silicate minerals. The disseminations may occur both in pure sericite-quartzite and in chlorite-rocks. The size of the grains and the structure are exactly the same as those of the pyrite ores of Eastern Bjurfors. Dense streaks are sometimes found here, too, in the otherwise fairly even-grained ore. The solid ores rich in zinc are very regularly interbanded, one cm wide bands rich in zinc and rich in pyrite inter-

changing with each other. In *pyrrhotite*-bearing ores belonging to the deeper portions of the ore, the pyrrhotite is also found enriched in bands or streaks. Certainly the banding is not at all so regular here as in the zinc-rich types, but a tendency towards the development of a similar structure can be established. Schlieren of dense *arsenopyrite* have been found in a couple of places in the chloritic pyrite ore. The gangue minerals seem to be the same here as in the Eastern ore. *Quartz* and *calcite* are common, the latter often fairly abundant in the form of small spots or schlieren in the compact pyrite mass. *Chlorite, muscovite, hornblende,* and *plagioclase,* have also been observed.

Special Mineralogy.

The following minerals have been observed when examining the ores under the microscope: *Pyrite, pyrrhotite, chalcopyrite, sphalerite, arsenopyrite, galena, tetrahedrite, bournonite, jamesonite*[1] or *boulangerite*[1], *gudmundite, bismuth, electrum* (?), *magnetite, marcasite.* The order of crystallization and the mutual relationship of the different minerals are generally of the same character as those of the corresponding ores already described. The outlines of *pyrite* in the pure pyrite ores are often fairly irregular, while in cases where sphalerite occurs in greater quantities, it often forms very regular cubic crystals. In some cases, however, the pyrite grains have highly corroded outlines as compared with the boundaries of *sphalerite, pyrrhotite,* or *chalcopyrite* crystals. When chalcopyrite is abundant, skeleton-like textures are even found of the same appearance as the corresponding textures in the Eastern Bjurfors ore. Pyrrhotite is generally present, but usually appears in but very small quantities. The sphalerite contains the usual inclusions of pyrrhotite and, to a smaller extent, chalcopyrite. More abundant chalcopyrite inclusions are only found in the specimens richest in copper. The quantitative importance of pyrrhotite is less here than in the Eastern Bjurfors ore. It occurs as large or small uniform grains and shows no evidence of mechanic deformation in the shape of translation lamellae. In many cases it is extensively changed into marcasite.

Arsenopyrite occurs differently here to what was the case in the ores earlier described. Unlike the Eastern Bjurfors ore, it is fairly common and has been found in most of the specimens examined. It occurs in rather abundant quantities, but usually forms quite small grains arranged in groups or rows in sphalerite, or, to a smaller extent, in pyrrhotite. When arsenopyrite occurs in sphalerite it sometimes seems to be arranged in rows similar to those formed by the small pyrrhotite grains. In some cases aggregates are found of arsenopyrite grains lying close together, often with a skeleton-like appearance, and not infrequently we find galena enriched in the cavities of such crystal skeletons. (Pl. 28, b).

Galena and *antimony minerals* appear sporadically, but the mutual relationship and the proportions between these components are not so regular as for instance at Bjurliden. *Boulangerite* (or *jamesonite*) thus seems to be the

[1] Cf. p. 80.

most common of the antimony minerals, and, besides, it may occur practically without galena. On the other hand, galena-bearing specimens entirely without antimony minerals are sometimes found here. The insignificant quantity of galena found in the types rich in boulangerite forms narrow lamellae parallel to the cleavage planes. In certain cases the boulangerite here also replaces *tetrahedrite*. *Bournonite* has been found in one specimen only, but then quite plentifully, in regular intergrowth with galena in the same manner as at Bjurliden. In close association with the lead-copper-antimony sulphides, *gudmundite* usually occurs in small crystal aggregates. In one instance, however, the mineral has been observed in a specimen quite free from other antimony minerals. Small quantities of pyrrhotite are often found together with gudmundite, but no regular intergrowths have been observed of the type found at Bjurliden. *Bismuth* in the shape of extremely small, rounded grains in galena is found in the parageneses richest in lead-antimony, and *electrum* may possible occur in one of the specimens rich in chalcopyrite.

Contrary to what was the case at the Eastern Bjurfors ore, magnetite seems to be entirely lacking in the more solid ore types here. On the other hand, *rutile* has been observed as insignificant grains in zinc-rich disseminations.

Sulphur and Metal Contents.

The two northernmost ore beds are the most solid ones and also those richest in zinc. One analysed section contained as much as 38 % Zn, but as the drill hole here seems to be practically parallel with the bands and on the whole follows one and the same sphalerite band, this value is hardly representative of any considerable portion. But there do occur sections a couple of metres thick with about 10 % Zn. The average content of the whole beds of this section, however, is probably about 5 % Zn, to which must be added a lead content of maximum 0.5 %. The sulphur content is on an average 35—40 %, some parts having up to 45 % S.

The two southern ore bodies contain an average of about 30 % S and very little Zn, but the eastern part of the ore bed next to the southernmost one contains an average of 3—3.5 % Zn.

The mean arsenic contents are low, but still decidedly higher than in the Eastern ore. The average from drill hole No. 1, for the two southern ore beds poor in sulphide, is thus 0.18 % As, and for the two northern beds, richer in sulphide, 0.36 % As. The same sections were also analysed for selenium, the result being 0.002 % and 0.012 Se, respectively. The contents of gold and silver are also low, silver generally 20—30 gr/t; in the northern beds we find 72 gr/t Ag, and in the parts richest in zinc there occur values slightly exceeding 100 gr/t Ag. The gold contents vary in the solid ores from 1 to 2 gr/t Au.

The Western Bjurfors Ore.

The westernmost mineralized belt of the Bjurfors group has been examined by means of four drill holes. Primary rocks and alterations are of identically the same character as at the other Bjurfors ores, although the alterations here are not at all so extensive as in the former cases. The ore zone forms a belt in which solid and disseminated *pyrite* and *pyrrhotite* beds interchange. The ore zone is up to 4 m thick and contains 0.5 m wide beds having up to 42 % S, but usually the sulphur contents are less than 30 % S. *Chalcopyrite* and *sphalerite* occur, but nowhere in such quantities as to be of economic importance. Sphalerite is found locally, however, enriched along the contacts to the solid ores.

Besides the minerals already mentioned, the microscopic examination also disclosed *arsenopyrite*, *galena*, and *ilmenite*, in small quantities. With regard to the mutual relations between the different minerals there is practically nothing to add beyond the description of the other Bjurfors ores. The relation of the sphalerite to the *plagioclase* in a specimen especially rich in plagioclase is of great interest, however. Here the sphalerite is introduced into the plagioclase grains in the shape of small "blebs", and the plagioclase grains along the contacts towards homogeneous, large sphalerite grains become intensely powdered with sphalerite (Pl. 29, a). In many cases this texture produces the impression that the plagioclase replaced the sphalerite, but that this is not the case is borne out by the fact that we often find the sphalerite clearly brecciating the plagioclase plates, when it often penetrates the plagioclase along cleavage planes.

6. Norrliden.

2 km WNW of the Bjurfors ores there occurs a deposit, examined in a number of intersecting prospecting trenches. At the time of this investigation, however, they were badly caved in, for which reason the account below mainly refers to results obtained with specimens taken in connection with the work of exposing the rock, and to the map simultaneously prepared by J. Eklund.

The greater part of the ore consists of a *pyrite breccia* in *sericite-quartzite*, the pyrite brecciating the quartzite in the form of an irregular net-work. The ore dips mainly 65°—70° to the S. In the pyrite breccia other sulphides are practically lacking, which is also evident from an analysis of this ore type: 18.2 % S, 18.0 % Fe, 0.02 % Cu, 0.2 % Pb, 3 gr/t Au, and 25 gr/t Ag. *Pyrrhotite* occurs in the westernmost part of the ore, together with a little *sphalerite*, *galena*, and *boulangerite*.[1] A determination of the lead content in a small specimen rich in galena gave 1.2 % Pb. The contents of gold and silver in the same section were 2 gr/t Au and 100 gr/t Ag.

The country rocks seem to have been of varying composition. In the hanging wall we thus find beautifully agglomeratic greenstones, which, even in the

[1] Cf. p. 80.

immediate proximity of the ore, show no palpable alterations in their mineral composition. On the other hand, a certain recrystallization can be established. At the eastern part of the ore body we find similar greenstones also in the foot wall.

The alteration of the wall rock seems to have been more intense in the foot wall, where pure *sericite-quartzites* are found. Their primary rocks cannot be definitely established in every case. It is possible that some of the sericite-quartzites originate from acid rocks, but on the other hand it seems undeniable that also greenstone agglomerates have been transformed into sericite-quartzite. As a matter of fact it it possible in some of these types to recognize the agglomerate structure characteristic of the greenstones, the sericitization apparently having been most intense in the groundmass of the agglomerates. Towards the north we find, instead, darker *quartzites rich in biotite*.

7. Österbäcken.

Immediately west of Österbäcken, about 1 km NE of Örträsk village, a number of electric indications have been examined by three drill holes. Disseminations of *arsenopyrite, pyrite, pyrrhotite, sphalerite, galena,* and *antimony minerals,* were then found. Beds with more solid arsenopyrite ore up to 2—3 dm thick were also found in these zones. The disseminated rock consists of *sericite-quartzite*. Under the disseminated zone we first find calcareous, quartz-veined greenstone, and then graphite-phyllite, also with veinlets of sulphides, mainly pyrrhotite.

The arsenopyrite ore is extremely fine-grained and the analysis of these types has disclosed a certain content of gold and silver. An analysis of a 2 dm thick bed rich in arsenic showed 14.2 % As, 7.1 % Zn, 250 gr/t Ag, and 6 gr/t Au. The following minerals can be seen megascopically: *arsenopyrite, pyrite, pyrrhotite, sphalerite,* and a *lead-antimony mineral.*

Under the microscope two main types of ore can be distinguished which, however, may appear simultaneously in the same polished section. One is a coarse mixture of pyrite, pyrrhotite, and sphalerite, together with gangue minerals, where the size of the sulphide grains usually varies between 0.03 and 0.10 mm, and the other type consists of fine-grained sections extremely rich in arsenopyrite, the grains having an average size of 0.01—0.02 mm. In the coarser parts the pyrite occurs in the form of large, irregular grains, and irregular, small arsenopyrite grains are often enclosed in them. The conditions may be reversed, however, "broken", irregular pyrite grains having been found enclosed in larger arsenopyrite grains (Pl. 29, b). In these cases we get a definite impression of the pyrite having been replaced by arsenopyrite. But also in this type of ore the arsenopyrite occurs in the shape of extremely small crystals (0.01—0.02 mm), mainly enriched in gangue minerals. The arsenopyrite crystals are then often gathered into small skeleton-like aggregates.

Pyrrhotite and sphalerite corrode the pyrite to a certain extent, but as a rule no replacement of any importance can be seen as regards arsenopyrite. Here

these minerals mainly seem to fill the cavities formed in the skeleton-like nests mentioned above. Due to mechanic deformation the pyrrhotite grains are often granulated and show undulatory extinction.

Galena most often occurs together with sphalerite and replaces all the minerals so far mentioned. *Boulangerite*[1] occurs in fairly abundant quantities together with galena, and in some cases galena is practically absent. *Tetrahedrite* has been found in a few cases together with galena and boulangerite, and some *chalcopyrite* also occurs in the same paragenesis. *Bismuth* has also been observed together with galena in a specimen taken from the analysed section rich in Ag. *Gudmundite* is rather common in the parageneses rich in antimony, in the shape of small grains, in some cases as a distinct reaction product between pyrrhotite and a sulphide solution rich in antimony.

The sulphide in the dense schlieren mainly consists of fine-grained arsenopyrite. Together with it we find small pyrite grains, generally enclosed in arsenopyrite. Other sulphides are more sporadic. This development has pronounced fluidal textures, as far as the mutual orientation of the individual sulphide grains is concerned, and the sericite flakes in the gangue mass display a distinct fluidal arrangement of the same kind.

8. Ö. Högkulla.

a. *Location, Shape, Tectonic Features.*

The Ö. Högkulla ore is situated immediately W of the village of Ö. Högkulla. As a result of the investigations carried out, this ore, besides the Eastern Bjurfors ore, is the one best known as regards shape and extension. The ore at the surface is thus almost completely exposed, and at a level 30 m below the rock surface the ore has been investigated by drifts and cross-cuts. Drill holes cutting the ore body about 70 and 130 m below the rock surface supplement our information regarding the depth of the ore.

The solid ore consists of two lenses, as will be seen from fig. 20. The southern and most continuous lens has a very regular pitch of 45° to the south. The northern lens has a steeper pitch, about 70° to the S, but it soon pinches out downwards. At the 30 m level, it is thus considerably smaller and contains more barren rock. As will be seen from the map, the individual lenses strike E—W. The electrical indications show, however, that immediately E of the exposed ore the mineralized zone curves and assumes a more north-southerly strike. In this north-southerly "tail" there occur small lumps of ore, one of which has been traversed by a trench. This ore, 1.5 m wide, was found to consist of chloritic pyrite ore with some sphalerite.

b. *Altered Rocks.*

The ore lies chiefly in a fine-grained quartzporphyry. In the western part of the area, included in the underground work, there occur dense rocks which,

[1] Cf. p. 80.

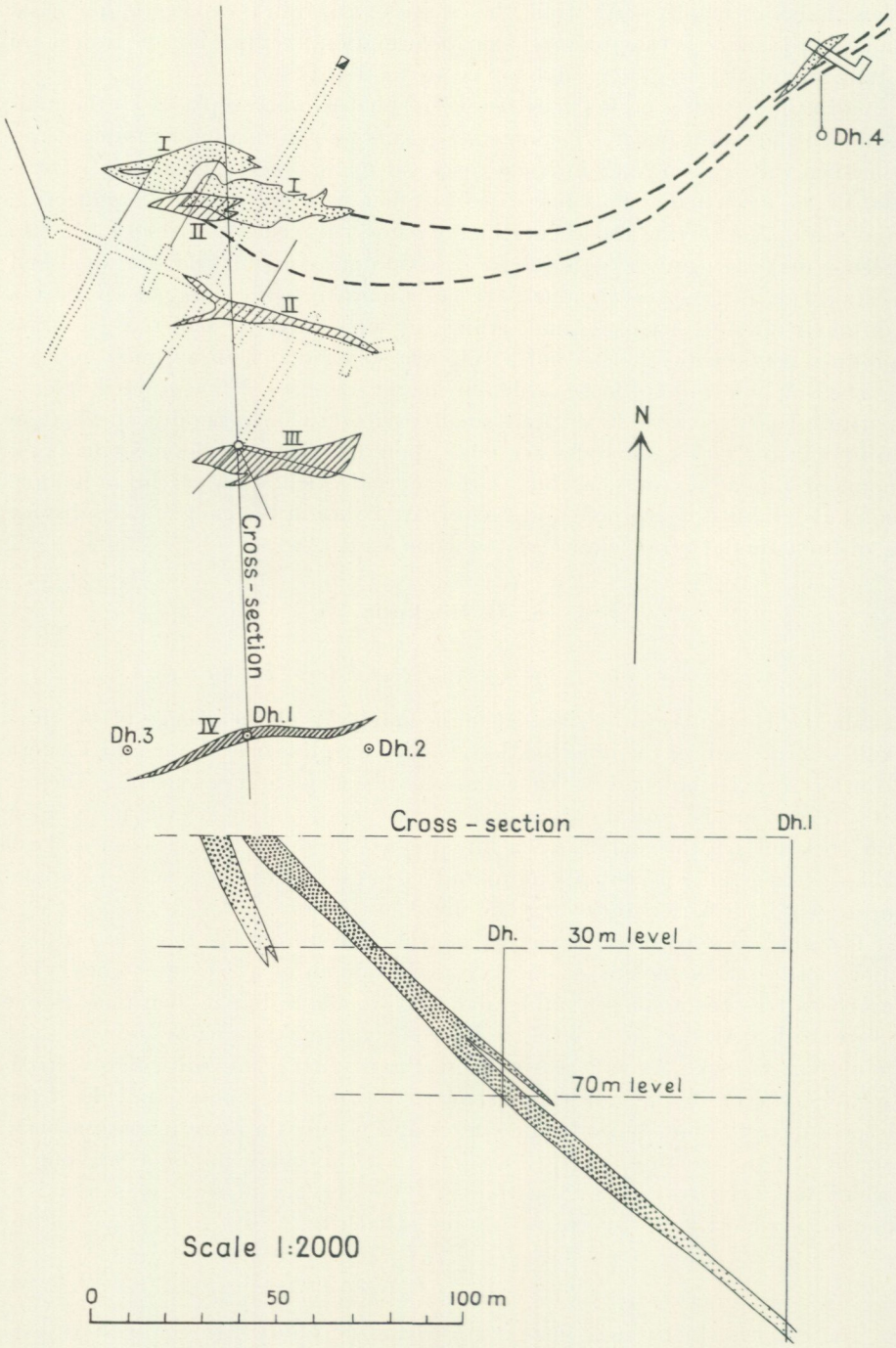


Fig. 20. The Ö. Högkulla ore. Plans of the ore bodies at the surface (I), 30 m level (II), 70 m level (III), and 130 m level (IV). The broken lines = electrical indications.

megascopically, are quite flinty. On microscopic examination there appear to be massive tuffs corresponding to the quartzporphyries. In the hanging wall there occur partly stratified tuffs with interstratified beds of graphite-phyllite.

The alterations here are not at all so extensive as in the previously described ore deposits and are probably always closely associated with the precipitation of the sulphide minerals. Altered rocks differing considerably from the primary rocks occur chiefly only close to the ore contacts or in the continuation of the solid ore bodies. Generally the formation of ore-quartzites is incomplete, even close to the ore, and under the microscope an increased percentage of *chlorite* and *sericite* is often the only sign of the mineralization in the wall rock. In sections very intensely brecciated by sulphide veinlets, the sericitization is more extensive, however, and in portions in which sulphides are present in the same proportions as silicates, sericite constitutes the prevailing gangue mineral, whereas quartz is less common and felspar is practically lacking.

The dense, flinty tuffs in the western part of the 30 m level sometimes display a peculiar flamy appearance with quite white spots in the otherwise grey rock. At one locality it has been observed how a quartz vein grades into similar diffuse spots, and it is thus probable that the flamy texture mentioned is the result of an irregular local silicification of the rock. Other mineralogical changes of importance cannot be detected, however.

In the foot wall of the ores we find *garnet-bearing types*. Locally, and generally immediately connected with the ore itself, there occur true chlorite-quartzites with spots of garnet and abundant *magnetite* octahedrons. As already mentioned, these intensely altered types occur in the immediate vicinity of the solid ore bodies. In the deepest drill holes we find, below the ore zone, a comparatively wide garnet-bearing zone which evidently represents the pinching-out of the solid ore lenses.

Under the microscope the altered types richest in chlorite are found to consist of a *chlorite-quartz* groundmass in which garnet occurs as large irregular poikiloblasts. The formation of garnet evidently took place at the expense of chlorite. In the cases when the groundmass consists of pure chlorite, the garnet crystals have, in fact, no inclusions, while quartz inclusions are otherwise found in the same amount as in the surrounding groundmass. *Calcite* is, as a rule, comparatively abundant, and in the cases when garnet forms large spots, calcite and quartz are intimately intergrown with the garnet mass. *Magnetite* occurs partly as idiomorphic homogeneous crystals, partly as irregular grains including quartz and chlorite. In both cases it is, however, replaced along cracks and cleavage planes by a yellowish brown, frequently almost isotropic mass, the greater part of which probably consists of *iron hydroxides* and possibly some mineral belonging to the *serpentine* group. *Carbonates* often occur in connection with this mass, in which case biotite, too, is sometimes found at the margins of the grains. Small grains of *ilmenite* have also been observed in this association.

In one of the specimens investigated *plagioclase* occurs in comparatively large amounts. It is often zonal, and the composition corresponds to andesine—

labradorite. The central parts of the plagioclase grains have often been intensely altered to *sericite* and *prehnite*. In the same specimen, but without any directly visible association with the sericitization, *epidote* occurs in large amounts. In a plagioclase-free specimen, sericite has been found in well-defined spots, a mode of occurrence that seems to prove that plagioclase existed also here but has in this case been entirely replaced by sericite.

A garnet-free chlorite-rock was found to display structures closely resembling the structures in certain chlorite-rocks from the Eastern Bjurfors ore (cf. p. 117 and Pl. 15, b). Thus, the groundmass consists chiefly of a fibrous mass of extremely small chlorite flakes without any visible parallel arrangement. In places the chlorite has been recrystallized and occurs as large flakes. Sulphides occur as comparatively abundant disseminations, *pyrrhotite* predominating and forming very characteristic plates parallel to (0001). However, what contributes to give this type a certain resemblance to the type described on p. 117 is the presence of small irregular quartz spots indicating a secondary addition of quartz, as well as the occurrence of the same zonal minerals with pleochroic haloes as were found in chlorite-rocks from the Bjurfors ores, and which were interpreted as *orthite*. Further, *titanite* has also been found, in the same specimen, though in comparatively small amounts.

In the chlorite mass there finally occur more or less well-defined plates of *chloritoid*, frequently with polysynthetic twinning. The mineral often gives the impression of growing through the fine-grained chlorite mass, but on the other hand it also seems to be corroded by the coarser chlorite generation.

Quartz veins. Also at Ö. Högkulla we find quartz veins obviously associated with the ores. As the outcrops around the ore are very sparse, a general survey of the occurrence and frequency of the quartz veins can be gained only at the 30 m level. Generally they appear as straight and marked fissure veins with varying directions. The veins occurring in the vicinity of the ore generally carry some *pyrite* and *pyrrhotite*, sometimes also *galena* and *sphalerite*. In addition, these types usually contain some *chlorite*. In one case a *fluorite*-bearing quartz vein has been observed, the fluorite being enriched chiefly towards the contacts with the wall rock.

Though the data available are not sufficient for a complete analysis of the relationship between the fissuring and the general tectonic evolution, there are certain features that may indicate a resemblance to the conditions at the Eastern Bjurfors ore. Thus, steep fissures striking parallel to the ore bodies were formed later than fissures with an oblique strike to the ore. Along the former there have occurred small faults in the foot wall, parts nearer the ore having moved downwards in relation to parts situated farther from the ore. If the same explanation is applied here as at Bjurfors, these small faults thus represent a "subsidence" in the wall rock immediately after the precipitation of the ore.

c. *Ores.*

Main Types.

The Högkulla ore consists chiefly of a solid *sphalerite-pyrite ore* containing more or less *pyrrhotite*. Pyrite and sphalerite are enriched in bands, one or two cm wide. The structure is the same as in the previously described zinc-rich pyrite ores, but the band-structure is more decided and common at Ö. Högkulla. Pyrrhotite may occur both in the sphalerite bands and in the pyrite bands, and towards the contacts of the ore bodies pyrite practically disappears, and we find an interchange between sphalerite bands and pyrrhotite bands. The bands have often a winding course but follow the boundary-lines between ore and wall rock or inclusions of barren rock. There often appears an intense crumpling of the bands, the axes of the minute folds, however, being quite irregularly orientated. There is thus scarcely any folding in the proper sense of the word, the structures in question probably having been formed by flow movements in a comparatively plastic mass. In the lower ore portions where the zinc contents are considerably lower, the band-structure disappears, and the sphalerite is irregularly distributed among the other sulphides. Galena and antimony minerals are visible to the naked eye, forming small schlieren, generally arranged parallel to the banding. In portions poor in zinc in the eastern point of the ore, a porphyritic type appears, cubes of pyrite up to 1 cm in diameter occurring as phenocrysts in a compact mass of pyrrhotite. Locally we also find very dense ore types, usually rich in pyrrhotite, and containing large amounts of small round inclusions of quartz, carbonates or chlorite.

Arsenopyrite is generally not visible to the naked eye in the solid ores, but when lead-antimony minerals are enriched in schlieren, there are often found arsenopyrite crystals with diameters up to 1 mm, either in these schlieren or in close relation to them in the adjacent solid ore. At the 30 m level, however, there has been observed a solid, fine-grained arsenopyrite ore as fragments (2—4 cm in diam.) in the solid zinc-rich ore. These fragments display sharp contacts to the surrounding ore, and are often angular, the structure closely resembling the brecciation of dense arsenopyrite ores that occurs at Boliden and has been described and illustrated by Ödman (*87*, p. 143).

In the solid ore types the gangue minerals are very insignificant. *Quartz* and *calcite* are predominant, some *chlorite* is generally present, and sometimes *sericite* is observed, too. In the relatively pure pyrrhotite ores and also in the pyrite ores at lower levels calcite predominates among the gangue minerals, in which case it occurs as uniformly distributed small dots or as small streaks in the sulphide mass.

When the solid ores wedge out, they generally grade into more irregular sulphide breccias, and we find, e. g. in the drill holes, traces of a mineralization in the direction of the strike from the solid ore. This type is characterized by irregular but comparatively uniformly distributed veinlets of pyrrhotite and pyrite, whereas sphalerite is of subordinate importance.

Special Mineralogy.

On microscopic examination, the following minerals are found in addition to the minerals observed megascopically: *tetrahedrite, bournonite, jamesonite,* (probably also *boulangerite*), *gudmundite, pyrargyrite, bismuth, electrum* (?), *stannite, magnetite, ilmenite, rutile.* Excepting the oxide minerals, all these minerals occur in galena-schlieren.

On the whole, the microscopical textures closely resemble the textures of the previously described zinc ores. In the sphalerite-pyrite-banded ore types the sphalerite bands consist of comparatively pure *sphalerite,* always, however, with some admixture of *pyrrhotite.* In the purest zinc bands pyrrhotite occurs chiefly as small staves or blebs, which generally do not display any regular arrangement along the crystallographic directions of the sphalerite. Occasionally, however, a very regular orientation of this kind may be observed (Pl. 18, a). In several cases pyrrhotite occurs in larger amounts and we find an alternation between pyrite-free sphalerite-pyrrhotite bands and bands very rich in pyrite. At places bands consisting of sphalerite with insignificant amounts of other sulphides alternate with pyrrhotite-pyrite bands with low sphalerite contents. Generally, however, the difference between pyrite-rich and pyrite-free bands is caused only by the uneven distribution of pyrite, whereas the "groundmass" is the same. In the cases when there occur sphalerite bands with insignificant amounts of other minerals, the subordinate groundmass between the pyrite grains in the pyrite bands also consists chiefly of pure sphalerite.

On the whole it is possible to distinguish two modes of occurrence of *pyrite.* It occurs as large, fairly irregular crystals, generally 0.5—1 mm, occasionally up to 1 cm (in the porphyritic pyrrhotite ore types). On microscopic examination these grains show irregular outlines and are often replaced more or less intensely by *sphalerite* and *pyrrhotite,* in which case they may be disintegrated and form skeleton-like aggregates. It would appear, however, as if the sphalerite replaces the pyrite crystals more intensely than does the pyrrhotite, as sphalerite mainly occurs close to the pyrite remainders, whereas the pyrrhotite to a large extent embeds pyrite grains displaying less strongly marked corrosion phenomena (Pl. 17, a). In a porphyritic ore in which pyrite crystals occur with still visible cubic outlines in a fairly uniform pyrrhotite-sphalerite mass, the same thing is indicated, and in this case it is also possible to obtain a numerical measure of the relationship between pyrite and sphalerite. The pyrites are, in fact, intensely corroded, partly their margins, partly their central parts, which is evidenced by abundant, irregular, frequently rounded corrosion holes. According to volumetric determinations the pyrite "phenocrysts" amount to 7 % of the whole polished surface. In these, 16 % of the probably primary pyrite crystals consist of corrosion holes filled with other sulphides, 91 % of which consist of sphalerite, the rest being pyrrhotite and some chalcopyrite. In the pyrites the ratio sphalerite : pyrrhotite is thus approx. 10 : 1. In the groundmass which, besides gangue, consists chiefly of pyrrhotite and sphalerite, the corresponding ratio is 5 : 6. Further, the pyrite

grains are generally surrounded by sphalerite which may have replaced some pyrite, but here not included in the sphalerite that is assumed to have replaced pyrite. The same relationship between sphalerite and pyrite in a mixture of sphalerite, pyrrhotite, and pyrite has also been mentioned from Bjurliden.

The other mode of occurrence of pyrite is represented by the crystals of a very regular cubic habit which often occur in the ore types rich in zinc, and which generally do not exceed 0.1—0.2 mm. These pyrite crystals are as a rule considerably less corroded by the surrounding sulphides than the type mentioned above. It would appear, however, as if the formation of this pyrite should be regarded as a recrystallization of an earlier pyrite generation. It is, in fact, sometimes found how large pyrites are brecciated or corroded and "flow apart" in the replacing sphalerite, in which case beautifully idiomorphic pyrite crystals are formed (Pl. 30 b). A similar origin was also assumed for certain pyrite crystals at the Eastern Bjurfors ore, though the gradations from one type to another were not so distinct in that deposit as at Ö. Högkulla.

On microscopic examination *arsenopyrite* is found to be fairly common and occurs in the majority of the investigated specimens as occasional, idiomorphic crystals. In the ore types containing megascopically visible fragments of pure arsenopyrite, the arsenopyrite crystals are to some extent corroded by sphalerite, but in the main sphalerite would appear chiefly to fill the interstices between the arsenopyrite crystals. The fragments consist of fine-grained arsenopyrite, which, however, has sometimes been recrystallized, as large, uniform crystals also may be found.

Chalcopyrite is present in insignificant amounts, but is very uniformly distributed and occurs in small streaks, generally in close association with the lead-copper-antimony minerals. In two cases *valleriite* has been observed in the chalcopyrite as minute worm-like grains. Chalcopyrite is found, too, as small blebs in sphalerite together with pyrrhotite.

Galena has been found in all the specimens examined, with one exception, and only in specimens where it occurs in very insignificant amounts, are *antimony minerals* entirely lacking. Of these latter *tetrahedrite* and *bournonite* are the most common. The former may, certainly, also here, form regular intergrowths with galena of the same appearance as at Bjurliden, but these intergrowths are not at all so abundant at Ö. Högkulla as at Bjurliden. In several cases tetrahedrite occurs in homogeneous grains, and is then corroded by galena or galena-bournonite intergrowths. In the majority of the specimens bournonite forms very regular intergrowths with galena. The galena contents in these intergrowths generally range from 15 to 25 vol.-%.

It has not been possible in all cases with certainty to distinguish between *boulangerite* and *jamesonite*. However, it would seem as if jamesonite is the more common of these two minerals. In most cases they form crystals that are fairly free from galena, disregarding the insignificant veinlets of galena which may penetrate them either along the cleavage planes or, sometimes, along irregular cracks. Bournonite has also been observed as veinlets in jamesonite,

As was the case at Bjurliden, there is often observed a distinct tendency to a zonal arrangement around the copper-free lead-antimony-sulphide, boulangerite or jamesonite being surrounded by bournonite with galena, and this zone by tetrahedrite with galena, pure galena occurring outermost. Generally all the zones are not developed, and either bournonite or tetrahedrite is thus often lacking.

Bismuth and perhaps also *electrum* occur as minute grains in galena or in bournonite-galena intergrowths. *Pyrargyrite* forms small irregular grains, sometimes occurring on the cleavage planes of the boulangerite.

Gudmundite is very common and occurs in all cases when other antimony minerals are also present in comparatively large amounts. It often occurs as independent idiomorphic crystals in the quartz or calcite spots that are found in the solid ores. It displays the same mode of occurrence as at Bjurliden; regular intergrowths with pyrrhotite and ramiform skeletons are, however, less common here. The mineral has a general tendency to originate along the contacts between the pyrrhotite and the lead-copper-antimony minerals. Gudmundite seems sometimes to be intensely replaced by galena and bournonite-galena intergrowths. In many cases, however, pyrrhotite seems to be the mineral that has been replaced, the remainders being partly converted into gudmundite through the addition of antimony from the attacking solution.

The occurrence of *stannite* in association with the antimony minerals is of great paragenetic interest. Stannite forms homogeneous rounded or irregular grains which are corroded by the lead-copper-antimony sulphides. It replaces sphalerite, however, and has also been observed as small round blebs in it, having the same appearance as e. g. the chalcopyrite blebs. Similar modes of occurrence are mentioned in the text-book of Schneiderhöhn-Ramdohr (*72*, p. 478) from deposits classified as high-temp. hydrothermal, but they are in other respects not associated with tin-bearing parageneses.

Magnetite generally seems to be absent in the solid ore types. When present, it forms very irregular aggregates, probably due to its having been intensely crushed and more or less replaced by sulphides. *Ilmenite* rarely occurs separately in the sulphide mass; it should probably be regarded as belonging to the wall-rock parageneses. In a chlorite-quartzite bed between two solid ore bodies *hematite* has been observed, partly surrounding ilmenite grains. These grains are furthermore surrounded by *titanite*. In the same rock *rutile* frequently occurs as small rounded grains.

In several instances the Ö. Högkulla ores show traces of a fairly intense mechanic deformation. Thus the pyrrhotite grains rather often show translation lamellae, and the deformation being more intense, we find a kind of flow structure in which case the pyrrhotite grains display a distinctly uniform optical orientation within certain areas (Pl. 30, a). The often very local character of this mechanic deformation is apparent from the fact that entirely unaffected parts may occur close to textures of the kind illustrated in Pl. 30 a. Pl. 18 a shows the texture in the same polished section in a sphalerite-band only 1 cm from the area pictured in Pl. 30 a.

In other cases the deformation is followed by an irregular recrystallization which gives rise to the dense ore types with abundant round inclusions. Pl. 31 a and b show the texture of this ore type. In this type we also find occasional pyrites displaying traces of having been subjected to an intense mechanic deformation.

Supergene alterations of pyrrhotite are of very subordinate importance at Ö. Högkulla. Only occasionally has any alteration been observed, in which cases but *secondary pyrite* is formed.

Sulphur and Metal Contents.

The zinc and lead contents are fairly constant in the solid ores. There are thus found values ranging from 15 to 30 % Zn and from 0.5 to 1.5 % Pb. The average contents in the solid ore bodies of the outcrops are probably approx. 22 % Zn and 0.9 % Pb. At the 30 m level the average contents of the zinc-rich southern ore body are 24 % Zn and 1 % Pb and approx. at the 70 m level there occur a zinc-rich section with 16 % Zn and 1.1 % Pb and a poorer pyrrhotite-pyrite section with 5 % Zn and 0.1 % Pb. According to the results from the drill holes towards the ore at a depth of about 130 m, portions rich in zinc are there lacking, and there are only minor pyrrhotite lenses with low zinc contents. The same type occurs also at the 30 m level, where it forms the pinching out of the northern ore body.

Of the precious metals, gold occurs only in minute quantities, the highest values being only 1.7 gr/t Au, and the average content in the zinc-rich ores about 0.5 gr/t. Silver, on the other hand, is of greater importance, the silver contents on the whole following the lead contents, the average values ranging from 150 to 200 gr/t Ag.

The distribution of the other elements is best seen from an average sample of the whole solid, zinc-rich ore at the 30 m level:

S	36.0 %
Zn	24.4 %
Fe	33.5 %
Pb	1.05 %
Cu	0.17 %
As	0.14 %
Sb	0.19 %
Ag	196 gr/t
Au	0.4 gr/t
SiO_2	3.4 %
CaO	0.89 %

Relations to the Wall Rocks.

The solid ores always display very sharp contacts against adjacent rocks. As in the Eastern Bjurfors ore, the contacts are covered with a thin chlorite

film, and it always appears as if the boundary-lines originated as fracture planes, along which the ore solutions penetrated. Further, there have often been found veins of solid ore branching off from the main ore body. Such veins may occasionally cross each other, fragments of the adjacent rock thus being detached. Inclusions with quite sharp contacts against the ore occur also in the interior of the ore. They are, however, more angular here than was the case in the Eastern Bjurfors ore. On the whole, it seems as if replacement has been of very little importance for the deposition of the Ö. Högkulla ore; most of the space now occupied by the solid sulphide mass probably having been formed by displacement. This conception is also verified by the fact that neither residual quartz phenocrysts nor other residual structures are found in the solid ore types. As already mentioned, the ores often display very marked band-structures, but this banding cannot possibly be due to a pre-ore schistosity. The surrounding ore-quartzites and quartzporphyries are, in fact, distinctly massive. If the band-structure should be considered some kind of a residual replacement structure it is very strange that the most pronounced band-structure is found in an ore surrounded by wall rocks that are more massive than the other rocks in the area. The banding might instead be regarded as due to some kind of fluidal structure. A similar explanation has been advanced by Spurr (*75*, p. 115) in the case of the banding in Mandy Mine which evidently in many respects is very similar to Ö. Högkulla. Such a conception does not imply, however, that the movements need have occurred in a kind of "ore magma". Flow movements may in fact occur also in a more or less crystallized sulphide mass, when this mass is subjected to strong mechanical deformation, as was assumed in the case of the chlorite banding of the Eastern Bjurfors ore. As regards Ö. Högkulla there are, as mentioned above, evident traces of a deformation occurring in a stage before the last sulphides crystallized.

As already mentioned, the solid ore bodies at their points grade into irregularly disseminated zones in which replacement may obviously have played a certain part. However, at least in the vicinity of the comparatively solid ore also these zones are developed as very marked breccias with veins of fairly solid ore between which true disseminations may occur. The only portions of the ore that may with certainty be regarded as the result of replacement are these disseminations, in which the sulphides probably spread out from the solid ore veins.

9. Skäggträskberget.

Previous investigations at Skäggträskberget have disclosed an arsenopyrite-bearing quartz vein about 1 km W of Ö. Högkulla. The quartz vein proper may attain a width of 1 m and carries arsenopyrite as lumps or uniform disseminations. Generally, the wall rock has to some extent been altered to sericite-quartzite and disseminated by sulphides. The whole mineralized zone is usually 3 to 4 m wide. According to earlier information (*80*, p. 117), pure

arsenopyrite has been found with up to 50 gr/t Au, but in the average samples analysed by the Geol. Surv. there were found but insignificant traces of gold.

A mineralized area situated about 300 m N of the quartz vein in question is, however, of greater interest. In contradistinction to the conditions at the Ö. Högkulla ore the alterations around the ores are here fairly extensive, especially when considering the insignificant dimensions of the individual ore bodies. Generally *sericite-chlorite-quartzites* have been formed during the alterations. Light-brown *biotite* frequently occurs and often shows a decided tendency to originate in close association with the crystallization of the sulphides. This is especially the case in a light quartzite type with veinlets of *sphalerite*. This quartzite is somewhat coarser than is commonly the case in this area (size of grain 0.03—0.1 mm compared with 0.01—0.03 mm in the more common types), and the biotite flakes are very regularly crystallized along the contacts of sphalerite grains or in the immediate vicinity of them.

As a matter of fact, the formation of biotite here seems at least to a certain degree to correspond to the chloritization at other previously described ore deposits. We thus find pure *biotite-rocks* corresponding to chlorite-rocks at other localities. Further, there occurs *amphibole* skarn in which the amphiboles appear as needles in a mass of biotite. The amphibole has a very faint colour in thin sections. The main optical data are: $\gamma = 1.638$, $\alpha = 1.618$, $c : \gamma = 16°$, $2V_\alpha = 83°$.

The sulphide mineralization is generally characterized by comparatively poor disseminations, *pyrite* and *pyrrhotite* being the most common minerals, but, on the other hand, disseminations with *arsenopyrite, sphalerite, chalcopyrite, galena,* and *jamesonite* have also been observed megascopically. Within the altered area there occur, however, at least three relatively solid ore bodies, which in spite of their small size (the largest ore being max. 100—150 m²), are of a certain interest on account of the extremely complex composition. In the same specimens we may thus find *dense arsenopyrite* and *pyrite ores* intensely brecciated by *chalcopyrite, pyrite, sphalerite,* and *galena*. However, there is generally an obvious tendency to a differentiation into zinc-lead ore and copper ore. It is an interesting feature that the arsenopyrite conspicuously accompanies the zinc-lead ores. This relationship is most clearly seen in the results from the drill holes. In one of these drill holes an ore has thus been found, the central part of which consists of copper ore with low zinc and lead contents, whereas its marginal sections consist of zinc-lead ore with arsenopyrite streaks:

Drill hole No. 1, Skäggträskberget.

	S %	Cu %	Zn %	Pb %	As %	Ag g/t	Au g/t
46.00—47.38 (1.38 m) . . .	25.0	0.64	18.9	0.70		70	0.8
47.38—47.75 (0.37 m) . . .	22.7	2.85	3.17	0.99		157	0.9
47.75—48.45 (0.70 m) . . .	30.5	0.70	7.15	3.17		234	0.5
48.45—49.38 (0.93 m) . . .	22.0	3.05	1.32	0.14		78	0.4
49.79—50.53 (0.74 m) . . .	25.4	4.26	0.79	0.34		128	0.9
50.53—50.97 (0.44 m) . . .	28.4	1.52	17.3	0.22	5.84	71	4.0
50.97—51.64 (0.67 m) . . .	15.6	1.53	6.18	0.10		48	3.6

The results of the analyses from this drill hole clearly demonstrate the above-mentioned differentiation, and at the same time they give an idea of the quality of the solid ores. Certain parts of the ores are pure pyrite ores including more or less sericite-quartzite but without any very considerable contents of either zinc, lead, copper, or precious metals. As a megascopical survey discloses the arsenopyrite to be highly enriched in the sections 50.57—51.64 m, the gold content has a decided tendency to increase with increasing contents of arsenopyrite.

On microscopic examination, the same relations are found here between pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena, as in the previously described ore deposits. In the ore types rich in sphalerite and arsenopyrite, pyrite is quantitatively subordinate. The abundant *arsenopyrite* occurs in highly varying dimensions, from 0.01 mm to 0.2 mm. Partly it forms idiomorphic crystals lying free in the sphalerite mass, partly it occurs as irregular crystal skeletons. In complex *pyrrhotite-sphalerite ores* the skeleton-like type was found to be surrounded by pyrrhotite, whereas the arsenopyrite in the sphalerite occurred chiefly as idiomorphic separate crystals. In other cases, however, there occur very distinct zonal remainders (Pl. 32, a) also in sphalerite. In two or three specimens fairly rich in galena — though the amount of galena is insignificant as compared with the copper-iron-zinc sulphides — arsenopyrite is found as quite decided crystal skeletons, the interstices of which are mainly filled with pure galena (Pl. 32, b). In these specimens we thus find a certain relationship between galena and arsenopyrite.

The ore types richest in zinc also contain some *chalcopyrite*, partly as small blebs together with pyrrhotite or as irregular grains in sphalerite crystals. In the present case the inclusions never display any arrangement along the crystallographic directions of the sphalerite. In most cases, however, chalcopyrite is also found as separate streaks, replacing and brecciating pyrrhotite and sphalerite. In the ore types rich in copper, the chalcopyrite often forms large uniform grains, as a rule with distinct twinning. Sphalerite also occurs in these ore types, generally as small, frequently highly corroded grains. In the purest chalcopyrite portions there are only quite insignificant, irregular remainders of sphalerite. In occasional cases, however, when the sphalerite forms large uniform individuals in these ore types, it contains practically only chalcopyrite as inclusions, pyrrhotite generally being almost lacking.

Tetrahedrite occurs in galena schlieren, always as uniform, homogeneous grains. Though the mineral on the whole is apt to occur in close association with galena, it sometimes also occurs as entirely separate grains, often in chalcopyrite, and this is the case in a polished section of an ore type extremely rich in copper, which carries only slight amounts of galena and sphalerite. In the same polished section *pyrargyrite* has been found, and this mineral also occurs as separate irregular grains within chalcopyrite crystals. In other cases, this mineral has also been observed in the more common association, *viz.* directly together with tetrahedrite in schlieren of lead-antimony minerals.

Jamesonite has also been observed in minute amounts, surrounded by tetrahedrite. It occurs in ore types rich in sphalerite and galena.

Though *galena* is generally closely associated with the ores that are fairly rich in zinc, we find also in the purest copper ores a certain galena content, the mineral displaying a comparatively uniform distribution in the chalcopyrite. The galena then forms streaks, veinlets or irregularly rounded grains in uniform chalcopyrite crystals. However, it was probably still in solution, at least to some extent, also after the complete crystallization of the chalcopyrite, as galena in many cases clearly replaces chalcopyrite.

The ores have frequently been subjected to a conspicuous mechanic deformation, but this deformation is generally of a fairly local character. The most conspicuous traces of the dynamic influence are generally found to be a certain development of translation lamellae in pyrrhotite, and, in places, cataclastic textures in pyrite and arsenopyrite. The supergene alteration has been far more intense near the rock-surface than is the case at the ores previously described. Thus, the pyrrhotite has in most cases been almost completely changed to *marcasite* in all specimens from the rock-surface. Frequently only small inclusions in sphalerite have escaped alteration (Pl. 20, b).

A microscopic examination of the *sericite-quartzite pyrite ores* only discloses pyrite and gangue minerals. The pyrite grains are very irregular in shape and seem to have been subjected to an intense cataclastic deformation. The sizes of the grains average 0.02—0.04 mm.

In one of the prospecting trenches there was found a poor dissemination of sphalerite and pyrrhotite in chlorite-quartzite. On megascopic examination there could also be observed a white, needle-shaped antimony mineral. The microscopic examination showed the needles to consist of a mineral, the general optical properties of which indicate *jamesonite*. However, in this case there is often found a slight but fairly distinct polysynthetic twinning. The twinning is not so pronounced as in geocronite and the reflection pleochroism is more distinct than for geocronite. The mineral is generally uniform; only in one case does galena occur as narrow veinlets. In addition, there occur small amounts of another mineral belonging to the antimony group. This mineral is obviously of later origin and sometimes occurs around winding cracks in the jamesonite. The optical properties of the mineral indicate *boulangerite*.

Quartz veins. In addition to the large quartz vein described in the beginning of this chapter, several small quartz veins have been observed in the vicinity of phyllites WNW of the small solid ore bodies mentioned. These veins generally do not exceed 1 dm in width and brecciate the quartzporphyries in a very irregular manner. They are accompanied by *arsenopyrite*, not in the quartz vein proper, however, but always as idiomorphic crystals close to the vein contacts in the adjacent wall rock. These veins seem to be of exactly the same type as the relatively frequent arsenopyrite-quartz veins which occur in several places in the Skellefte District and which may sometimes be gold-

bearing (see e. g. *42*, p. 60). Owing to their geological occurrence and distribution at Skäggträskberget, these veins must be regarded as being directly associated with the mineralization that gives rise to the comparatively solid ore bodies at Ö. Högkulla and Skäggträskberget. In prospecting trenches at Skäggträskberget there have been found quartz veins from which there are spread small lumps of *solid pyrite ore* exactly similar to ore types directly connected with the comparatively solid sulphide ore bodies at Skäggträskberget.

10. Low-grade Disseminations in the North-Western Parts of the District.

The sulphide mineralization found in the low-grade metamorphic northern parts of the mapped area is, as a rule, not very extensive. Generally, only insignificant *pyrite* or *pyrrhotite* disseminations have been found in more or less *sericitized rocks*. Such belts occur immediately E of Kotjärn and N of Önusträsket. According to information received from A. Högbom and J. Eklund there have been found in the first-mentioned case narrow belts with fairly abundant sulphides, veinlets of relatively solid pyrite brecciating the sericite-quartzite.

At Önusberget immediately E of Önusträsket there occur sulphide-bearing quartz veins as fissure-fillings. The veins have a thickness of 2—3 dm and penetrate the quartzporphyry and keratophyre tuffs that occur close to the phyllites. *Arsenopyrite* and *chalcopyrite* are visible to the naked eye. Under the microscope there are observed conspicuous traces of a very intense cataclastic influence. Especially the arsenopyrite grains are intensely crushed. However, the chalcopyrite, too, is traversed by cracks on which *covellite* occurs in comparatively large amounts. *Sphalerite*, too, has been observed under the microscope as insignificant irregular remainders in the chalcopyrite. An analysis of a comparatively sulphide-rich portion of the vein discloses a gold content of 7 gr/t.

D. Summary of the Alterations in the Wall Rocks.

In order to obtain a general survey of the important constituents in the mineralizing solutions, in addition to the elements occurring in the sulphide phase, it is of course very important to be able to survey, as far as possible, all the chemical variations in the composition of the original rock that can be suspected within the mineralized area. When making a careful study of the processes that have created the mineral associations observed, due regard must be paid to those changes in the chemical composition of the rocks that can be established around the ores, as well as to the mineralogical appearance resulting from these changes. If we consider that the deviations from the normal rock-types originated in metasomatic alterations in connection with the introduction of the sulphides, as is usually the case with this type of rocks, the difference in chemical composition between primary and altered rocks may

thus be looked upon as a measure of the intensity of the alteration. On the other hand, the mineralogical development gives an indication of the pressure and temperature conditions at the time of the mineralization.

In order to establish the real differences in the chemical composition between altered and unaltered rocks, it is, however, necessary to study the course of the alterations in rocks which may be presumed to have had a fairly constant original composition. As already pointed out in the discussion on the regional metamorphic processes, this condition is best filled in the quartzporphyry lavas and also in some of the pyroclastic derivates of those types.

1. Zoning around Bjurliden and the Bjurträsk Ores.

The most complete sections through the altered zone in the quartzporphyry being from Bjurliden, the significance of those variations will first be discussed. The diagram, fig. 21, the lower part, presents a summary of the mineralogical variations from the contact between a minor ore lens and the unaltered porphyry as they appear in one of the drill holes. Nos. 81—84 here represent a calcareous zone which is evidenced by the occurrence of calcite in specimens 81 and 83 as well as by an abundant quantity of anorthite in specimens 82 and 84. This zone is on both sides bordered by sericite-rich quartzites. Between these types and the ore, we chiefly find felspar-bearing rock-types with a small garnet content, but next to the ore the garnet disappears, gahnite appearing in its place. Sericite also begins to reappear. We certainly do find narrow, highly calcareous zones also between specimens 85 and 93, but they are so similar to the types represented by specimens 81—84 that they do not call for a special examination. The variations are so frequent that an exhaustive analysis of the whole section would necessitate specimens being taken at very short distances from each other. It is thus quite clear that the curves in the diagrams do not claim to portray the exact mineralogical variations in detail for the whole section. The lines connecting the values for the various minerals in the different thin sections have merely been drawn better to illustrate the graphic presentation of the variations in the mineral composition of this section.

If the results of these diagrams are compared with the zoning mentioned in the special description of the altered rocks of the Bjurträsk ores, certain similarities can be established. Between the felspar-free quartzites next to the ore and the unaltered rocks there thus occurs, in both cases, a zone characterized by incompletely destroyed alkali felspar, where streaks rich in sericite and streaks rich in lime-minerals alternate. Probably due to certain dissimilarities in the original material, however, it is not certain that the same numerical values can be used to denote the same metamorphic strength in the two cases. Thus specimens Nos. 87 and 89—92 in the Bjurliden diagram (fig. 21) represent types that must be considered to belong to the transitional zone, although the content of alkali felspar is still so large that the corresponding types at the Bjurträsk ores should be regarded as belonging to group III in fig. 12. The simultaneous, comparatively high anorthite content and the occurrence of

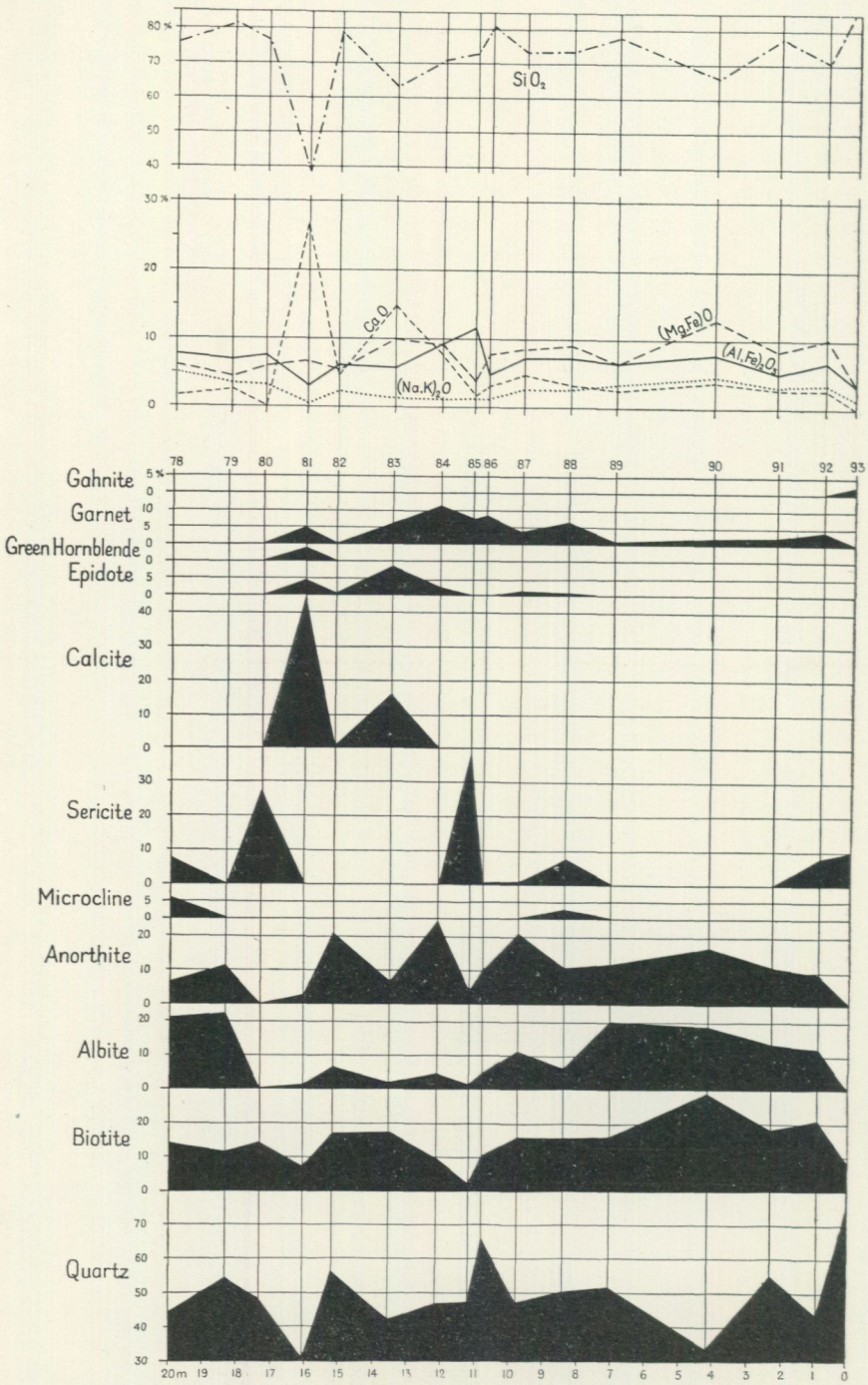


Fig. 21. Diagram illustrating the mineral variations in quartzporphyry in a section from the ore (0 m) to unaltered rock (20 m) in drill hole 3, Bjurliden. The values are in volume per cent. Each of the figures 78—93 thus represents one thin section. In the upper part the oxides have been calculated and are presented in mol.-%.

garnet in the Bjurliden types, however, indicates that the rocks are distinctly affected by the mineralizing solutions.

In order to obtain a better survey of the chemical significance of the variations mentioned, the compositions of the various rocks have been calculated on the basis of the general formulae for the various minerals included in Table 6, after p. 194. The elements which are assumed mainly to substitute each other have there been arranged together, thus forming the following oxides (expressed in molecule-%): $(Al, Fe)_2O_3$, (Mg, Fe)O, CaO, $(Na, K)_2O$, SiO_2. Of course such a calculation cannot be expected to give very exact values, but on the other hand the main features of the chemical variations are no doubt elucidated.

These oxides have been plotted in the upper part of fig. 21. It will be seen that the various curves have quite irregular courses, without any tendency towards successive uniform changes from the unaltered rock to the ore contact.

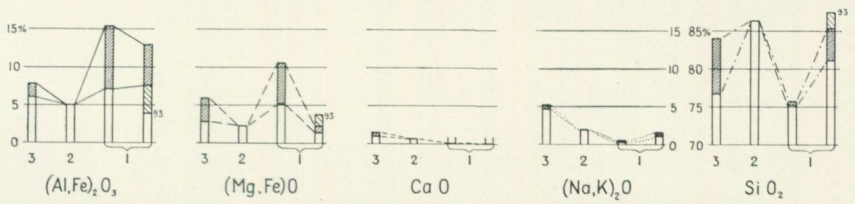


Fig. 22. Diagram showing the variations of the main oxides of altered quartzporphyry on the north side of the Bjurliden ore. Section from the contact of the ore (the right column in each diagram) to unaltered porphyry (the left column). The values are calculated from volumetric analyses and given in mol.-% (horizontal lines in the colums). Shaded parts = range of variation between the analyses in the same zone. 1 = quartzite (felspar-free) zone; 2 = transitional zone; 3 = unaltered porphyries.

Fig. 22 is an attempt to summarize some of the altered types through the quartzporphyry on the northern side of the main ore. Due to the scarcity of exposed sections within this part of the area at the time of the investigation, it was not possible in this case to follow the variations in detail as it was in the case illustrated by fig. 21. Only the main types can be stated, and as it is impossible to give an absolutely reliable report on their exact location in relation to the ore contact, only the mutual location of the various altered types has been shown in the diagram. Thus No. 96 is a sericite-quartzite rich in gahnite, No. 97 a sericite-quartzite poorer in gahnite, both taken from the immediate neighbourhood of the ore contact. These two thus represent the types of development nearest the ore and may be compared with No. 93 in fig. 21. A few metres from the ore contact we still find felspar-free quartzites, now rich in staurolite, andalusite, etc. Nos. 94 and 95, which mutually have the same position in relation to the ore contact, thus represent an outer type of development of the quartzite zone. The transitional zone with incompletely destroyed felspar is represented by one single specimen, No. 98, and as there were no specimens available of unaltered quartzporphyry north of the ore, the above-mentioned types have been compared with a comparatively unaltered porphyry south of the ore, No. 99, and with the least altered type in fig. 21, No. 78. The mineral composition of the specimens used expressed in vol.-%,

Table 4.

	78	99	98	94	95	96	97	93
Quartz	44.5	50	73	58	67	57	66	75
Plagioclase	27.5 (Ab_{77} An_{23})	39.5 (Ab_{90} An_{10})	6 (Ab_{60} An_{40})	—	—	—	—	—
Microcline	6	—	—	—	—	—	—	—
Biotite	14	5	5.5	7	4	1.5	4	8
Muscovite	6.5	4	14.5	—	—	11	12.5	9.5
Chlorite	—	0.5	—	—	11	—	—	—
Epidote-zoizite	0.5	—	—	—	—	—	—	—
Calcite	—	1	—	—	—	—	—	—
Andalusite	—	—	—	23.5	—	—	—	—
Staurolite	—	—	—	8	8.5	—	—	—
Gahnite	—	—	Traces	1.5	—	14.5	6.5	2
Sulphides	—	2	1.5	1.5	4	16	11	5.5
Magnetite	—	—	—	0.5	5.5	—	—	—

is shown in Table 4. It will be seen that also in these cases the tendency towards a successive uniform change from unaltered rock to the ore contact is not very conspicuous. The variations between types displaying the same zonal relationship to the ore body, are, however, relatively important.

On the whole the same zoning is thus found at Bjurliden as at the Bjurträsk ores, *viz.* an inner quartzite zone in which the felspar is completely destroyed, and an outer transitional zone towards the unaltered rocks, where sericite-rich and anorthite- or calcite-rich rocks alternate. In fig. 23 the values of $(Al, Fe)_2O_3$, $(Mg, Fe)O$, CaO, $(Na, K)_2O$, and SiO_2, for the inner zone (1), the transitional zone (2), and the unaltered rock-types (3) have been placed in relation to each other, both as regards the rocks of the Bjurträsk ores and the rocks of Bjurliden. The dispersion of the values in the individual zones, indicated already in fig. 22, is now still more pronounced.

Figs. 24 and 25 are intended to show the same variations in triangle diagrams. For the sake of comparison, analyses Nos. 1 and 2 of the unaltered quartz-porphyry, and analysis No. 3 of the unaltered agglomerate, have also been included. It will be seen that the alterations lead to a more and more decided dispersion of analyses from areas representing unaltered or slightly influenced rocks.

In the above discussion only the different complex oxides have been mutually compared. Considering the variations occurring within the individual groups, an attempt thus being made to investigate the variations in the Fe : Al ratio in $(Al, Fe)_2O_3$, the Fe : Mg ratio in $(Mg, Fe)O$, the Na : K ratio in $(Na, K)_2O$, in different parts of the mineralized area, the following general conditions can be established. The micas being potash micas, the ore-quartzites will be proportionally enriched in K in relation to Na during the alteration. The same will be true of the lime-rich quartzites, though to a smaller extent. It is more difficult to obtain a clear conception of the variations $Fe^{++} : Mg^{++}$ and $Fe^{+++} : Al^{+++}$, as in the individual minerals these elements may mutually substitute each other to a fairly high degree. By studying the minerals that substitute

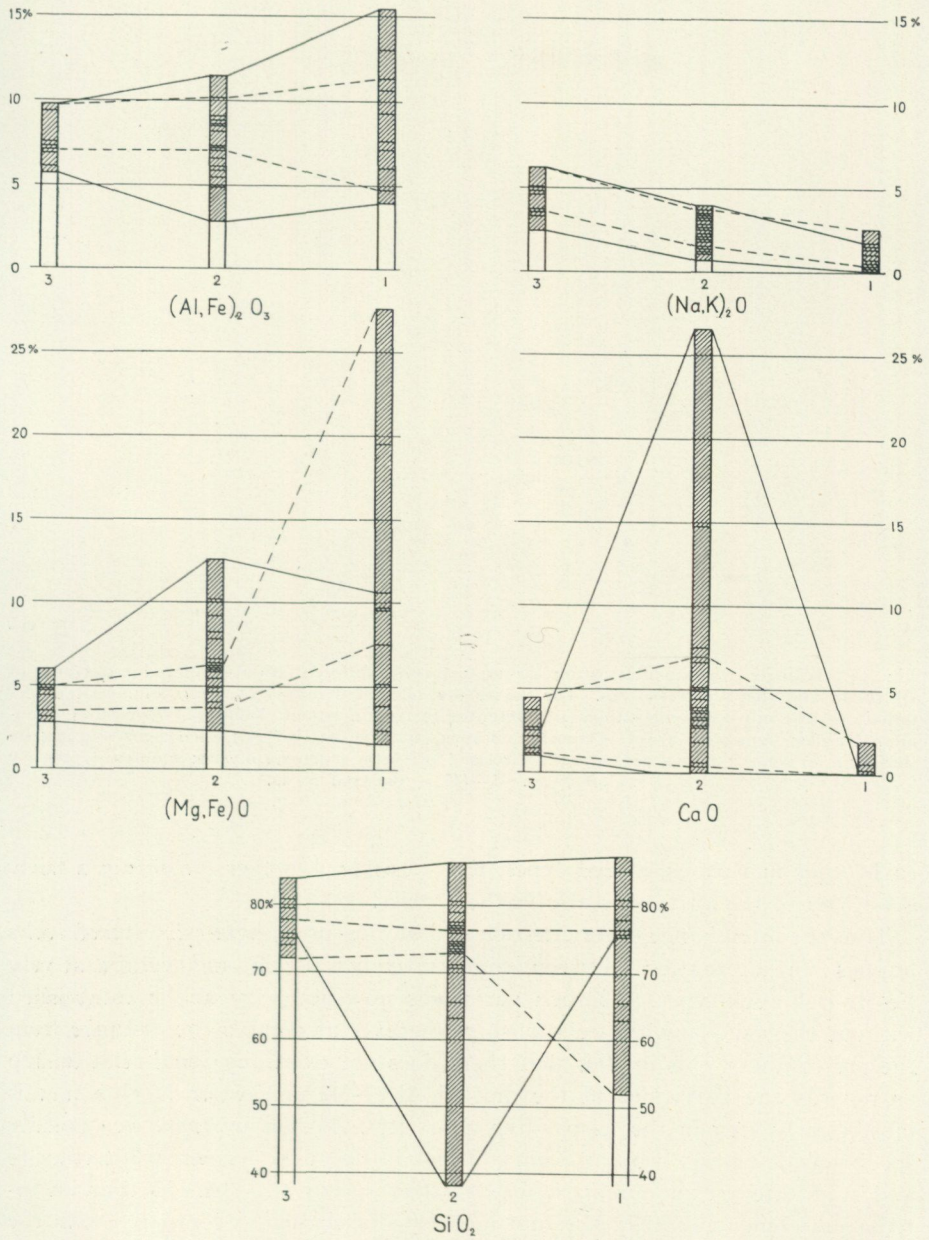


Fig. 23. Diagram showing the variations of the main oxides in altered quartzporphyries and agglomerates at Bjurliden and the Bjurträsk ores. The shaded columns illustrate the range of variation in the different zones of alteration: 1 = the quartzite (felspar-free) zone, 2 = transitional zone; 3 = unaltered rocks. Each horizontal line in the columns represents one analysis, calculated from volumetric determinations and presented in mol.-%. In No. 3 also the chemical analyses 1—3 are plotted. Unbroken lines show the variations at Bjurliden only, broken lines the variations at the Bjurträsk ores only.

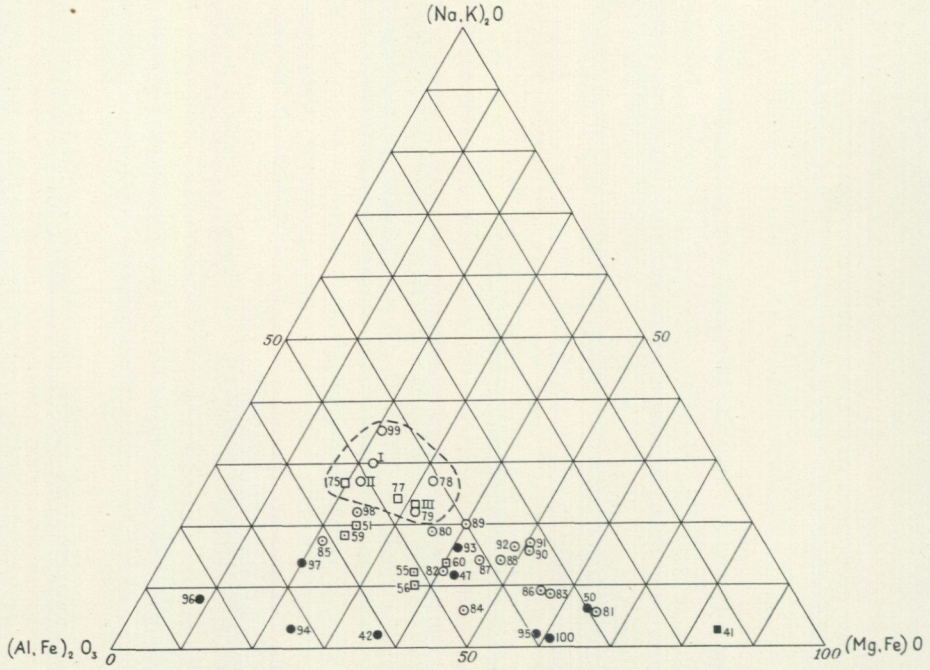


Fig. 24. Triangle diagram illustrating the metamorphic differentiation in altered rocks around Bjurliden and the Bjurträsk ores. The values are calculated in vol.-% from volumetric determinations (the mineral compositions are presented in fig. 12, 21, and Table 4). Open signs = unaltered rocks; signs with a dot = transitional zone (2 in fig. 22 and 23); filled signs = quartzite (felspar-free) zone (1 in fig. 22 and 23). Circles = primary quartzporphyries; squares = primary agglomerates. I—III = analysed rocks.

each other in various altered types, it is possible, however, to obtain a fairly good idea of the variations also in these cases.

Thus the interchange of sericite-rich and biotite- or chlorite-rich altered rocks implies an alternation between comparatively Al-rich and comparatively Fe-Mg-rich rock-types. As such variations now actually can be established without their showing any relationship whatever as regards the distance from the ore contacts, this implies that there does not exist any zonal relationship as regards the variations in the mutual Al-Fe-Mg-proportions. This fact is most clearly seen in the felspar-free quartzites. If, for instance, we consider specimens 94 and 95, we find plenty of andalusite in the former, while chlorite and staurolite are predominant in the latter specimen. There is thus an intense enrichment of Al in the first-mentioned specimen as compared with the latter. Closely associated with these types we also find extremely magnetite-rich chlorite-quartzites, i. e. types with an extreme enrichment in iron as compared with the types mentioned above. Finally the occurrence of cordierite- and cummingtonite-bearing quartzites are examples of altered rocks highly enriched in magnesium.

The above-mentioned variations, immediately established in the mineralogical

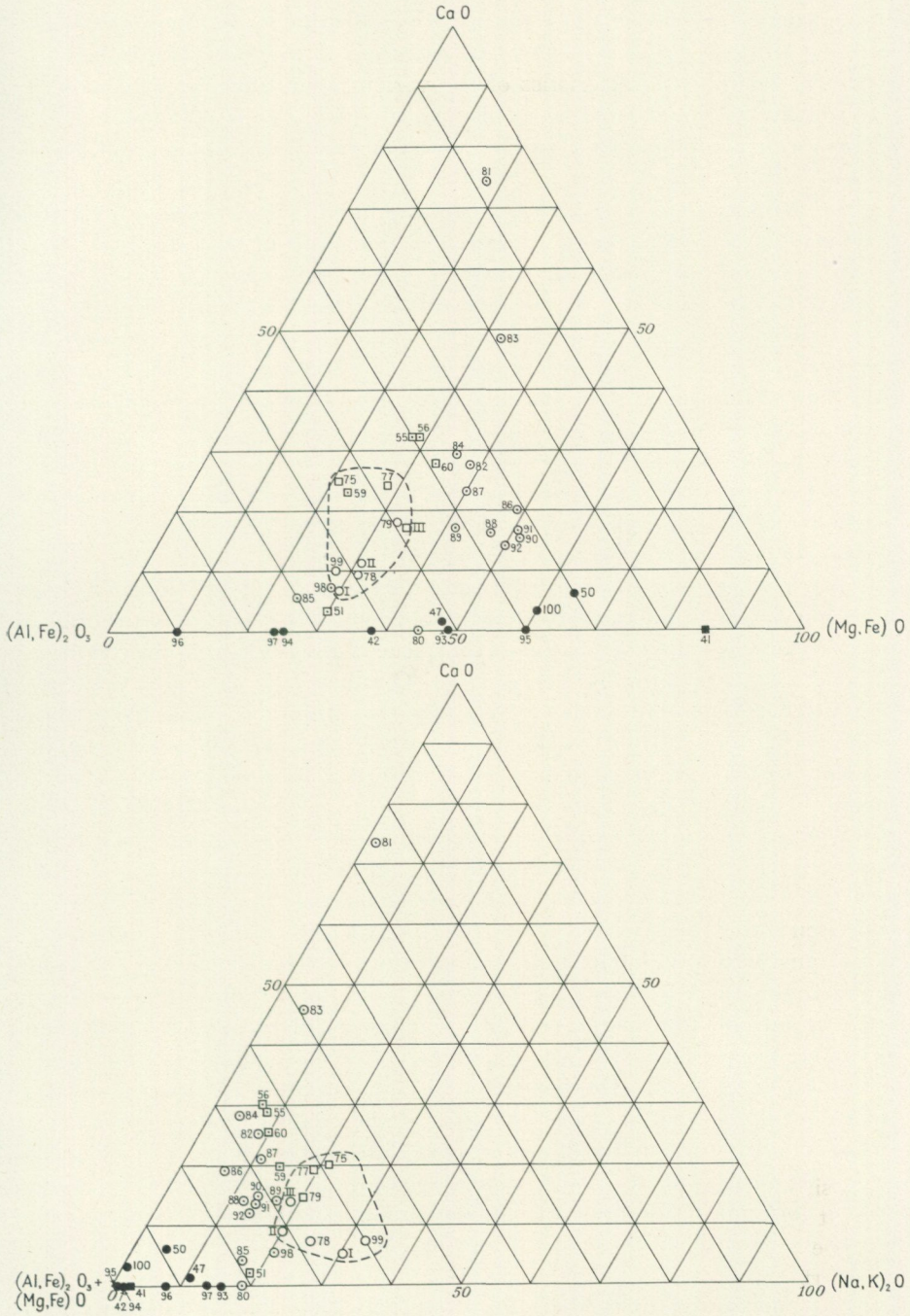


Fig. 25. Triangle diagrams illustrating the metamorphic differentiation in the altered rocks around Bjurliden and the Bjurträsk ores. Signs and figures are the same as in fig. 24.

dissimilarities, are evidently so large as to considerably exceed those that might be expected to occur as a result of substitutions in the individual minerals.

If the chemical characteristics of the various zones illustrated by figs. 23, 24, and 25 are summarized, the following results are thus obtained:

Innermost zone (*quartzite zone*) (1): Difference between original and altered rocks:

(Na, K)$_2$O has decreased, Na_2O being reduced quite considerably, while K_2O may even have increased. In any case the value of the ratio $K_2O : Na_2O$ would appear to be greatly increased.

CaO has decreased and is probably entirely absent in most cases.

As a whole (Al, Fe)$_2$O$_3$ and (Mg, Fe)O possibly show a slight increase. The variations in each of these groups, however, are so large that (Al, Fe)$_2$O$_3$ and (Mg, Fe)O values may occur that are even lower than the corresponding contents of the original rocks.

SiO_2, finally, shows no distinct tendency either towards increase or decrease. The variations within the zone, however, are very much greater than in the original rocks.

Transitional zone (2):

What has been said above regarding (Al, Fe)$_2$O$_3$, (Mg, Fe)O, and (Na, K)$_2$O in the inner zone is practically true of this zone, too. The changes of the original rocks are only less intense. The most conspicuous difference from the conditions in zone 1 is the great dispersion of the CaO values.

It will be seen from the above facts that the alterations connected with the origin of the ores do not chiefly involve the enrichment of certain definite elements within the altered area taken as a whole. An intense variation in the chemical compositions of the rocks must, instead, be considered the most characteristic feature. In the inner zone we find how altered rock-types, extremely enriched in for instance Al, Mg, or Fe, in relation to the original rock, are close by corresponded by rocks characterized by a deficiency in the same elements. The occurrence of cordierite-, garnet-, staurolite-, andalusite-, and magnetite-bearing quartzites, etc., can thus not be explained as the result of a metasomatic process with a general supplement of substances in connection with the introduction of the ores. It would seem more probable that these rocks were formed mainly by a metamorphic differentiation under the influence of the ore solutions. In the triangles this differentiation is conspicuous as a dispersion of the analyses from the part of the triangle that represents the compositions of the unaltered rocks. Thus dots representing rocks which on account of their mineralogy and mutual location in relation to the ore bodies must be presumed to represent a similar grade of alteration, often lie quite far apart in the diagrams (e. g. 94 and 95).

In the mineralized areas where the alterations generally speaking only lead to the development of sericite- or chlorite-quartzites, we also find an interchange between types in which sericite, chlorite, or biotite are predominant, and these circumstances make it difficult to decide to what extent certain

elements are particularly enriched in the area as a whole. It is not possible in these cases to make quantitative calculations on the basis of the material available. Within the northern parts of the mapped area we find a fairly intense calcite invasion associated with the sericitization, a phenomenon that will be dealt with in greater detail later (see p. 167).

2. Mutual Relations of the Minerals.

In the cases dealt with above the relations between the chemical compositions of various altered types as found in thin sections have been discussed. In order to obtain a complete view of the processes that have contributed to giving the rocks their present appearance, it is necessary, however, also to pay due consideration to the cause of the changes that may be discerned in the mineral sequence of each individual specimen. When one mineral has been found to be formed at the expense of another, it is possible from the difference in chemical composition of the two minerals to establish the direction in which the chemical changes tend to occur. The sum of these different directions with regard to chemical alteration in one and the same thin section thus constitutes an expression of the general course of the metamorphism in the specimen.

The development of the commonest alteration types, sericite-quartzite and chlorite-quartzite, implies that the felspar, generally plagioclase, is replaced by chlorite or sericite. The observations in the field as well as the microscopic examinations indicate the origin of sericite to be later than the origin of chlorite, or that the sericitization at least includes and alters chlorite. In the pure sericite- and chlorite-quartzites, sericite and chlorite, respectively, must of course also have been formed at the expense of biotite, and in the marginal parts of the altered areas this alteration can often be directly observed under the microscope.

To a smaller extent and usually in close connection with the crystallization of the ore minerals themselves, changes in the opposite direction are found. I am then thinking of such processes as the felspathization of sericite- and chlorite-rich rocks, the development of hornblende in chlorite-rocks, the formation of late biotite in some chlorite-quartzites, etc. These changes, however, overtake rocks that were altered earlier in agreement with the instances first mentioned.

With regard to the minerals that usually prove to be later than chlorite and mica, it is true that the development of garnet as such cannot be said to represent a change in chemical composition. This mineral may well have been developed from the material already present by a change in the pressure-temperature conditions towards a higher grade of metamorphism, towards a more high-grade mineral facies. The table below is intended to give a survey of the mineralogical alterations that can be established by microscopic examinations, and which really constitute a change in the chemical composition

of the solid phase from one case to the other. For the sake of simplicity H_2O and SiO_2 have been excluded from this table.

		Increase in	Decrease in
1.	Plagioclase → Chlorite	(Fe, Mg)	Na, Ca
2.	Plagioclase → Sericite	Al	Na, Ca
3.	Biotite → Sericite	Al	(Fe, Mg)
4.	Chlorite → Hornblende	Ca	
5.	Chlorite (Sericite) → Plagioclase	Ca, Na	(Fe, Mg) (Al)
6.	Biotite → Andalusite	Al	(Mg, Fe), K
	Biotite → Staurolite	Al	(Mg, Fe), K
	Andalusite → Staurolite	(Mg, Fe)	Al
	→ Gahnite	Zn	
7.	Chlorite (Biotite) → Staurolite	Al	(Mg, Fe)
8.	Chlorite → Sericite	Al, K	(Mg, Fe)
	Sericite → Chloritoid	(Mg, Fe)	Al, K

This survey shows that the relations between the individual minerals do not indicate any clear tendency towards a uniform enrichment of certain elements during the mineralization, which is in agreement with the conditions found when considering the relations between the various types of altered rocks. The formation of minerals which in one stage means an increase in certain elements is often superseded in the next stage by a change in the opposite direction. This fact is best demonstrated by Nos. 6 and 8 where the same element occurs in both columns, but in different stages of the mineralization. A metamorphic differentiation of this kind is most conspicuous in No. 8, where the chloritoid often appears in association with the sericite-rich parts of the rock, and the simultaneous occurrence of sericite and chloritoid thus illustrates a metamorphic differentiation, practically *in situ*. Of course alterations 4 and 5 are quantitatively of much less importance than 1 and 2, but occur in areas which must be considered earlier to have been subjected to alterations 1 and 2, possibly also 3.

3. Relationship between Sulphides and Altered Rocks.

As already pointed out the sulphide minerals in most cases seem to have been precipitated mainly after the crystallization of gangue and wall-rock minerals. A very intimate relationship, however, is often found between sulphides and certain silicates, the latter sometimes being found within or on the surfaces of sulphide grains. When the development of such late silicates involves a composition decidedly deviating from that of the minerals occurring in the surrounding rocks, we may in these post-sulphide minerals find an expression for those elements which occur in the solutions in addition to the sulphides themselves at the time of their crystallization.

In some cases we may thus find gahnite, and less often garnet, in fairly intimate connection with sulphides. Calcite often occurs together with sulphide grains, but is then always more or less replaced by the sulphides.

The mica and chlorite minerals, however, display the most unmistakable relationship to the sulphide minerals. They occasionally appear as a thin coating on pyrite grains, and in their present development they must thus have crystallized later even than the sulphide grains themselves. In many cases, however, such a behaviour only implies a recrystallization of minerals occurring in the rock already before the crystallization of the sulphide. In this mode of development we thus find coarse chlorite in chlorite-quartzite, coarse sericite in sericite-quartzite, etc. In other cases, however, there are also formed new minerals and quite often biotite is found surrounding ore grains. This mode of occurrence is most common in chlorite-quartzites, but has also been observed in some sericite-quartzites. The extremely labile equilibrium conditions at the time of this mineral formation is demonstrated by the previously mentioned observations from the Bjurträsk ores, where chlorite of the same type as that occurring in the groundmass had crystallized along one side of a pyrrhotite grain, and biotite on the other. Whether one mineral or the other is formed is evidently purely accidental. In extremely sulphide-rich disseminations chlorite has been found in close association with the sulphides, the other minerals then being sericite and plagioclase.

It is apparent from the above that there is nothing to indicate the crystallization of the ore minerals to be connected with a practically simultaneous enrichment of certain specific elements. In some cases it is evident that quartz, in other cases that calcite was the main element introduced. The formation of felspar in close connection with the crystallization of the sulphides indicates that also Na_2O was present in the late solutions, and the origin of biotite from chlorite shows that K_2O may occur. An enrichment in Al is indicated by the formation of spinel, and an enrichment in Fe-Mg by the origin of chlorite, or more often the origin of biotite from sericite-bearing quartzite.

If we finally consider the relations of the individual ore bodies to the different types of altered rocks, we often find a certain tendency towards a distinct relationship. The ore solutions that have deposited pyrrhotite and chalcopyrite in relatively large quantities thus seem extensively to give rise to the origin of altered rocks rich in iron and magnesia. The individual ore bodies at the Eastern Bjurfors ore are thus generally surrounded by pure chlorite-rocks. The same conditions are found at the Bjurträsk ores, where the copper ores are surrounded by and occur in black chlorite masses. The pure pyrite ores, on the other hand, preferably occur together with sericite-quartzites, and the relationship between a pyrite and sericite formation is clearly indicated also in the mineralized areas poor in sulphides. Thus when the mineralization gives rise to pure sericite-quartzites, the sulphide minerals consist practically only of pyrite. It would appear as if the solutions having a higher S-content also mobilized iron and magnesia in contradistinction to what is the case in the solutions poorer in S, where these elements are retained in the altered country rock. It is impossible, however, to obtain any quantitative data for the above-mentioned relationships from the material available, as the amount and extent of the observations made in the various cases differ

quite considerably. We are merely establishing the general impression obtained by a survey of the observations in the area.

4. Conclusions.

A survey of the results discussed above shows that we cannot possibly draw any exhaustive conclusions regarding the elements really added in connection with the sulphides, only on the basis of the information obtained by a study of the chemical alterations of the country rocks. The abundant and fairly equal distribution of quartz and calcite in similar ore types from localities where the chemical activity was considerable, e. g. Bjurliden, and from ores where the chemical activity was of very little importance, e. g. Ö. Högkulla, shows, however, that at least SiO_2 and $CaCO_3$ really were introduced.

As regards other elements, it is not possible to determine what may have been their mutual proportions in the original ore solutions. Generally the alterations seem very largely to represent interchanges within previously existing materials, endogenous as regards constituents, exogenous as regards the source that started the process, *viz.* the solutions emanating from the ores.

The significance of interchanges of substances in connection with metamorphic processes of various kinds has long been stressed by several geologists in Fennoscandia. In Sweden such conceptions have lately been emphasized particularly by Magnusson, who has established very important interchanges in pre-existing materials in connection with the formation of the Middle-Swedish iron ores (*55*, *56*, *57*). From Långban (*57*, pp. 64—69), he also mentions the formation of cordierite-andalusite-quartzites through an interchange of materials, although they in this case are of a very local character. In a later paper (*19*) Eskola has used the term metamorphic differentiation, and he has also attempted to outline some general principles according to which this differentiation may be considered to develop. Eskola presents the following classification:

1. Differentiation within a rockmass due to
   a. the growth of crystals or aggregates of crystals (the concretion principle),
   b. the concentration of the least soluble substance (the principle of the enrichment of the stablest constituents), or
   c. the extraction and redeposition of the most soluble substances (the solution principle);
2. Transfer of substances into and from a rockmass, effecting
   a. addition,
   b. metasomatism, or
   c. extraction of substances.

Of course it is often impossible to make a clear distinction between Groups 1 and 2 in the cases occurring in nature, which is also emphasized by Eskola.

It must also be remembered that cases in which a small area seems to be represented by the conditions in Group 2 might perhaps just as well be explained in accordance with the conditions in Group 1, the investigation being made to cover a larger area. In cases when interchanges of the previously existing materials might be suspected, the investigated area must of course comprise all parts of the influenced country rocks.

The altered rocks under discussion in this investigation seem to be best explained as having originated under conditions corresponding to Group 1 b and to a smaller extent possibly also to 1 c. As very little is known about the absolute concentrations in the ore solutions, it is not possible to present any exact data. The interchange of substances between the solid and the liquid phases involves that the system tends towards an equilibrium, and it would *a priori* seem probable that this equilibrium should display certain variations during the course of the alteration, i. e. under different P-T-values. In other words, it may be expected that the proportions between the elements in the solution that are required for an equilibrium according to the Law of Mass Action would vary during the course of the alterations. Under such circumstances the final results will to a certain degree be dependent upon to what extent the equilibrium mentioned would have had time to become realized before the appearance of P-T-values calling for new equilibria. On the basis of these considerations we arrive at the result that at least in many cases the equilibria have not been attained, which is evidenced by the irregular and partly very frequent variations in various types of altered rocks.

E. Relation of Sulphide Mineralization to Regional Metamorphism and Granites.

The mineralized zones of the Malånäs District are located in areas which, as regards regional metamorphism, display rather different mineral facies from case to case. As already mentioned the introduction of the sulphides and the alterations connected with it are later than the mineral associations formed under the influence of the regional metamorphic processes. A question of very great importance is whether the mineralogical development of this latter mineralization displays any special relationship to the grade of the regional metamorphism. First the four main ores, which are of a similar size, will then be considered.

Bjurliden and the Bjurträsk ores are situated a good distance in on the high-grade side of the isograde for complete biotite- and amphibole formation, while the Bjurfors ores and Ö. Högkulla are located between the isograde for complete biotite facies and the isograde for complete chlorite facies. Of the two last-mentioned ores Ö. Högkulla must in all probability be considered to be located in a lower-grade *milieu* than the Bjurfors ores, even though it is difficult to express this difference in figures. The observations used when drawing the isogrades on the map of metamorphism, fig. 6, however, show low values in the vicinity of Ö. Högkulla for the ratio biotite: "primary" chlorite, and

entirely biotite-free types are also found. In addition, the recrystallization that can be established in the quartzporphyries immediately outside the areas affected by the sulphide mineralization, is much less pronounced and less extensive at Ö. Högkulla than at the Bjurfors ores. From this fact it appears that the Bjurträsk ores and Bjurliden lie within areas displaying the distinctly highest metamorphic grade, Ö. Högkulla in an area displaying the lowest metamorphic grade, while the Bjurfors ores have an intermediary position.

If we then consider the mineralogical aspect and the extent of the mineralization in each individual case, it is also possible to establish a gradation to a certain extent parallel with the above. The minerals characteristic of a higher grade of metamorphism, *viz.* garnet, cordierite, staurolite, andalusite, and spinel, which are abundant at the Bjurträsk ores and Bjurliden, are entirely absent at the Bjurfors ores. Garnet actually occurs at Ö. Högkulla, but it is usually of a relatively local character, and as the formation of ore-quartzites is generally quite insignificant, this mineralization as a whole appears to be connected with far less intense alterations than the Bjurfors ores, where the corresponding formation of ore-quartzite is very extensive. Fairly considerable quantities of hornblende also occur at Bjurfors in connection with the sulphide mineralization, while at Ö. Högkulla calcite, epidote, and chlorite occur together without any signs of a hornblende formation.

A study of the minerals occurring as gangue in the ores themselves indicates differences of a similar character. These mineral assemblages will chiefly denote the facies conditions under which the ore minerals crystallized. Of course we cannot expect to find a certain equilibrium association for each ore body, it being probable, *a priori*, that different parts of the ore were crystallized under different temperatures. However, a summary of the various mineral associations observed in each ore may give fairly good information as to the conditions under which the sulphides crystallized.

Fig. 26 is a summary intended to portray the characteristic parageneses. As the gangue minerals are often very unevenly distributed in the sulphide mass, exact volumetric analyses are of little value in this case. It is sufficient for the discussion to state the minerals observed, but an attempt has also been made in the diagram to make a rough estimation of the relative amounts of the minerals. The Ca-free Fe-Mg-Al-silicates and the Ca-bearing minerals representing higher grades of metamorphism in the facies classification have been placed at the top. This diagram clearly shows that the associations characteristic of high-grade metamorphism predominate at the Bjurträsk ores and at Bjurliden; at Bjurfors, on the other hand, there is a mixture of the two. The latter fact is best illustrated by the distribution of the Ca-bearing minerals. It is furthermore characteristic that in the two biotite-bearing specimens from Bjurfors, i. e. those representing a higher metamorphic grade as regards the Fe-Mg-Al-silicates, we also find a clear tendency towards a higher grade in the development of the Ca-bearing minerals. At Ö. Högkulla, finally, we find only low-grade associations. The quantitatively greater part of the Högkulla ore is a calcareous, solid ore, thus represented in the diagram by specimen

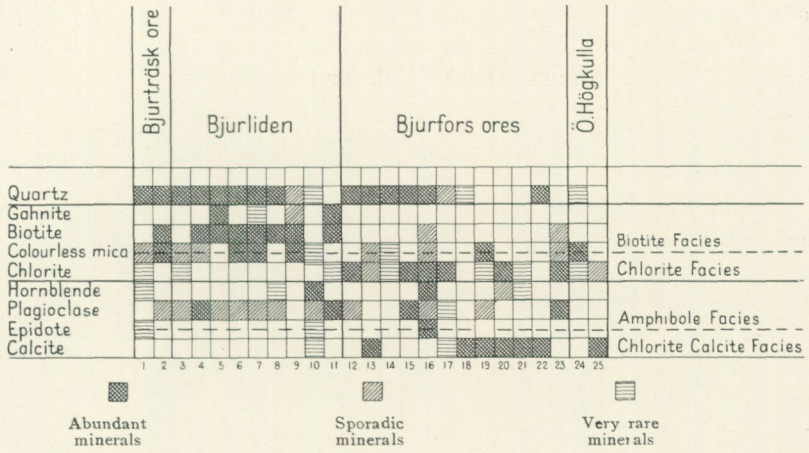


Fig. 26. Diagram showing the approximate distribution of gangue minerals in the ores. (Estimated from thin sections, represented by the figures 1—25).

1. Solid pyrrhotite sphalerite ore.
2. Solid pyrrhotite chalcopyrite ore.
3. Pyrite pyrrhotite dissemination.
4. Pyrite dissemination.
5. Sphalerite-rich dissemination.
6. Solid ore; pyrite, pyrrhotite, sphalerite.
7. Solid porphyritic pyrite ore.
8. Solid pyrrhotite ore with sphalerite.
9. Solid ore; pyrite, pyrrhotite, sphalerite.
10. Solid sphalerite-banded pyrite ore.
11. Solid pyrrhotite ore.
12. Chalcopyrite dissemination.
13. Pyrrhotite chalcopyrite breccia.
14. Solid pyrrhotite ore with pyrite cubes.
15. Solid chalcopyrite-rich ore.
16. Solid, complex ore with rounded inclusions.
17. Solid pyrite ore.
18. Solid, dense pyrite ore with chalcopyrite schlieren.
19. Solid magnetite-rich pyrite ore.
20. Solid chalcopyrite-rich ore.
21. Solid pyrite ore, rich in chalcopyrite.
22. Solid pyrite ore with sphalerite.
23. Solid ore with some sphalerite.
24. Sulphide breccia; pyrrhotite with some sphalerite.
25. Solid zinc-rich ore.

No. 25, and this association, often containing quartz, too, may thus be considered representative of that ore.

The mineral associations in the ores themselves as well as the extent and mineralogical development of the altered rocks surrounding the ores show that the Bjurträsk ores—Bjurliden, the Bjurfors ores, and finally Ö. Högkulla represent three types of development, which in the order mentioned represent decreasing alteration intensity and to a certain extent also decreasing metamorphic grade as regards mineral facies. On the whole these differences have a parallel in the position of the different types in relation to the isograde for the regional metamorphism, as in areas characterized by higher metamorphic grade, the mineralization is more extensive and usually displays more high-grade altered mineral parageneses than in the lower-grade regional metamorphic areas.

Also when considering the relations of the ores to their wall rocks we find, however, certain regular differences. As mentioned in the discussion on the individual ores, the Bjurliden and Bjurträsk ores were mainly deposited by replacement, displacement having been of very little importance. At Ö. Högkulla the conditions are reversed; there the displacement structures by far dominate the replacement structures, and at the Eastern Bjurfors ore distinct

signs of replacement as well as displacement are found in many cases. We can thus establish a certain relationship also between the relation of the ores and their wall rocks and their location in high- or low-grade regional metamorphic areas.

The above-mentioned relationship between regional metamorphic zones, the behaviour of the ores, and the general character of the mineralization, lead to the assumption that the relative difference in the physical-chemical equilibrium conditions that caused the different regional metamorphic zones, also existed at the time when the ores were deposited. The differences in appearance and mineralogy between the various ores may then be taken to indicate that they were precipitated under different temperatures, but we may also consider that the temperature conditions in the surroundings in which they were precipitated in one case lead to rapid crystallization and but slight chemical reactions between the ore solution and the wall rock, whereas in the other case, the crystallization covered a longer time and the chemical activity was more extensive.

The above discussion has only referred to the conditions in the solid ore bodies. If the discussion is extended also to comprise the poorer and economically unimportant mineralized areas that occur both in high-grade and above all in low-grade regional metamorphic areas, certain differences may also here be discerned in different areas. Of course the question of replacement or displacement types will be of no importance in these types, as the sulphides never appear more abundantly than to give the mineralization the character of disseminations, thus having a replacement character. In the chlorite-facies areas the alterations of the silicate rocks have led to the formation of sericite-quartzites only. As was mentioned already in the general discussion on the regional metamorphism, however, the character of the sericite formation is almost regional as soon as the low-grade side of the isograde for complete biotite facies is reached. Intensive sericitization in connection with the introduction of pyrite occurs here and there localized to certain belts, but generally speaking it is impossible to separate the regional sericitization from the alterations of a local character. As was pointed out in the discussion on the regional metamorphic processes, these circumstances caused a special biotite-sericite-chlorite zone to be denoted between the isograde for complete biotite facies and the isograde for complete chlorite facies. On account of these conditions it might be supposed that regional metamorphism and sulphide mineralization took place almost contemporaneously in the northernmost parts of the investigated area. As was mentioned above there are reasons to assume that the hiatus that can be established between the mineralization of a regional character and that following the ores, is relatively insignificant in the southern parts of the area. If the regional metamorphism has the character of a temperature front advancing from south to north, it would *a priori* be expected that the above-mentioned hiatus would become smaller and finally disappear northwards. This seems to be at least a possible explanation of the difficulty

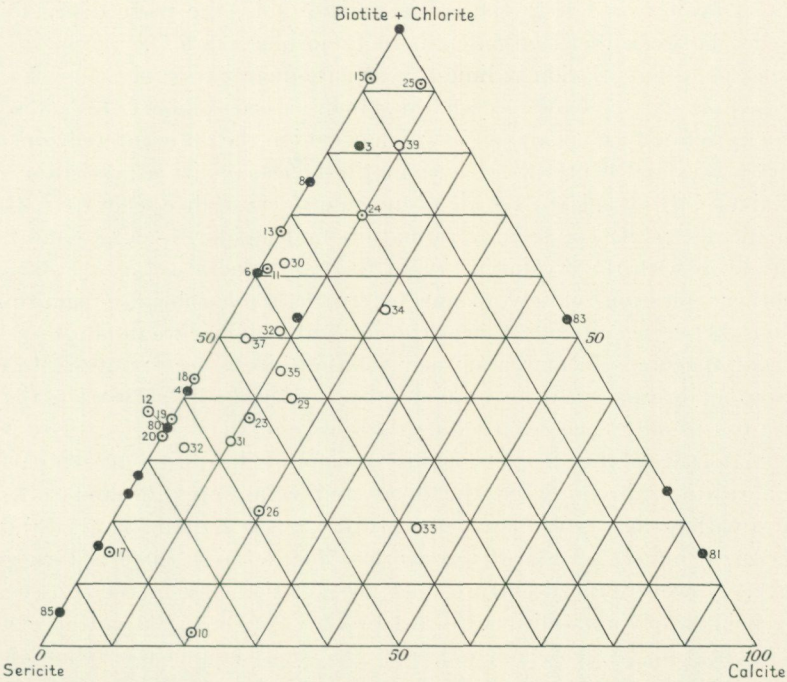


Fig. 27. Triangle diagram illustrating the distribution of calcite and sericite in more or less altered quartzporphyries, in different metamorphic grades. Filled circles = rocks in biotite facies; circles with a dot = rocks in transitional facies ("sericite-biotite facies" or incomplete biotite facies); open circles = chlorite facies. The figures are the same as in figs. 6, 7, and 21.

in telling apart regional and local mineralization processes in the northernmost parts of the investigated area.

In the low-grade metamorphic areas the sericitization is in most cases accompanied by an introduction of calcite in the country rocks. This means a decided difference from the conditions in the biotite-facies areas, where calcareous minerals, and particularly calcite, do not generally occur together with sericite. Even at the Middle Bjurfors ore, for instance, where the sericitization as well as the calcite formation are often rather extensive, we hardly ever find sericite and calcite in the same thin section; this in spite of the fact that the thin sections may have been taken from specimens quite close together. In fig. 27 the proportions between chlorite + biotite, calcite, and sericite have been calculated for a number of quartzporphyries from different parts of the investigated area. We find here how the types from areas characterized by complete biotite facies almost entirely differentiate and fall either along the biotite-calcite side or along the biotite-sericite side, while the types from areas characterized by complete chlorite facies, and to a certain extent also types from the transitional zone between these two types of facies, generally fall inside the triangle. The more intense the alteration, i. e. the nearer the

points of projection fall to the calcite-sericite side, the more distinct is this difference between rocks of different metamorphic grade.

The same differentiation in lime-free sericite-quartzites and CaO-rich altered rocks is also indicated by the alternation between sericite-quartzites and sericite-free rocks rich in basic plagioclase, which occurs in the outer altered zone at the Bjurträsk ores and Bjurliden. Under biotite-facies conditions, sericite can thus be established to display a decided tendency to crystallize separately from the CaO-minerals, while the sericite formation under chlorite-facies conditions is simultaneous with the crystallization of the CaO-minerals.

Another question closely connected with the problems regarding the relations between sulphide mineralization and regional metamorphism is the source of the ore solutions and their relationship to the granites. In earlier descriptions dealing with the sulphide ores in the Skellefte District, the older granite has usually been regarded as the source of the ores — at least for the great majority of the deposits. This conception has been based partly on certain relationships between the dikes and veins, ores, altered rocks, and granites within the western parts of the district (the Kristineberg area), partly on a certain mineralization of the contacts of the large eastern Jörn granite massive. However, the literature does not mention any further observations in the field supplying additional direct proofs of such a relationship. In a recent publication, A. Högbom (*43*, pp. 228—229) emphasizes that also the younger granite, the Revsund granite, may have mineralized contact zones, and he seems inclined to leave the question open to what extent one granite or the other was responsible for the main part of the ores.

Ödman (*88*, p. 108) emphasizes that in several deposits in the eastern parts of the Skellefte District, there is nothing to indicate a genetic connection with the Jörn granite. The location of the ores in relation to the various granite massives and certain other circumstances would rather imply a relationship to the Revsund granite.

As regards the ores in the Malånäs District we may say that all results from the field here contradict a relationship to the Jörn granite. We have seen how the regional metamorphism is absolutely independent of the Jörn granite, but that it does display a certain conformity with the contacts of the Revsund granite. We also know that the sulphide mineralization is later than the regional metamorphism, and that the minerals formed by the regional metamorphic processes are subjected to a secondary alteration during the sulphide mineralization. As it thus seems impossible to consider the Jörn granite as the source of the ores, we can here only count with the Revsund granite. But if this granite is considered to be of a palingene nature, it is perhaps more correct to say that the ores emanate from the same magmatic source, as has contributed to creating the granite in question, depositing them in an outer zone in relation to the granite. Due to the deposition of the ores being greatly dependent on the main tectonic features in the district, the question as to the magmatic source of the ores must be considered comparatively unimportant as compared with the connections that possibly may exist between ore zoning

and tectonic features. In this connection the problems in certain alpine districts may be called to mind, as expressed in some papers, e. g. (*37*) and (*74*). The distribution of the elements is in these cases placed in relation to the main tectonic and metamorphic features and not to certain intrusive rocks.

F. Relation of Sulphide Mineralization to Tectonic Features.

It is naturally of great practical and theoretical importance that it be established whether there exists any relationship between the tectonic features and the distribution of the sulphide ores. As regards the deposits of sulphide ores in the Skellefte District, it may be stressed that generally speaking the tectonic conditions seem to be decisive as regards the deposition of the sulphides. The chemical character of the rocks, on the other hand, is of but very subordinate importance in the cases so far known, this in contradistinction to what is the case e. g. in Bergslagen, where the original limestones of the leptite series have been of very great importance. On the basis of the information gained in the mapped area, a few comments will first be made on some features of a general character.

The general results indicate that the formation of ore in the main begins at a comparatively late stage of the tectonic development. The advance of the solutions will thus be dependent upon the openings in the rocks created during the deformation. In earlier papers on the ore formation in the Skellefte District it has been stressed that the ores are apt to occur in the immediate vicinity of the phyllites. This relationship is quite natural considering the tectonic conditions in such areas. It has previously been pointed out that the great difference in plasticity between phyllite and massive rocks gives rise to very irregular tectonic conditions, which often result in fissuring and the formation of large joint lines in the vicinity of the phyllites. It is obvious that in such areas this will create favourable conditions for the advance of the mineralizing solutions.

Of the relatively solid ore bodies in the area in question, it is only the sulphide deposits at Ö. Högkulla and Skäggträskberget that are found to be directly orientated along tectonic lines that are related to phyllite beds. These ore bodies are orientated to planes of schistosity striking east-west and dipping to the south, and the Ö. Högkulla ore lies in the direct continuation of these tectonic lines. This structure is also directly observable in the latter deposit, in the boundary lines of the bed of barren rock that divides the ore into two parts. The linear structure of the ore bodies is very conspicuous at Ö. Högkulla, displaying a very regular pitch 45° to the south. In the case of the ore at Skäggträskberget the pitch is 50°—60° to the WSW—SW. Thus, the orientation of the ore bodies does not coincide with the great tectonic fold axis, which pitches 30° to the west and according to which the great bending of the layers has occurred. Owing to its general character, this fold axis must, at least in the immediate vicinity, be considered fairly constant, and conse-

quently it should prevail also at Ö. Högkulla, as regards the major tectonic features. On the other hand, the east-westerly structure dipping to the S, which interferes with steep north-southerly tectonic planes, may be of decisive importance for the distribution of the ores. The latter has been observed both at Ö. Högkulla and at Skäggträskberget. In fact, in the eastern part of the former ore there is a "tail" running SW—NE (cf. page 138), and at Skäggträskberget we know of north-southerly structures immediately S of the small solid ore bodies. The large arsenopyrite-bearing quartz vein, for instance, has penetrated along these structures. Both at Skäggträskberget and at Ö. Högkulla the north-southerly planes seem to delimit the mineralized areas towards east and west.

Of the other solid ore bodies in the area, the Bjurträsk ores are the only ones where the surroundings are so well exposed as to permit an investigation of the relation between the tectonic features and the origin of ore. As has already been mentioned in the chapter on the tectonic features (p. 17), the rocks there show a very decided linear structure pitching WSW. Both the small folds and the boundaries of the rock beds are, in the main, orientated in the same system of linear structure. A glance at the map suffices to show that the deformation of the rocks here must be such as to "loosen" the bedrock and create openings where the metal content of the ore solutions may be deposited. Two main directions of strike are found, one running WSW and one NW. It is possible both in the shape of the altered area and in the ore body itself, to some extent to recognize the influence of these directions (see map of ore bodies and alterations, Pl. 34 and fig. 11). The investigations of the minor ore indicate that this ore in the main coincides with the linear structure of the rocks and the general direction of the axes, which was also to be expected considering the tectonic features.

It is also possible to establish in detail a mineralization along the linear structure, which is here very distinct. In places it may be found how the pyrite dissemination is enriched around the highly elongated fragments of the agglomerates or within those fragments. Further, it is sometimes possible to establish a distinct enrichment of the sulphides in the bendings of layers where the rocks have to a large extent been altered to chlorite-quartzites and have been minutely crumpled. As these bendings have occurred according to the general linear structure, the mineralization, too, must obviously coincide with this structure. All these observations indicate a comparatively intimate relationship between the formation of the linear structure in this region and the sulphide mineralization. However, the linear structure must in the main have been initiated and formed before the mineralization took place. This is borne out *inter alia* by the fact that the indistinct tendency towards a uniform optic orientation of the quartz, which has been traced in single cases, e. g. in the fragments of the unaltered agglomerates, is entirely obliterated by the recrystallization which follows the sulphide invasion.

At Bjurliden the outcrops do not permit such a detailed examination as at the Bjurträsk ores, nor is it possible in this case to determine with certainty

special tectonic features that may have had a decisive influence on the deposition of the ores. Possibly the slight bending of the layers, conspicuous especially in the appearance of the quartzporphyry bed (see the map, Pl. 38), may have had a certain influence on the formation of space.

It is very interesting, however, to compare the mineralization in the regions on either side of the large tectonic line which divides the area immediately S and E of the river Malån into two regions with different tectonic styles. In the southern area there are rocks with distinct linear structures, B-tectonites, and here the mineralization gives rise to the formation of solid sulphide deposits surrounded by altered areas. In the northern area with distinct linear schistosity (S-tectonites dominating), the mineralization has quite another character. About 200 m N of the above-mentioned tectonic line there occurs a belt of rocks which have very largely been altered to quartzites with an abundant pyrite dissemination. The mineralization is known partly from outcrops, partly from prospecting trenches. Between these it has been followed as almost continuous electric and magnetic indications for a distance of about 2 km. This development as very continuous disseminations, in which, however, there are never any concentrations of solid ores, is in good agreement with the general tectonic features of the same area. All rock boundaries and tectonic lines are, in fact, orientated into the S-surface, this making them very continuous. It would appear as if the difference in the type of mineralization might be expressed in the following manner. In the northern area the sulphides are mixed fairly uniformly with a rock of comparatively high plasticity; in the southern zone, on the other hand, the sulphides are precipitated in local spaces created by the deformation and folding of the beds. On the whole, the tectonic conditions do not appear to favour the formation of solid ores in rocks of very high plasticity. This may be the reason why a mineralization of an "ore character" is so rarely met with in the rocks of the phyllite series, though in many cases a fairly abundant dissemination of additional sulphides may be found.

As regards the Bjurfors ores and Norrliden, the available observations in the field do not allow of any further conclusions other than those already advanced when describing the individual ore bodies. A noteworthy fact is that the comparatively solid ore bodies of Snåttermyran, the Bjurträsk ores, Bjurliden, and the Bjurfors ores, seem to lie on a straight line running parallel to the major tectonic lines in the field and parallel to the general direction of strike of the layers. Further, Norrliden lies in the extension of the parallel line represented by the above-mentioned disseminated belt in the highly schistoze region S of Malån. It is impossible to ascertain with certainty, however, whether these relationships are to be regarded as accidental. We m a y here have before us certain tectonic lines of very great importance for the regional distribution of the sulphide ores, though, in field observations and on the map, it is not possible to perceive anything indicating the presence of such structures.

G. Differentiation in the Ores and Distribution of Elements.

1. Ore Types and Associations of Elements.

In the preceding chapter we have considered the relations between the sulphide mineralization as a whole and the geological processes of a regional or local character that are met with in the mapped area. As appears from the description of the separate ores, the mineralization, however, displays fairly great variations as regards the chemical composition in the various cases. What are the factors that give rise to such variations, and what laws determine the formation of the chemical characteristics of the individual ore bodies? To answer these questions it is necessary first to ascertain the nature of these characteristics.

Considering first of all the elements that are quantitatively predominant, *viz.* Fe, Cu, Zn, and S, the following facts are found. Merely a general survey suffices to give the impression that there exist continuous gradations from pure pyrrhotite or pyrite ores to, on the one hand, ore types rich in copper and, on the other, ore types rich in zinc. If the ratios $\frac{S}{Zn + S}$ and $\frac{S}{Cu + S}$ are calculated, it might thus be expected that the values of these would present continuous gradations between high values (ores poor in Zn and Cu) and low values (ores rich in Zn or Cu).

To express this in figures, the ratios $\frac{S}{Zn + S}$ and $\frac{S}{Cu + S}$ have been calculated from the available analyses and are given in per cent. The values thus found have been arranged in 5 % groups, 95—100 %, 90—95 %, etc. To gain an idea of the quantitative importance of the different percentage classes, a calculation has been made for each analysis to ascertain what part of the total analysed ore portion is represented by the analysis in question. Certainly this is a rather rough approximation, which, however, is necessary for the following reasons. The analysed samples have, as a rule, been taken only with a view to ascertain the economic value of the ore, and consequently sections of an inherently homogeneous nature have been analysed. As a result, an analysis may in one case represent a fairly wide section of the ore, e. g. 10 m, whereas in another case an ore section 1 m in width may be covered by several analyses.

The same quantitative importance can thus not be attached to each individual analysis when summing up the analyses of the same percentage class. It is also evident that average analyses of large and inherently heterogeneous ore portions cannot contribute anything of value to solving the details of the distribution of elements, and such analyses have therefore not been included. The diagrams (fig. 28) thus indicate the quantitative distribution of the percentage classes within the analysed parts of the respective ores.

In the case of the ores that have been thoroughly analysed, i. e. the Eastern Bjurfors ore, Ö. Högkulla, and, to some extent, Bjurliden, the possible errors

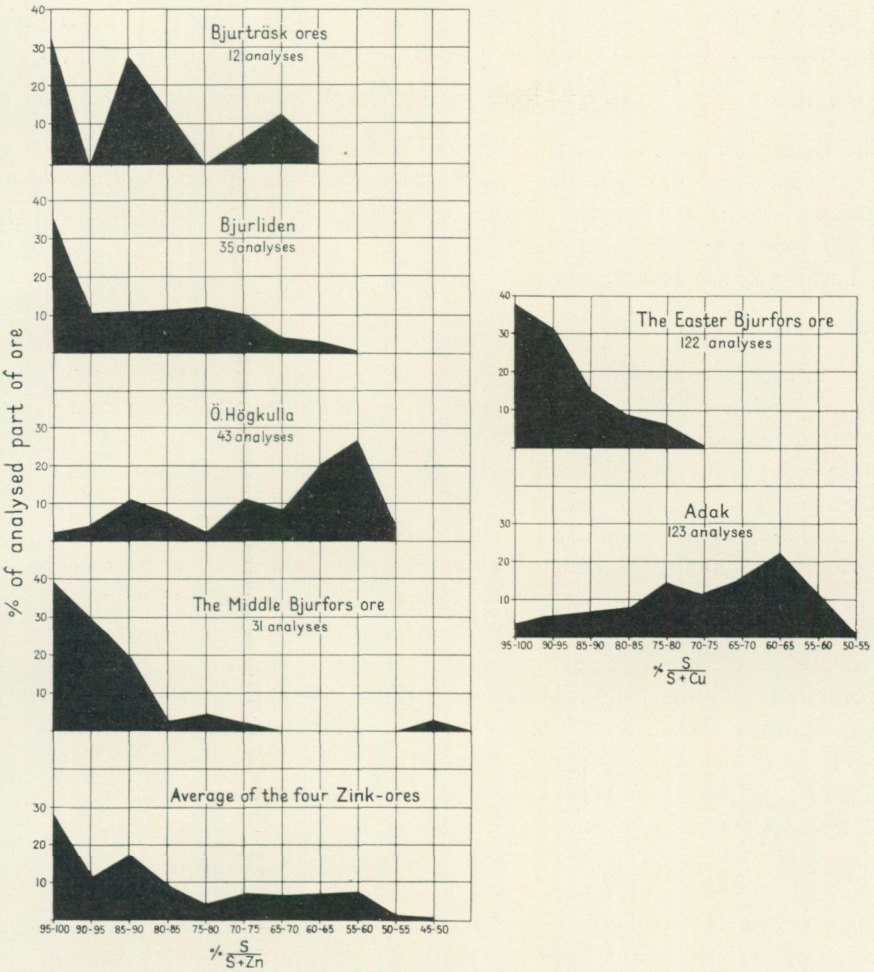


Fig. 28. Diagram showing the quantitative distribution of percentage classes within the ores.

in the calculation of the relative quantities are of no decisive importance. As regards the Middle Bjurfors ore and above all the Bjurträsk zinc ore, from which latter only 12 serviceable analyses were available, the same representative diagrams obviously cannot be expected.

If the diagrams for the zinc ores are first taken into consideration, it is true that certain undulations of the curves are found, but the curves display no coinciding discontinuities. Thus, if a mean curve is plotted for the four ores, each separate ore being taken as a unit, it will display a fairly smooth course. In the case of the ores that have been analysed more thoroughly and comparatively uniformly, these curves may be used to characterize the ores from a chemical-graphical point of view. Ö. Högkulla appears as an ore rich in zinc with mostly high, uniform Zn contents, Bjurliden, on the other hand, as a Zn ore with highly varying zinc contents, and the Middle Bjurfors ore, finally, mainly as

a pyrite (or pyrrhotite) ore, generally with low, but in places with very high zinc contents. It must be kept in mind, however, that in the case of Bjurliden the values of $\frac{S}{Zn + S} = 95—100$ % are not fully represented as to quantity, The reason for this is that the pure pyrrhotite portions of the ore have been far less analysed than the zinc-rich portions. However, obviously this will not influence the relative course of the curve in the parts representing comparatively zinc-rich ores.

Turning now to the Eastern Bjurfors ore, which is by far the best known of the ores in question, the curve of $\frac{S}{Cu + S}$ drops very uniformly from types poor in copper to the ore parts with the highest copper content. For purposes of comparison the values for an ore of an entirely different type, *viz.* the Adak ore situated outside the Malånäs field in the parish of Malå (cf. A. Högbom (*42*, pp. 45—46)) have been included. In this deposit the ore minerals consist chiefly of chalcopyrite and pyrrhotite, pyrite being of very subordinate importance. The ore generally has the character of a breccia in which chalcopyrite and pyrrhotite veinlets, the thickness of which varies between 1 cm and 1 m, penetrate the altered wall rocks. The quantitative importance of the various analyses cannot, at the present stage, be determined due to the irregular distribution of the analyses, and in this diagram each analysis has therefore been taken as unit in the quantitative calculation. The comparatively large number of analyses, however, will, also with this method, give a fairly good survey of the existing conditions. But it should be noted here as in the case of Bjurliden, that there also occur pure pyrrhotite portions, which being of no importance from an economic point of view, have not been analysed. Thus, also here the values $\frac{S}{Cu + S} = 95—100$ % are not fully represented as to quantity, when considering the mineralization as a whole. This diagram, too, which to a large extent contains sulphide mixtures that are considerably richer in copper than the diagram of the Eastern Bjurfors ore, shows, however, continuous variations in the Cu and S contents.

The impression received from a general survey of the field data, *viz.* that the Cu : S and Zn : S ratios display continuous gradations, is thus completely verified by the examination of the results of the analyses. Upon examining the variations in the ratio Cu : Zn, other relations are disclosed. Merely the sharp classification into copper and zinc ores when grouping the ores suggests the possibility of a discontinuity in the quantity curves of $\frac{Cu}{Cu + Zn}$. On the basis of the analyses available it is not possible, however, to illustrate this discontinuity by figures. The reason for this is that the ores occurring in the Malånäs field represent so pure types that a determination of both the copper and zinc contents of the same sample was considered necessary only in exceptional cases. Bjurliden and Ö. Högkulla are thus so pure zinc ores that a determination of the copper content was made only in one case on a small ana-

lysed section (from Bjurliden, in which case no Zn was found). In the Bjurfors group there occur one copper ore and one zinc ore. An average analysis of the outcrop of the Eastern Bjurfors ore (the copper ore) gives $\frac{Cu}{Cu+Zn} = 96$ %, and the values for the most predominent part of the ore are probably between 90 % and 100 %. The previously mentioned parts of slight quantitative importance in which sphalerite bands are found, are, on the other hand, very poor in copper. In small areas it is thus no doubt possible to find low values also of the ratio $\frac{Cu}{Cu + Zn}$. Similarly, the copper content of the Middle Bjurfors ore is very low, and the average of $\frac{Cu}{Cu + Zn}$ is in all probability less than 5 %.

The Bjurträsk ores also contain two separate ore bodies. The copper ore, which — though very small — is of great interest for the present discussion, gives $\frac{Cu}{Cu + Zn} = 95.5$ %. The eastern, main ore is chiefly a zinc ore with $\frac{Cu}{Cu + Zn}$ from 0 % to 20 %. A small part of the ore is developed as copper ore with values between 80 % and 100 %, and finally there is one analysis, which, however, represents an insignificant section, with the value 46 %.

A distinct tendency towards a differentation into copper ores poor in zinc and zinc ores poor in copper can be established also in the very small ore deposits at Skäggträskberget. This tendency is most evident in one of the drill holes where an ore lens, 5 m thick, was pierced (see analyses, page 147). It appears from the results of the analyses that the central portion is composed of copper ore and the marginal parts of zinc ore. Though the separation is never so complete as in the cases previously mentioned, it is found, however, that a decrease in the copper content from one section to the other always corresponds to an increase in the zinc content and vice versa.

The study of the variations in the Cu : Zn ratio thus shows that if percentage classes expressed by the factor $\frac{Cu}{Cu + Zn}$ are brought into relation to the quantitative importance of the different classes in the Malånäs District, as was done in the case of the factors $\frac{S}{Zn + S}$ and $\frac{S}{Cu + S}$, this new diagram will give very pronounced maxima for the regions 0—10 % and 90—100 %, whereas the intermediate parts will be very sparsely, if at all occupied.

The most conspicuous differentiation of the elements found in the sulphide phase is thus seen in the differentiation into copper and zinc ores. This differentiation is in itself not very remarkable as the same thing is found in sulphide ore regions all over the world. It now remains to be investigated how the elements are distributed that are here of far less quantitative importance, *viz.* lead, silver, gold, bismuth, arsenic, and antimony.

Of these, lead is almost solely associated with the zinc ores. This association is in agreement with the general experience as regards ores, and need scarcely

be verified by any analyses. The lead contents are, what more, too low in the majority of the copper ores to occasion any determination of lead in these types. As regards the Malånäs District, more than 99 per cent of the existing lead quantity is probably in zinc ores. It is, at least in the Malånäs District, equally evident that antimony, bismuth, and silver, first of all follow the lead and will thus also be associated with the zinc ores. As regards gold and arsenic, the literature gives many examples of a certain geochemical relationship between these elements, and this relationship can be established in many cases in the Skellefte District. We need only point to Boliden, Rackejaur, Holmtjärn (cf. A. Högbom (*42*) and O. Ödman (*87*, *88*)), which contain solid dense arsenopyrite lumps with high gold contents. At Boliden Ödman has found the arsenopyrite ores to be a special and oldest type. Though the gold contents are very considerable also in the arsenopyrite lumps from Holmtjärn, Ödman seems to consider the majority of the gold to be more closely associated with the chalcopyrite. In this very minute ore body the relationship between the different ore types is most probably very intimate, and as a unit the ore body in itself represents a contemporaneous enrichment of gold and arsenic, when compared with the other ores in the Skelefte District. On the whole it would thus appear that in many cases arsenic has a tendency to be enriched in a special differentiation product in which gold is also enriched.

In the ores that occur in the Malånäs District, both gold and arsenic contents are as a rule comparatively low. As it is never possible to presuppose a complete differentiation (as has already been mentioned arsenopyrite also accompanies the late veinlets that are rich in lead), it is therefore in this case more difficult to ascertain the general relationship that may exist. The occasional higher gold contents in the field are, however, also in the Malånäs District associated with arsenopyrite of the dense solid type. Thus, the dense arsenopyrite streaks from Österbäcken contain 6 gr/t of Au; at Skäggträskberget 4—5.5 gr/t are found in the parts that are richest in arsenopyrite, whereas the parts rich in chalcopyrite in the same deposit contain $<$ 1 gr/t.

Very instructive conditions are found at Ö. Högkulla. As was mentioned in the description of the deposit, there is one single locality where there occur small fragments of dense arsenopyrite ore enclosed in the solid zinc-rich ore. In all, some twenty fragments, about 2—3 cm in diameter, have been observed. The gold content in the adjacent ore never exceeds 1 gr/t and averages 0.4—0.5 gr/t. Small pieces of the above-mentioned fragments, however, showed, a gold content of 19.5 gr/t. The gold has thus been enriched about 40 times in these fragments.

Finally it remains to be investigated how arsenic and gold behave in relation to the copper-zinc differentiation. Do the arsenopyrite ores occur quite independently of these elements, or do they show a close relationship to either the copper or zinc fraction? As regards the Malånäs District, the answer to this question must be that there is a distinct relationship between the zinc-lead ores and the arsenic enrichment. In the cases when dense arsenopyrite ore has been observed, it always occurs together with ore portions that are rich in zinc

but poor in copper or entirely copper-free. This is especially conspicuous at Skäggträskberget and Österbäcken. Further, it should be pointed out that both at Ö. Högkulla and Bjurliden there have been observed fragments of dense arsenopyrite in the solid zinc ore, though these fragments have a decidedly local character. In the ores of the Bjurfors group the same relationship is quite conspicuous. The average As content in the Eastern Bjurfors ore (the outcrop of the copper ore) is thus 0.07 %, whereas the average content found in the broadest section through the Middle Bjurfors ore (the zinc-bearing ore) is 0.28 % or four times as large as in the former case. This difference is also observed in the microscopic examination. In the case of the Eastern Bjurfors ore, arsenopyrite has been observed in but very few polished sections and only as solitary grains. In the Middle Bjurfors ore, on the other hand, arsenopyrite has been found in more than 50 % of the polished sections examined, and it always occurs fairly abundantly in the various specimens.

It cannot at present be said whether this arsenic enrichment in the zinc-lead fraction also applies to the Skellefte District as a whole. In a number of other deposits the association is not at all so evident, at least not on a rapid survey of the existing conditions. However, this question will no doubt be answered, when the conditions prevailing at Boliden and Rackejaur have been investigated from a similar point of view.

2. On the Causes of the Differentiation in the Ores.

The above study of the distribution of the elements in the sulphide phase shows that the elements may be placed in certain groups as regards their relative distribution. The two most important groups are characterized, one by an enrichment in Cu, the other by an enrichment in Zn, Pb, Ag, Sb, and, to some extent, Bi. Probably also a third main group should be added, characterized by an enrichment in As and Au, which group, in the Malånäs District, shows a closer relationship to the Zn-Pb-group than to the Cu-group. The above-mentioned groups also contain Fe and S as important constituents, but on the basis of the available material it is not possible to determine whether these last-mentioned elements are especially enriched in one group or the other. The arrangement of the elements in these groups of course does not imply that they are entirely separated. This classification only portrays a geochemical enrichment of certain elements in certain associations.

From a general geological point of view this classification is not a new one. On the contrary, we find many striking resemblances in various ore districts in different parts of the world, and in the main this classification corresponds to the classification in certain metal zones. In the zonal theory, however, arsenic and to a certain extent also gold are regarded as belonging to an innermost zone adjacent to the magma reservoir, zinc and galena occurring in the outermost zone, whereas copper occupies an intermediate position. Considering these facts, it may seem remarkable that the As-Au-group in this case shows a closer relationship to the more "remote" Pb-Zn-group than to the Cu-group. This indicates that in the case of the Malånäs area also other factors

than those leading to the formation of certain metal zones must have influenced the origin of the element groups appearing here.

Trying to ascertain to what extent the distribution of the elements depends on the variations in the temperature and pressure under which the metals may be assumed to have been deposited, we find that the enrichment of elements in certain associations is entirely independent of these variations. A measure of the relative differences in the conditions at the time of the formation of the ores will be found in the mineral associations of the gangue parageneses and of the altered rocks. The extent of the alterations and the position of the ore bodies in relation to the isogrades of the regional metamorphism are also of importance. These factors are obviously more or less the same in the various parts of the separate ore groups (such as the Bjurfors ores, Bjurliden, the Bjurträsk ores, etc). These ore groups contain, however, all the various products of differentiation (the Eastern Bjurfors ore and the Middle Bjurfors ore in the Bjurfors group, the eastern and western ores in the Bjurträsk group, parts of copper ore, zinc ore, and arsenopyrite ore at Skäggträskberget, etc). A differentiation according to decreasing temperature and distance from a magma reservoir, as described e. g. by Emmons (*14*), is thus not applicable to the differentiation w i t h i n the Malånäs District.

In a further study of the factors that may have contributed to the creation of the element associations found, it is thus most appropriate to examine to what extent the sequence of crystallization may cause a separation in agreement with that found empirically. As the most evident differentiation is between Zn, Pb, and Cu, the minerals will first be considered in which the predominent part of these elements is concentrated, i. e. sphalerite, galena, and chalcopyrite. As has already been stated, there exists a quite unquestionable sequence between these minerals: sphalerite is replaced by chalcopyrite, which, in turn, is replaced by galena. The sequence of crystallization sphalerite → chalcopyrite → galena is equally distinct, no matter whether the investigation refers to ore types poor in zinc and lead and rich in copper or to zinc-lead ores poor in copper. Such a sequence of crystallization, however, cannot possibly explain the intimate association between lead and zinc. On the contrary, these results imply that t h e d i f f e r e n t i a t i o n m u s t h a v e b e e n c a u s e d b y o t h e r f a c t o r s t h a n t h e s e q u e n c e o f c r y s t a l l i z a t i o n a n d m u s t h a v e t a k e n p l a c e i n t h e o r e s o l u t i o n s b e f o r e t h e a c t u a l c r y s t a l l i z a t i o n s t a r t e d.

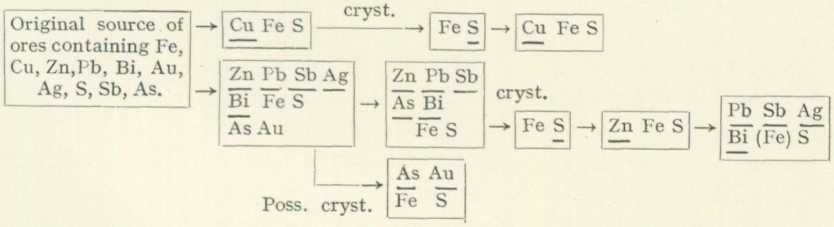
A further examination of the behaviour of S and Fe in the copper and zinc ores, discloses the general sequence of crystallization to be pyrite → pyrrhotite → chalcopyrite and pyrite → pyrrhotite + sphalerite. This sequence of the different minerals may well serve to explain the successive gradations from pure pyrite ores to ore types rich in copper or zinc. The early crystallization of the pyrite further implies that the excess of sulphur in the ore solutions was first precipitated in the solid phase. The fact that the differentiation into pyrite ore and sphalerite or chalcopyrite ore is in all probability the result of a differentiation by crystallization, whereas the differentiation into copper ore and zinc-lead ore implies an earlier differenatition into two separate phases,

is in good agreement with the general course of the percentage curves (cf. fig. 28). In the former case curves with continuous changes are obtained; in the latter case the curve should be highly discontinuous, as was apparent from the general comments on this question. It is obvious, however, that the presence of single analyses containing both copper and zinc in fairly considerable quantities does not contradict the conception of there being an advanced differentiation between copper and zinc. Even if the differentiation was complete, such results might nevertheless be expected. A mixture of the different fractions would of course also give rise to such results. Only by a statistical treatment of a very large number of analyses, representing comparatively homogeneous sections, would it be possible to gain an idea of the quantities of elements belonging to other fractions that may be present in the respective differentiated phases.

The further differentiation in the zinc ores resulting in the enrichment of Pb, Sb, Ag, Bi, in the last liquid phase, sometimes as a kind of ore-pegmatitic veinlets, is in agreement with what might be expected as a result of the sequence of crystallization established. It may further be pointed out that the insignificant content of chalcopyrite present in the zinc-rich ores, is, as a rule, intimately associated with the schlieren of lead-antimony minerals. This chalcopyrite has thus been enriched by the comparatively complete precipitation of iron and zinc sulphides. The presence of the minerals bournonite and tetrahedrite also proves a certain enrichment in copper simultaneously with the enrichment in lead.

Finally, as regards the arsenopyrite fraction that is rich in gold, it is not possible, on the basis of the material from the Malånäs District, to obtain any reliable information as to the factors that lead to the formation of the dense arsenopyrite ores. The fact that these solid arsenopyrite lumps often have an independent appearance would suggest that also this fraction is a separation product of the same character as the copper and zinc-lead fractions. As regards the Malånäs District, however, the segregation of the fraction rich in arsenic and gold presumably did not occur until after the separation into a Cu- and a Zn-Pb fraction.

A schematic survey of the differentiation of the elements in the Malånäs ores will thus have the following appearance:



The elements underlined are those assumed to be enriched in relation to the immediately preceding group. Cryst. indicates the point where the crystallization is assumed to have begun, thence regulating the continued differentiation.

If, finally, we desire to investigate what physical-chemical factors have had a decisive influence on the general distribution of the elements, great difficulties are encountered. As a result of the complex character of the original ore solutions and our insufficient knowledge of their real composition both with regard to constituents and concentration, it is only possible to indicate certain factors which may have been of more or less importance. A few examples will be quoted below from the very extensive literature on the migration possibilities of the metal sulphides.

Attempts have been made to explain the sequence of the various sulphides from different points of view. As regards high temperatures the importance has been emphasized of the so-called Fournet series (see e. g. Berg, *2*, p. 243) in which the elements are arranged according to decreasing affinity to sulphur at temperatures of about 1,000°. Kordes (*52*) has discussed the importance of the S_2-dissociation pressure, Wells (*83*), and later, Lindgren (*53*, pp. 122, 123) and Newhouse (*60*) have pointed out the agreement between mineral sequence and Schürman's series, in which the elements have been arranged according to the variations in the solubility. Further, it has been suggested that the metals migrated as halogenides, a hypothesis that is of special interest in view of the discovery by Newhouse (*61*) of NaCl in inclusions in certain galenas.

If the available data are examined on which the different attempts at explanations have been based, it might in many cases be possible to explain the order of crystallization; on the other hand, there is nothing either in the individual cases or in any combinations of different factors that might explain the relationship observed between certain elements. If we are to comprehend the element groups found, however, we must necessarily presume that at least within certain temperature ranges there must have existed certain resemblances in the properties of the elements that are enriched in the same group.

The only investigation known to the author resulting in a classification in close agreement with the conditions obtaining in nature, is the investigation carried out by Freeman (*22*) on double sulphides between metal sulphides and Na_2S. The importance of alkali sulphides in the formation of sulphide deposits has been discussed by several authors. Freeman has investigated the melting points of double sulphides, which, according to his calculation, lie between 560° and 660°, and has also studied their behaviour in relation to water. On the basis of his results he establishes the following classification:

1. Nickel, copper, iron: forming double sulphides with sodium, which are insoluble in, but are slowly broken down by, water, yielding colloidal suspensions of copper and iron sulphides and solutions of sodium sulphide.

2. Zinc, lead, silver, iron: forming double sulphides with sodium, which are insoluble in, but rapidly broken down by, water, yielding colloidal suspensions of the heavy metal sulphides and solutions of sodium sulphide.

3. Gold, antimony, arsenic, iron: forming double sulphides with sodium which are entirely soluble in water. Precipitation of the heavy metal sulphides is effected by oxidation of the sodium sulphide molecule.

This classification shows a certain agreement with the associations found in the ores, excepting antimony, however, which according to the results in the present case rather belongs to group 2. Freeman's results have, however, been criticized by Foreman (*21*), Stevens (*76*), and Gruner (*32*), who stress that elements belonging to group 3 are not soluble in water in the presence of silica. The assertion by Gruner that alkali sulphides are of no importance for the migration of metal sulphides is based on the assumption, however, that colloidal solutions cannot be conceived to play any part, as they would immediately be precipitated by electrolytes. The question regarding the stability of colloidal solutions is not quite clear, however. Thus, Lindgren seems inclined to attribute great importance to colloidal solutions in the ore formation of the kind now discussed. J. Kania (*50*) has made a survey of the existing results of investigations intending to elucidate the factors that may influence the stability of colloidal sulphide solutions. He has also carried out some investigations of his own. However, the results presented supply no definite explanation of the question as to the importance of colloidal solutions in the formation of the ores, but, on the other hand, it does not seem impossible that they may have been of great importance. In any case, the fact remains that when trying to explain the original differentiation into certain element associations, the classification found by Freeman suggests a possible solution of the problem and agrees, in the main, with the results found in nature.

In the discussion on the alterations in the wall rocks (cf. p. 158) it was stated that the most conspicuous change within the altered area, as a whole, was the leaching of alkalis, mainly Na_2O. As the alterations are considered chiefly to precede the precipitation of the sulphides, the ore solutions must really have contained Na_2O at a certain stage of the mineralization. Thus the information that can be gained from a study of the alterations in the wall rocks, at least does not contradict the possibility of the alkali sulphides having had a certain influence on the differentiation of the ores. Also if we suppose that double sulphides with Na_2S are of great importance, there are in all probability several other factors which complicate matters. In the later stages of the process of differentiation, the conditions of solubility and precipitation in different concentrations are doubtless of decisive importance.

3. Dissimilarities in Distribution of Elements in Ores of Displacement Type and Ores of Replacement Type.

Above it has been stressed that the main differentiation giving rise to ceratin specific ore types is independent of the regional metamorphic zoning as well as of the variations in the parageneses of gangue or altered rocks. In the case of the various ore groups it was possible, however, to establish a certain relationship between the altered types and the relations of the ores to the wall rock on the one hand, and, on the other hand, the position of the ores in relation to the isograde of regional metamorphism. In this chapter certain characteristic features in the distribution of the elements within the individual

ore types will be discussed with a view to elucidating some problems concerning the genesis of the ores.

At first, Ö. Högkulla and Bjurliden will be compared. The parageneses of these ores resemble each other very closely, and it may thus be supposed that the ore-forming solutions had very similar compositions. When mapping the ores the impression was gained that the compounds in certain sections are distributed much more uniformly at Ö. Högkulla than at Bjurliden. This difference is best visible in the appearance of the galena. At Ö. Högkulla this mineral is distributed fairly uniformly, at Bjurliden, on the other hand, it often occurs as distinct veinlets or schlieren with an irregular distribution in the ore body.

However, also the diagrams of the quotient $\frac{S}{Zn + S}$ indicated that the zinc is distributed much more uniformly at Ö. Högkulla than at Bjurliden. These diagrams comprised all the analysed area regardless of the sulphide content of the analysed sections. If we wish to compare ores of the replacement type with ores of the displacement type, it may be desirable to find a method of drawing the diagram which also distinguishes solid and disseminated ore types. Of course the author does not mean to suggest that it would be possible to determine merely from the sulphide content of an ore body to what extent displacement or replacement has been of decisive importance. In fact, replacement may also create entirely solid ores, but in the case of some deposits, e. g. Ö. Högkulla, the most solid ore portions show distinct displacement contacts, whereas the replacement that has occurred is found in the disseminated points of the ore. Further, it may be of interest, also where considering the ores of replacement type, to compare the distribution of the elements in the relatively solid and the relatively disseminated portions.

As regards the zinc ores, attention should first be paid to the distribution of the zinc within the ore body, which distribution may be expressed by the variations of the ratio $\frac{S}{Zn + S}$. In order to determine the quantitative importance of the different percentage classes, an estimation has been made of that part of the whole analysed sulphide compound to which each analysis corresponds. The approximation in this case may be compared to the corresponding approximation in the preceding diagram, fig. 28, and with the present method of drawing the diagrams, it does not imply any serious source of error.

The third factor intended to give an idea of the "solidity" of the ore has been expressed in the ratio: Sulphide : sulphide + barren rock. In the ores now under consideration, in which ore breccias play a very subordinate part, this factor in the main illustrates successive gradations from solid ore bodies to disseminated ores. It is generally possible to calculate this ratio within certain error limits, the Zn and S contents being known. Other elements belonging to the sulphide phase are usually of so little quantitative importance that, in most cases, a correction for them is not necessary for the present

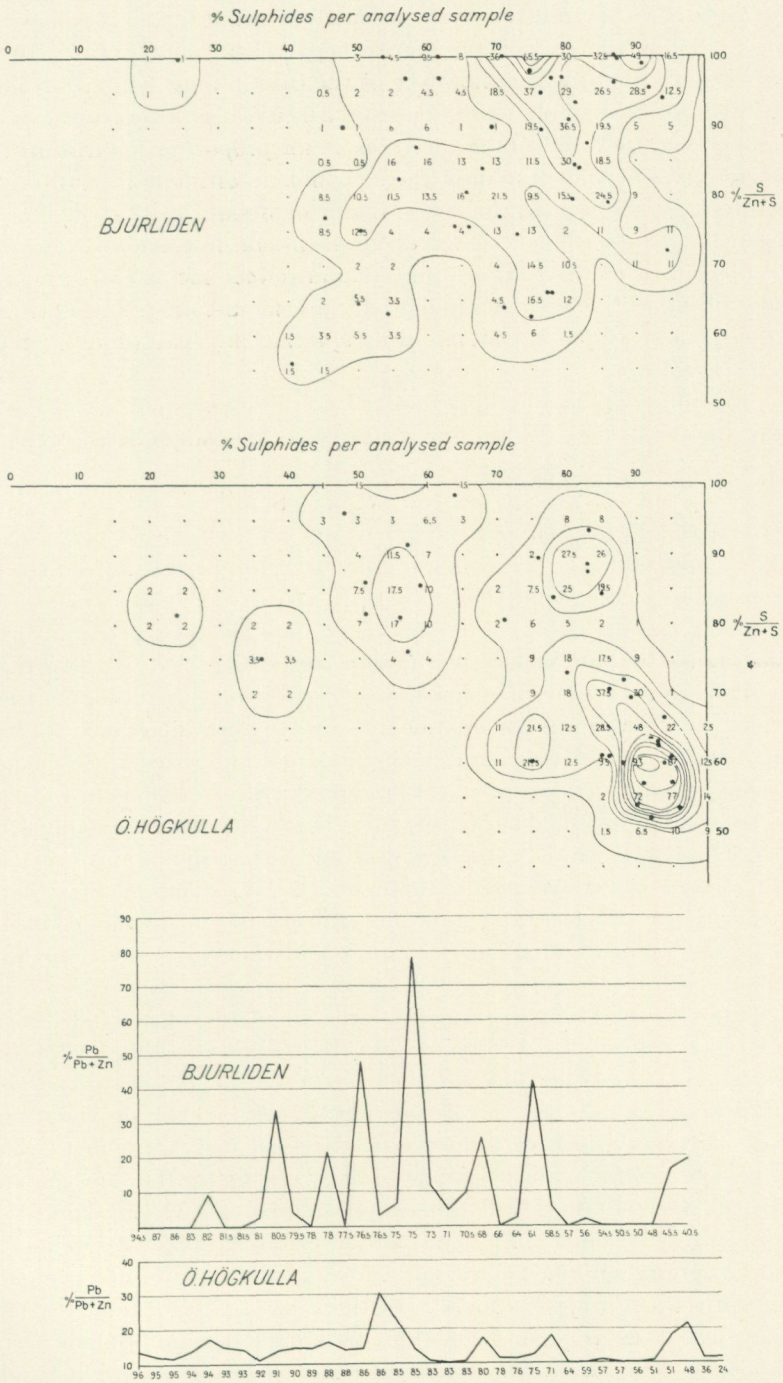


Fig. 29. The upper diagrams show the quantitative distribution of percentage-classes and sulphide contents of the analyses. The figures represent $^0/_{00}$ (per mille) of the part of the ore included in the analyses, obtained by a re-calculation of the individual analyses (represented by dots in the diagram). The lower diagrams illustrate the lead: zinc ratios. The figures along the abscissa represent sulphide content per analysis.

investigation. To permit an exact calculation being made, it is however necessary to know the proportions between pyrrhotite and pyrite. If the Fe content is not known, which, however, is the case in most analyses from Bjurliden, this ratio must obviously be established by a subjective estimation. When, however, the limits of the variations in the proportions pyrrhotite : pyrite in the ores are known, it is in most cases possible to estimate the ratio sulphide: barren rock + sulphide within error limits of about ± 5—10 %, which is sufficient for the questions that the diagrams intend to elucidate. In any case, it would seem more advantageous to try to introduce such a correction than to exclude the subjective estimation and only use the S-contents to illustrate the variations in the sulphide content, thus ignoring any variations in the ratio pyrite : pyrrhotite.

The diagrams (fig. 29, the upper part) have been prepared according to the following method: The ratio sulphide : barren rock + sulphide is plotted along the abscissa, and the values of the ratio $\frac{S}{Zn + S}$ along the ordinate. Further, the part of the whole analysed sulphide compound, expressed in ‰, has been calculated and noted for each dot representing an analysis. To make these figures easy to comprehend they have been re-calculated and smoothed, and at each 5 % point a figure states the ‰ of sulphide mass per unit surface in the diagram. The unit surface will thus correspond to 5 × 5 % on the scale of the diagram. The re-calculation was carried out according to the same principles as used in the calculation of a petrofabric diagram ("Gefügediagramm", see e. g. Sander, p. 129); in the present case, however, the calculation has been carried out in a square the size of which corresponds to 10 × 10 per cent. Each figure in the diagram has thus been obtained by summing up the number of ‰ contained in a square with a side corresponding to 10 % and with its centre at the point denoted by the figure. As the diagram shows values in ‰ within a unit surface which is four times as small as the re-calculation square, each dot in the diagram is counted four times, and the value found in the calculation must consequently be divided by four. As will be seen, this re-calculation method fully corresponds to the calculation of a "Sander diagram" with a 2 per cent circle. The figures thus represent per mille of the ore per unit surface. It is further obvious that as the re-calculation square has been chosen as large as 10 × 10 %, the previously mentioned approximations will not have any very decisive influence on the final diagram. On the basis of the values obtained it is then possible to draw curves for the same ‰-figures, and the maxima obtained will thus imply a quantitative enrichment in ore portions with a certain S : Zn ratio and a certain degree of "solidity".

If the diagrams obtained for Bjurliden and Ö. Högkulla are compared, a striking difference of type is found. In the case of Ö. Högkulla the far predominant part is developed as a solid ore with high and uniform zinc contents. This appears from the distinct maximum seen in the lower right-hand part of the diagram. The less distinct maximum which appears between $\frac{S}{Zn + S} =$

= 85 and 95 % corresponds, in the main, to the solid ore type rich in pyrrhotite. The more irregular parts, representing lower sulphide contents, on the other hand correspond to the more disseminated points of the ores. It is further a characteristic feature that the zinc-rich sulphide mixtures are found among the solid ore types; in the disseminated parts very low values of the factor $\frac{S}{Zn + S}$ are found. As regards the Ö. Högkulla diagram, a certain reservation must be made, however. The chief maximum which gives the diagram its characteristic appearance is probably somewhat exaggerated, as one of the 35 analyses used corresponds to no less than 24 per cent. of the whole material. This analysis comes from a section of the outcropping ore, where, however, the ore body has a very homogeneous composition. At the 30 m level several samples of the same ore type have been analysed and the values are all grouped very regularly around the value of the analysis in question with a maximum dispersion of 13 %. If the analysed section that represents the fairly large ore portion mentioned had been divided into several minor sections, the chief maximum in the diagram might be expected to have a somewhat larger extent, but the general character of the diagram would in all probability be retained.

Quite another development is illustrated in the Bjurliden diagram. The maxima occurring here lie close to the line of entirely zinc-free ores. In the portions that are fairly rich in zinc the curves are hardly ever found to enclose any certain percentage groups. The diagram shows partly, as already stated, that the zinc contents of this ore are distributed much more irregularly than at Ö. Högkulla, and partly that in sulphide mixtures that are comparatively rich in zinc there is no very great difference in the type of distribution in the solid parts of the ore as compared with the disseminated parts.

As already mentioned, it was possible, during the mapping, to establish a considerable difference in the distribution of the galena at Ö. Högkulla, as compared with Bjurliden. Also this difference can be illustrated by the analyses. As Zn and Pb show a very close relationship, it may be appropriate to investigate the ratio $\frac{Pb}{Pb + Zn}$, which has been calculated in a diagram (fig. 29, the lower part), the analyses being arranged according to decreasing sulphide content. The much greater irregularity of the Bjurliden curve is very striking.

Finally, attention must be paid to the behaviour of quartz and calcite, which minerals occur as gangue. At Ö. Högkulla quartz occurs not only as a gangue mineral but also as separate veins, which obviously are very intimately connected with the ore formation. Carbonate veins are never met with, but calcite is very abundant as a gangue mineral in the solid ores themselves. At Bjurliden the material does not permit of any decisive conclusion as to the quantitative importance of pure quartz veins; on the other hand, masses of quartz and carbonate, apparently in the form of veins, have been segregated from the ore. In many cases, however, these have reacted so intensely with the wall rocks, forming lime silicates, that the original vein character is more

or less obliterated. The difference in the behaviour of the calcite in the two deposits would thus imply that at Ö. Högkulla the calcite has, on the whole, been retained within the ore, whereas at Bjurliden it has to some extent been separated as independent fractions.

The general comparison between the distribution of the elements in these two ores of a similar chemical composition, one of which is of a distinct re-

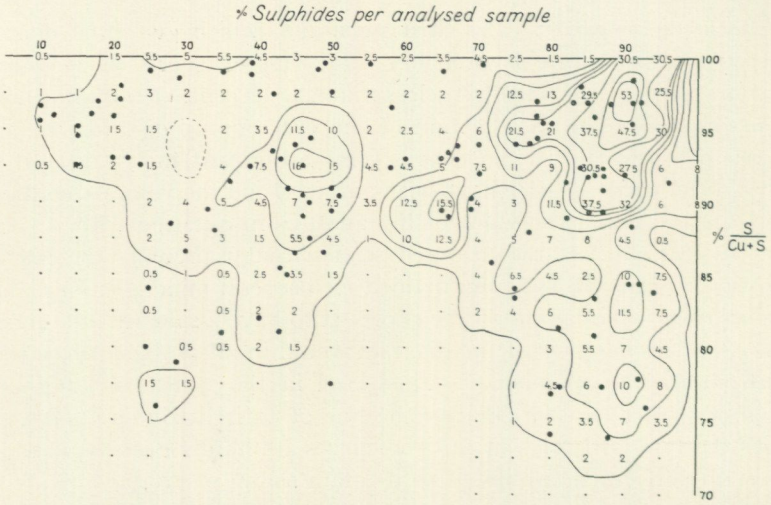


Fig. 30. Diagram showing the quantitative distribution of percentage-classes and sulphide contents of the analyses. (The diagram has been made according to the same principles as the diagrams in fig. 29).

placement type (Bjurliden), the other, on the other hand, of an equally distinct displacement type (Ö. Högkulla), thus shows that in the former ore the differentiation is much more extensive than in the latter. This is in good agreement with the interpretation adopted to explain the differences in the relations to the wall rocks, which has already been discussed (cf. p. 166). According to that view the Ö. Högkulla ore was deposited in a more low-temperature *milieu* and probably at a lower temperature, and it was thus precipitated more rapidly than the Bjurliden ore.

A diagram similar to those for Bjurliden and Ö. Högkulla has been made for the Eastern Bjurfors ore (fig. 30), illustrating the variations in the ratio $\frac{S}{Cu + S}$ and thus showing the distribution of the copper contents within the sulphide compound. As the variations in the Cu : S ratios are of a smaller order than was the case in the Zn : S ratios, the re-calculated points parallel to the ordinate have been placed at a distance from each other which in this case only corresponds to 2.5 %.

We find that this diagram, in its general character, is an intermediary type between the Ö. Högkulla and the Bjurliden diagrams. There is a maximum for comparatively solid ores poor in copper, corresponding to the solid pyrite ore

portions with low copper contents. From this maximum a belt branches off running parallel to the ordinate, including sulphide contents between 80 % and 95 %. Also in the parts corresponding to ore types that are fairly rich in copper there is a slight suggestion of a maximum corresponding to the solid ore types that are extremely rich in chalcopyrite and which often contain considerable amounts of calcite. This ridge that is formed by the curves also comprises the ore portions which, as already stated, may show displacement relations to the wall rocks.

In the middle part of the diagram the curves in the main run parallel to the abscissa, and the values of $\frac{S}{Cu + S}$ are chiefly between 85% and 95 %. This part corresponds to the banded ore types in which the sulphide compound thus shows medium and, within certain limits, uniform copper contents. The left-hand part of the diagram, finally, which corresponds to the comparatively disseminated portions, contains sulphide mixtures which are both rich in chalcopyrite and entirely free from chalcopyrite. The former corresponds to the copper-rich disseminations in the chlorite-rock which often occur at the pinching out of the copper-rich solid ores. The latter corresponds to the fairly common pyrite disseminations which often occur in the vicinity of the comparatively solid ore bodies.

The differentiation of the gangue minerals has already been mentioned in a previous chapter. It has been pointed out that the quartz occurring in the sulphide phase is enriched chiefly in the pyrite ores that are poorest in copper, whereas calcite is enriched in the copper-rich ore portions. Further is has been mentioned that all gradations may be established from calcareous copper ore to quartz-carbonate veins poor in silica. The carbonates in the veins certainly react with the wall rock, lime-silicates being formed, but the vein character is nevertheless always quite distinct and much better preserved than was the case e. g. at Bjurliden. Thus it is found that also when considering the differentiation products occurring in an "ore-pegmatitic" development, the Eastern Bjurfors ore holds a transitional position between Bjurliden and Ö. Högkulla. The summary, Table 5, pp. 188—189, shows the characteristics of the four main ores.

VIII. Comparison with other Sulphide Ore Districts.

From the very extensive literature dealing with the sulphide ores usually classified as mesothermal—hypothermal, according to Lindgren's terminology, a very large number of ores could be mentioned presenting certain similarities to the types described in this paper. I shall only touch upon a few cases, however, which for various reasons are of particular interest.

As regards the other ores in the Skellefte District only very few have so far been subjected to any thorough investigations, which, furthermore, have not yet been completed. It is consequently too early to try in this paper to give

Table

Characteristic features of

	The Bjurträsk Ores	Bjurliden
Main constituents	Fe, Zn, S, (Cu)	Fe, Zn, Pb, S
Position in relation to the isograde for the regional metamorphism.	A good distance in on the high-grade side of the isograde for complete biotite- and amphibole-facies.	= the Bjurträsk ores, maybe somewhat closer to the isograde for complete biotite- and amphibole-facies.
Alterations of wall rocks.	Considerable. Fairly high-temp. parageneses (gahnite, garnet, andalusite, cordierite, chloritoid, magnetite, staurolite, hornblende, An-rich and An-intermed. plagioclase).	= the Bjurträsk ores, chloritoid lacking, calcite and epidote more common.
Parageneses of gangue minerals.	Mainly biotite-facies. CaO in proportion to the presence of Fe, Mg, Al, chiefly bound in hornblende and anorthite.	= the Bjurträsk ores.
Formation of the ore space judging from the relations of the ores to the wall rocks.	Decided replacement, poss. displacement of very subordinate importance.	= the Bjurträsk ores.
Quartz and carbonate veins.	Owing to the covering of drift, knowledge of conditions incomplete. No very remarkable enrichment in quartz-carbonate veins in the exposed areas.	Calcareous quartz veins, reacting so intensively with the wall rock that the vein character is often quite indistinct. In some cases all carbonate is consumed in the formation of anorthite or hornblende.
Distribution of elements.	Insufficiently known. Galena, otherwise accompanying ZnS, is here observed only as insignificant, independent veinlets outside the ore proper.	Generally irregular. ZnS is equally irregularly distributed in the sulphide-mass, whether of a more solid or a disseminated type. PbS occurs very irregularly and displays a tendency to be enriched in ore-pegmatitic quartz-lead-antimony veinlets. However, it does not generally entirely separate from zinc as at the Bjurträsk ores.

a survey of the appearance of the ores in the Malånäs District in relation to the regional ore distribution of the Skellefte District. The most characteristic types of solid sulphide ores in the Skellefte District, however, are found also in the Malånäs District, pure, dense arsenopyrite, however, being of very insignificant importance. A common feature in the lead-bearing ores seems to be the abundance of antimony minerals. According to Ödman intergrowths exactly similar to those described from the Malånäs District seem to be very common at Boliden (*87*, p. 133) and to a certain extent also in the Holmtjärn ore (*88*, p. 100), and have also been observed by the author in several other,

5.

the four main ores.

Eastern Bjurfors Ore	Ö. Högkulla
Fe, Cu, S	Fe, Zn, Pb, S
Between the isograde for complete biotite-facies and complete amphibole-facies on the one hand and the isograde for complete chlorite-calcite facies on the other.	= the eastern Bjurfors ore, but in all probability closer to the low-grade conditions.
Considerable, but no especially high-grade parageneses. Of minerals indicating an enrichment in Fe, Mg, or Al, we find only magnetite besides chlorite and sericite. Plagioclase and hornblende plentiful.	Only inconsiderable compared with the conditions in the three other ores. Generally only low-temp. parageneses, locally garnet, magnetite, chloritoid. Calcite — epidote — chlorite together.
Both higher and lower facies associations. Calcite common both together with chlorite and independent. Hornblende in several cases, plagioclase common.	Only lower facies associations. Chlorite and sericite on the one hand, calcite and chlorite on the other, occur together.
Replacement as well as displacement structures very distinct. It cannot be determined which of these factors was of predominant importance.	Displacement completely predominent, poss. replacement of very subordinate importance.
Abundant quartz veins. Carbonate veins with more or less sulphides, which veins react intensively with the wall rock, forming hornblende. The vein character quite distinct, however, far more conspicuous than at Bjurliden.	Quartz veins as straight fissure veins. No carbonate veins, the carbonates retained in the sulphide-mass.
The chalcopyrite on the whole fairly irregularly distributed in the sulphide-mass, there being a slight tendency, however, towards the formation of certain percentage-groups. The distribution diagram of the ratio $\frac{S}{Cu + S}$ holds, as regards type, an intermediary position between the diagram for Bjurliden and the diagram for Ö. Högkulla.	In certain sections a much more uniform distribution of the elements than in the other ores. The ratio $\frac{S}{Zn + S}$ is concentrated around certain quantitatively predominent percentage-groups. Galena is far more uniformly distributed than at Bjurliden, especially in the more solid parts of the ore.

microscopically examined galena-bearing ores (Rävliden, Vindelgransele, Hornträskviken).

The types of alteration in the wall rocks described in this paper are perhaps not always those that are most characteristic as regards the Skellefte District as a whole. This is particularly true of the eastern parts of the Malånäs District. At Bjurliden and the Bjurträsk ores we thus find garnet, andalusite, gahnite, staurolite, and partly also cordierite, in a development and to an extent which is otherwise relatively uncommon in the Skellefte District. These associations to a certain degree resemble the associations found at the quartzitic sulphide

ores in Bergslagen, where cordierite, gedrite or cummingtonite, garnet, biotite, and to a certain extent gahnite, are the most characteristic quartzite minerals, cf. Geijer (*28*). In the majority of the ores in the Skellefte District chlorite- or sericite-quartzites are the quantitatively predominent alteration types. The occurrence at the Bjurträsk ores of amphibole skarn of a type similar to that often found in Bergslagen should also be remembered. True parallels to the Bergslagen skarn ores are entirely lacking, however.

The closest resemblance, as regards the character of the mineralization, in neighbouring parts of the Archaean rocks of Fennoscandia outside the Skellefte District, is otherwise found in Finland. In his description of Ottravara (*68*) and Karunsaari (*69*) in eastern Finland, Saxela, already, pointed out the great similarities between the sulphide deposits occurring there and the ores in the Skellefte District. Our present increased knowledge of the ores in the Skellefte District still more emphasizes this impression. Saxela thus states that at Ottravara there is an alteration to felspar-free sericite-quartzites next to the ore bodies, while in an outer zone felspar is regenerated, i. e. a zoning presenting a certain resemblance to the conditions at Bjurliden and the Bjurträsk ores.

Sulphide ores of a similar type are found in Fennoscandia also in the Caledonian mountains. Due to the dissimilarities in the tectonic conditions at the time of the ore formation, the shape of the ore bodies, however, is different in these cases, the linear structure then being much more pronounced. The mineralogical composition of the ores themselves as well as of the wall rocks nevertheless have certain points of resemblance. This applies especially to the ores of the Rödhammar and Flöttum types, to use Carstens' terminology (*7*). Two fair-sized ore deposits of this type have been more closely described from the Swedish part of the mountains, *viz.* Stekenjokk and Remdalen (A. Högbom (*38* a)).

As regards sulphide ores of a similar type found outside Europe, I wish only to call attention to the great similarities between the sulphide ores of the Skellefte District and some ore deposits in the Canadian Archaean rocks. Detailed descriptions of the most important ore bodies in Quebec (Horne mine (*8*, *63*), Amulet mine (*8*), Aldermac (*5*, *8*), etc.) and Manitoba (Flin Flon (*4*), Mandy mine (*75*, pp. 110—120)) make it possible to establish the very great similarities to the ores of the Skellefte field. These similarities apply not only to the original rocks, unaffected by the mineralization, but also to the altered types and to the ores themselves. As the Keewatin rocks, which contain these ores, are generally parallelled with the Svionian rocks in Fenno-Scandia, and if the Svionian interpretation of the supercrustal series of the Skellefte District is retained, a certain equality in the age of the Canadian and the North-Swedish ores is probable, too.

In the above-mentioned Canadian deposits the alterations of the wall rocks have the character of a silicification followed by chloritization and sericitization. Also the details of the structures are often very similar to the structures described in this paper. Such similarities can be found especially in the description of Flin Flon (*4*, p. 261). Chloritization of quartzporphyry leaving the

quartz phenocrysts intact is thus described from that deposit, i. e. structures corresponding to the conditions at Bjurliden and the Bjurträsk ores. The shape of the ore body itself and the contact relations to the wall rocks greatly resemble the conditions at the Eastern Bjurfors ore (cf. the map of the outcropping ore). The illustrations of gradations from solid ores to disseminations, and of chlorite banding and inclusions in the ore at Flin Flon, might just as well originate from the Eastern Bjurfors ore. As was the case at Bjurfors, there is also an abundant introduction of calcite at Flin Flon, and along the ore contacts actinolite is often found to have been formed.

The sphalerite- and pyrite-banded ore from Flin Flon is absolutely similar to the corresponding type from Ö. Högkulla. A comparison with specimens of banded ore from Flin Flon collected by O. Ödman gives the impression that these specimens might just as well have been taken from Högkulla. The similarity applies to the appearance of the banding, the thickness of the individual bands, and their quantitative distribution, as well as to the size of the individual grains in the ore. With regard to the contact conditions of the ores, Ö. Högkulla otherwise seems to be more similar to Mandy mine, judging from Spurr's description (*75*, pp. 110—120). In both cases the ore consists of very pure sulphides with a low content of gangue minerals, and displays sharp contacts towards sulphide-free and but slightly altered wall rocks.

A certain difference in the conditions for the development of the Canadian and the North-Swedish ores may, however, be established, at least with regard to the ores dealt with in this work. In the Canadian areas the large tectonic lines which were of decisive importance for the deposition of the ore and which have the appearance of great faults, are often very conspicuously developed. In the Skellefte District it has not been possible to establish such structures, at least not with the same degree of certainty. It is possible, however, that the graphite-phyllite beds in certain cases may constitute a certain parallel to the Canadian faults, it being a known fact — as already pointed out — that movements very often take place along such beds, and which thus to a certain degree have the character of dislocation zones.

IX. Summary of the Results.

The Malånäs District consists chiefly of a series of volcanic rocks forming the lowest part of the Archaean bedrock of the Skellefte District. There occur lavas as well as tuffs of quartzporphyry, quartzkeratophyre, keratophyre, and andesitic and basaltic greenstones. The volcanic rocks are overlain by a sedimentary series consisting mainly of argillaceous sediments, often graphite-bearing, with interstratified arenaceous beds. The transition from the volcanic to the sedimentary division consists of a series of rocks rich in tuffitic materials and with small interstratifications of graphite-phyllite. All these rocks are intruded by two granites, one older, the Jörn granite, which occurs imme-

diately north of the mapped area, and one younger, the Revsund granite, which delimits the supercrustal rocks towards the south.

The whole supercrustal series is intensely folded, the folds being overturned towards the north. In the eastern parts the fold-axes observed pitch towards WSW; in the western parts they are horizontal or pitch towards W. There is possibly an axial depression in the middle parts of the area. Certain areas with special structural features can be rather sharply delimited (areas with S-tectonites, areas with B-tectonites, etc.). In the western parts the major tectonic features are less distinct due to the occurrence of certain "secondary" detail structures.

A regional metamorphism, intensified towards the south, has overtaken the rocks. In the northern parts the original textures of the rocks are very well preserved; in the southern parts the corresponding rocks are more or less recrystallized. At the same time there is a change in the mineralogical composition of the rocks, the chlorite in the quartzporphyries in more high-grade metamorphism being replaced by biotite, and in the greenstones calcite or epidote + chlorite by hornblende. It is thus possible to draw isograde between points having the same grade of alteration. The regional metamorphism and the isograde display no relationship to the older granite, the Jörn granite, but on the other hand show a certain relationship to the younger granite, the Revsund granite. This makes it probable that the regional metamorphism is directly connected with the processes that have led to the development and introduction of the Revsund granite.

The area contains several sulphide ores. The solid ores consist mainly of pyrite and pyrrhotite with more or less chalcopyrite, sphalerite, and galena. The wall rocks, mainly of quartzporphyry composition, are altered to secondary quartzites in conjunction with sericitization or chloritization. Locally there also occur pure chlorite masses. Gahnite, cordierite, staurolite, andalusite, and garnet also occur in the eastern ores. Table 6, after p. 194, gives a survey of the parageneses with reference to the altered rocks as well as the ores themselves. Belts of low-grade disseminations of pyrite and pyrrhotite with no direct connection with the solid ores also occur.

Outside the zone of more intensely altered rocks surrounding the solid ores, the quartzite zone, we occasionally find a zone characterized by the felspar being incompletely destroyed. In this zone there is an alternation between anorthite-rich rocks and sericite-rich types. A survey of the occurrence of the elements in these zones reveals that the origin of the special types of altered rocks is chiefly due to interchanges in the earlier existing materials, while a real addition of substances in connection with the development of the sulphide ores is of comparatively small importance.

Contact relations and structures in the ores indicate that the deposition of the materials of the ore solutions occurred chiefly by replacement at Bjurliden

and the Bjurträsk ores, chiefly by displacement at Ö. Högkulla, while at the Eastern Bjurfors ore both replacement and displacement must have been of great importance. This dissimilarity is parallelled by dissimilarities in the extent and parageneses of the alterations, and in the gangue parageneses in the different ores. At Bjurliden and the Bjurträsk ores these circumstances indicate a relatively stronger thermal influence than at Ö. Högkulla, while the Bjurfors ores hold an intermediary position. These dissimilarities also have a parallel as regards the location of the ores in relation to the isograde for the regional metamorphism (cf. p. 163). Although the sulphide mineralization is later than the minerals formed in the regional metamorphism, there is nevertheless a certain relationship between the grade of metamorphism and the origin of the ores. As regards the source of the ore solutions, this must imply that they should be looked upon as having emanated from the same magmatic source as the Revsund granite.

The deposition of the ores is found to be greatly dependent on the tectonic features. In the mapped area the conditions in the B-tectonites thus seem better to stimulate the formation of solid ore bodies than the conditions in the S-tectonites. Due to the great plasticity of the phyllite beds in relation to other rocks, the possibilities of space formation in the volcanics adjacent to the phyllites are also relatively great.

A study of the differentiation in the ores discloses that there are continuous gradations between pure pyrite or pyrrhotite ores and, on the one hand, copper-rich, on the other zinc-rich ore types. The differentiation in zinc ore and copper ore, however, seems to be discontinuous, transitional types being of very little quantitative importance. These conditions can be verified to a certain extent by the analyses of the ores. There probably exists a third, special group, *viz.* the dense arsenopyrite ores, which in the Malånäs District, however, are of very small quantitative importance.

The differentiation within the individual ore bodies often leads to an enrichment of certain elements together with calcite and quartz, as a sort of ore pegmatites in the last stages of the ore formation. Lead together with antimony and silver is thus enriched in this phase in the zinc-rich ores, copper chiefly in the copper ores. This development is most clearly seen in the Eastern Bjurfors ore, where the following series of development can be established: Solid pyrite ore with but little copper — copper-rich, solid ore with carbonate — carbonate veins with chalcopyrite — quartz-carbonate veins — quartz veins.

A study of the sequence of crystallization and the general distribution of the elements in relation to the copper — zinc differentiation discloses that this differentiation must have taken place before the beginning of the crystallization. The development from pure pyrite or pyrrhotite ores to copper- or zinc-rich ore types, on the other hand, can easily be explained as a differentiation

through crystallization. Of the factors known that might contribute to explaining the associations established in the district, Freeman's grouping on the basis of the solubility of the metals as double-sulphides with alkali sulphide, might indicate a possible explanation of the "primary" differentiation.

The observations in the field as well as a study of the analyses show that the elements are most uniformly distributed in the most pronounced displacement ores, and most irregularly distributed in the most pronounced replacement ores. This also applies to the gangue minerals, which might be said to be retained within the ore bodies of the displacement type, while in replacement ores they often form independent segregations. Considering the earlier mentioned dissimilarities between the ores with regard to alterations, gangue parageneses, and location in relation to the isograde, these relations have been interpreted in such a manner that the replacement ores are supposed to have been formed under a higher thermal influence as compared with the displacement ores. The crystallization of the former has thus come to span a greater period of time than the latter.

Table 6.

Survey of the wall-rock, gangue, and ore minerals in some of the deposits in the Malånäs District.

An endeavour has been made to perform a rough estimation of the relative quantities of the various minerals in the deposits, the number of crosses in the table indicating the frequency.

	Ideal chemical composition	Sp. gr. (Values used for the calculations)	The Bjurträsk ores	Bjur-liden	Snåtter-myran	The Eastern Bjurfors ore	The Middle Bjurfors ore	Öster-bäcken	Ö. Hög-kulla	Skägg-träsk-berget	Önus-berget
Quartz	SiO_2	2.65	++++	++++	++++	++++	++++	++++	++++	++++	++++
Plagioclase	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2 + CaO \cdot Al_2O_3 \cdot 2SiO_2$	2.6—2.75	+++	+++	+++	+++	+++		++		
Microcline	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	2.55	++	+							
Biotite	$K_2O \cdot 6(Mg, Fe)O \cdot (Fe, Al)_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	2.95	++++	++++	++++	+++	+++	+++	+++	++++	
Chlorite	$3(Mg, Fe)O \cdot (Al, Fe)_2O_3 \cdot 2SiO_2 \cdot 3H_2O$	2.75	++++	++++	++++	++++	++++	+++	++++	++++	
Muscovite (sericite)	$K_2O \cdot 3(Al, Fe)_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	2.85	++++	++++	++++	++++	++++	++++	++++	++++	
Talc	$3MgO \cdot 4SiO_2 \cdot H_2O$	2.7	++++								
Phlogopite	$K_2O \cdot 6MgO \cdot Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$					++					
Chloritoid	$(Fe, Mg)O \cdot Al_2O_3 \cdot SiO_2 \cdot H_2O$	3.5	+++						++		
Gahnite	$(Zn, Fe)O \cdot (Al, Fe)_2O_3$	4.45	+++	+++							
Garnet	$3CaO \cdot (Al, Fe)_2O_3 \cdot 3SiO_2 + 3(Mg, Fe)O \cdot (Al, Fe)_2O_3 \cdot 3SiO_2$	3.9—4.1	+++	+++					+++		
Andalusite	$Al_2O_3 \cdot SiO_2$	3.15	+++	+++							
Staurolite	$(Fe, Mg)O \cdot 2Al_2O_3 \cdot 2SiO_2 \cdot H_2O$	3.7	+	+++							
Cordierite	$4(Mg, Fe)O \cdot Al_2O_3 \cdot 10SiO_2 \cdot H_2O$	2.7	++								
Hornblende	$2CaO \cdot 3(Mg, Fe)O \cdot Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	3.1	++++	+++	+++	+++	+++	+++		++++	
Actinolite	$2CaO \cdot 5(Mg, Fe)O \cdot 8SiO_2 \cdot H_2O$	3.0									
Cummingtonite Anthophyllite	$(Mg, Fe)O \cdot SiO_2$	3.2	+++	++							
Epidote-group	$4CaO \cdot 3(Al, Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O$	3.4	+++	+++	++	+++	++		+++		
Orthite	$4(Ca, Ce)O \cdot 3(Al, Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O$					++	+		+		
Prehnite	$2CaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot H_2O$	2.85	++						++		
Titanite	$CaO \cdot TiO_2 \cdot SiO_2$			++		++	++		+		
Tourmaline	$Na_2O \cdot 6(Mg, Fe)O \cdot 6Al_2O_3 \cdot 12SiO_2 \cdot 4H_2O \cdot 3B_2O_3$		++	++							
Calcite	$CaO \cdot CO_2$	2.7	++	+++	++	+++	+++	+++	+++		
Fluorite	CaF_2								++		
Pyrite	FeS_2		++++	++++	++++	++++	++++	++++	++++	++++	
Pyrrhotite	FeS		++++	++++	++++	++++	++++	++++	++++	++++	
Arsenopyrite	$FeAsS$		++	+++	+	+	++	++++	++	++++	++++
Chalcopyrite	$CuFeS_2$		++++	++	++	++++	++	+	++	++++	+++
Cubanite	$CuFe_2S_3$					++					
Valleriite	$Cu_{2-3}Fe_4S_7$		+	+		+			+	+	
Bornite	Cu_5FeS_4			+						+	
Covellite	CuS										++
Sphalerite	ZnS		++++	++++	++++	+++	++++	+++	++++	++++	++
Stannite	Cu_2FeSnS_4			+?					++		
Galena	PbS		+	+++	++	+	++	++	+++	+++	
Tetrahedrite	Cu_3SbS_3			++	+		+	+	++	++	
Bournonite	$CuPbSbS_3$			++			+		++		
Jamesonite[1]	$Pb_2Sb_2S_5$										
Boulangerite[1]	$Pb_5Sb_4S_{11}$			++			++	++	++	++	
Geocronite	$Pb_5Sb_2S_8$			++							
Gudmundite	$FeSbS$			++	+	+	++	++	++		
Pyrargyrite	Ag_3SbS_3			+	+				+	+	
Bismuth	Bi			+			+	+	+		
Electrum	$Ag\ (Au)$										
Dyscrasite (?)	Ag_3Sb			+			+		+		
Copper	Cu					+					
Sulphur	S			+							
Marcasite and sec. pyrite	FeS_2		++	++		++	++		+	+++	
Magnetite	Fe_3O_4	5.2	+++	+++	+++	+++	++		+++	+++	
Hematite	Fe_2O_3		+	+					+		
Ilmenite	$FeTiO_3$		+++	+++		+			++		
Rutil	TiO_2			+		+	+		++		

[1] Cf. p. 80.

391136. S.G. U. Ser. C. N:o 424. Gavelin.

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Resumé.

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Inledning.

Med Malånäsfältet har i föreliggande publikation betecknats ett område inom Norsjö socken i Västerbottens län beläget huvudsakligen omedelbart söder om Skellefteälven på ett avstånd av c:a 62 till 80 km västsydväst om Skellefte stad (se fig. 1). Malånäsfältet ingår i det större urbergsområde, huvudsakligen uppbyggt av suprakrustalbergarter, vilket av A. G. Högbom ursprungligen betecknats som Skelleftefältet (44). Genom den malmletningsverksamhet som under de senaste tjugu åren bedrivits inom Skelleftefältet har det visat sig innehålla ett stort antal sulfidmalmer och är sålunda att beteckna som Sveriges i närvarande stund nyaste malmdistrikt. En beskrivning av Skelleftefältets geologi och malmer har nyligen publicerats av Alvar Högbom (42) i anslutning till en berggrundskarta över fältet. I denna beskrivning har ävenledes Malånäsområdet behandlats och föreliggande avhandling avser att giva en detaljbeskrivning av Malånäsområdets geologi och malmfyndigheter, i största möjliga mån anknytande till A. Högboms framställning, samt vidare att mer ingående diskutera de mer aktuella problem som förefinnas inom området.

Malånäsområdet har alltsedan begynnelsen av det karteringsarbete och därmed sammanhängande malmletningsverksamhet, som Sveriges geologiska

undersökning bedrivit i Västerbotten, varit föremål för omfattande undersökningar. På grund härav har till mitt förfogande stått ett avsevärt material i form av kartor och stuffer samlade före den av mig 1933 påbörjade undersökningen. Hällkonturer och topografiskt underlag för berggrundskartan över området ha sålunda i huvudsak hämtats från en översiktskarta, som på grundval av Sveriges geologiska undersöknings material sammanställts av A. Högbom, och från malmfyndigheterna ha i många fall utnyttjats stuff- och kartmaterial samlat och framställt av A. Högbom, J. Eklund och K. A. Barkenberg. För uppdragandet av geologiska konturer och ledlinjer inom starkt jordtäckta områden har det synnerligen omfattande geofysikaliska materialet varit av utomordentligt stor betydelse.

Översikt och beskrivning av bergarterna.

A. Högbom ger i sin beskrivning följande indelning av urberget inom Skelleftefältet:

Yngre urberg
- Yngsta urbergsgraniter.
- Yngre suprakrustalformationen, Vargforsformationen.

Äldre urberg
- Diskordans.
- Yngre urbergsgraniter, Revsundsgranitserien.
- Äldre grönstensgångar.
- Äldre urbergsgraniter.
- Äldre suprakrustalformationen.
  - Porfyr-porfyritserien, Arvidsjaurporfyrer.
  - Fyllitserien med effusiva grönstenar.
  - Leptit-hälleflintserien.

Malånäsområdets berggrund uppbygges huvudsakligen av vulkaniska bergarter tillhörande den äldre suprakrustala formationens undre avdelning, leptithälleflintserien. Vidare förekomma representanter för den sedimentära bergartskomplex, som överlagrar vulkaniterna, nämligen fyllitserien. Däremot saknas helt Arvidsjaurporfyrer. I norr begränsas Malånäsområdets vulkaniska bergarter av det största inom Skelleftefältet förekommande, sammanhängande området av Vargforssediment, i söder uppträda stora massiv av intrusivbergarter tillhörande Revsundsgruppen.

Vulkaniterna variera med avseende på kemisk sammansättning mellan kvartsporfyriska och andesitiska eller basaltiska bergartstyper. Även strukturellt finner man betydande variationer; lavor och tuffer med väl bibehållna primära strukturdrag uppträda ofta i intim växling.

Den största utbredningen inom området ha kvartsporfyrerna. Av kvartsporfyriska lavor uppträda i stort sett tvenne huvudtyper. Den ena karakteriseras av att såväl kvarts- som plagioklasströkorn äro tämligen stora, i regel 2—3 mm, äro väl avgränsade från grundmassan och giva därigenom bergarten ett även makroskopiskt mycket karakteristiskt utseende. I den

andra typen äro strökornen mindre och i allmänhet även betydligt glesare fördelade. Kvartsströkornen nå upp till 1 mm i diameter, plagioklasströkornen äro i regel något mindre. I de bäst bevarade kvartsporfyrerna är grundmassan ofta nästan flintigt tät. Under mikroskopet finner man i dessa typer ofta väl bevarade primära texturer. Mikrogranitiska, mikrofelsitiska, mikrogranofyriska, mikropoikilitiska och sfärolitiska utbildningstyper äro iakttagna.

Den mineralogiska sammansättningen är tämligen likartad inom de olika kvartsporfyrtyperna, åtminstone vad beträffar typer av samma metamorfosgrad. Strökornen utgöras av kvarts och albitisk plagioklas. I två fall har kvartsporfyr iakttagits förande strökorn av andesin, men i övrigt av exakt samma utseende som den normala utbildningsformen.

Grundmassan i de normala kvartsporfyrerna består huvudsakligen av kvarts, plagioklas, understundom något kalifältspat, klorit eller biotit, mer eller mindre sericit, små mängder av klinozoizit, epidot, kalcit, apatit, ilmenit, zirkon, rutil, titanit. Pl. 1—3 visa vissa texturella drag hos dessa bergarter.

Av de pyroklastiska derivat, som motsvara de kvartsporfyriska lavorna, finner man omkring Bjurträskgruvan väl utbildade agglomerat, förande ljusa, täta fragment i en biotitrikare mellanmassa (Pl. 4). Större utbredning ha likväl bandade tuffer, i vilka skikt av något varierande sammansättning växellagra. Slutligen förekomma inom områdets västliga delar och i allmänhet i nära förband med fylliterna ljusa, finskiktade eller massformiga tuffer. Den mineralogiska sammansättningen i alla dessa typer är i stort sett densamma som inom lavorna, och de kemiska variationer, som förefinnas, visa sig motsvaras huvudsakligen av växlingar i proportionerna mellan de olika komponenterna.

De intermediära bergarterna representeras huvudsakligen av keratofyrer och täta kloritrika tuffer. På grund av det inbördes geologiska uppträdandet dessa typer sinsemellan och på grund av blottningarnas fördelning inom de områden, där dessa bergartstyper förekomma, ha de olika utbildningsformerna ej kunnat särskiljas från varandra på kartan. De mest typiska keratofyrerna förekomma som fragment i polymikta vulkaniska breccior. Dessa keratofyrer uppbyggas huvudsakligen av albit, klorit och sericit. I några fall inkommer även biotit. Kalcit, malmmineral samt understundom något kalifältspat ingå vidare i de flesta fall. Albiten uppträder dels som strökorn, dels som små lister oregelbundet fördelade i grundmassan, vilket senare bidrager att giva bergarten en synnerligen karakteristisk textur (Pl. 6). I de flesta fall torde mer eller mindre kvarts även vara närvarande, men på grund av grundmassans finkornighet är det ofta svårt att erhålla en säker uppfattning om de verkliga kvantiteterna. I den mån kvartsen blir rikligare uppstå bergarter, vilka kemiskt äro i det närmaste identiska med normal kvartsporfyr. På grund av texturella överensstämmelser med keratofyrerna och på grund av att dessa kvartsrikare utbildningstyper alltid äro mycket nära associerade med intermediära bergarter, ha de benämnts kvartskeratofyrer och på kartan sammanförts under samma beteckning som keratofyrerna.

De bergartstyper, vilka på kartan betecknats som »täta tuffer, huvudsak-

ligen av intermediär sammansättning», bestå huvudsakligen av en oregelbunden blandning av klorit, albit och kvarts i växlande proportioner. Härtill kommer ytterligare vanligen mer eller mindre sericit, kalcit, epidot, klinozoizit och malmmineral. I några fall är även kalifältspat iakttagen. Proportionerna mellan de olika komponenterna kunna förete betydande variationer, men som helhet betraktad torde denna grupp vara av intermediär sammansättning. I en del fall uppträda fragment av andra vulkaniska bergarter i sådana tuffer, en utbildningsform, som representerar ett övergångsled till de grova polymikta vulkaniska brecciorna.

Dylika grova breccior uppbyggas av väl avgränsade, ofta kantiga fragment av olika vulkaniter i en vanligen kloritrik mellanmassa. Fragmenten utgöras till största delen av kvartsporfyr och keratofyr, men även femiska vulkaniter förekomma. Storleken av de enskilda fragmenten kan variera från 1 meter till en eller annan cm i genomskärning. Strukturen framgår av Pl. 7 och 8. I allmänhet bilda dessa vulkaniska breccior tämligen väl avgränsade bäddar, vilka vid karteringen i fält lätt kunna följas på grund av sin karakteristiska struktur.

De mer femiska vulkaniterna ha på kartan sammanfattats under benämningen effusiv grönsten. Större delen av områdets grönstenar äro utbildade som amfiboliter, i vilka huvudbeståndsdelarna utgöras av hornblände och plagioklas (vanligen oligoklas—andesin, i några sällsynta typer albit). Såväl täta som vackert plagioklasporfyriska amfiboliter äro iakttagna. Biotit kan förekomma, understundom i tämligen riklig mängd, och i många fall uppträder något klorit även i de rent amfibolitiska typerna. En speciell typ utgör de rena klorit-albitgrönstenar, vilka uppträda vid Bjurforsmalmerna. Dessa grönstenar sammanhöra dock med och övergå i amfibolitiska typer. I dylika klorit-albitgrönstenar bildar albiten tämligen väl markerade lister, divergentstråligt orienterade i den kloritrika grundmassan (Pl. 12 b).

I grönstenarna inom områdets norra delar försvinner efter hand hornbländet under det att kloriten blir allt rikligare. Samtidigt uppträder kalcit och epidotmineral i allt större mängd. Utom redan nämnda mineral förekommer såväl i de hornbländeförande som i de hornbländefria grönstenarna ofta något kvarts. I små kvantiteter förekommer ilmenit allmänt, titanit och apatit däremot mera sällan. Vid Bjurberget uppträder slutligen även en pyroxenförande amfibolit.

Inom de hornbländeförande grönstenstyperna finner man flerstädes väl utbildad agglomeratisk struktur. Särskilt är detta fallet strax väster om Norrliden, där grönstenarna ofta innehålla rikliga fragment av olika grönstenstyper men även av sura bergarter (Pl. 9 och 10). I de klorit-kalcitförande grönstenarna förekomma understundom synnerligen väl utbildade blåsrum, fyllda med ett eller flera av mineralen klorit, kvarts, kalcit, zoizit (Pl. 11).

Den sedimentära bergartsserien utgöres huvudsakligen av finkorniga sediment, under det att mer grovklastiska bildningar spela en kvantitativt vida mindre dominerande roll. Den viktigaste typen i denna serie har benämnts grafitfyllit, efter sitt mest karakteristiska mineral, grafit. Då denna bergart vidare ofta håller en viss och i många fall ej oväsentlig kishalt, företrädesvis

magnetkis, kommer den att vid de geofysikaliska mätningarna vara av synnerligen stor betydelse. Grafithalten och magnetkishalten göra nämligen, att bergarten förorsakar starka indikationer vid användandet av elektriska undersökningsmetoder, under det att magnetkishalten gör att man även med magnetiska metoder får betydande utslag.

I de grafitrikaste typerna är skiffrigheten ofta så utpräglad, att varje spår av primär skiktning är fullkomligt utplånad. Inom svagare metamorfoserade typer och i synnerhet i fall, då även något mer grovklastiska skikt inkomma, är skiktningen väl bevarad. Den mineralogiska sammansättningen är tämligen likformig. Kvarts, sericit, klorit, plagioklas samt i en del fall något mikroklin bilda en ytterligt finkornig massa. Kalcit förekommer ofta i små kvantiteter, i högmetamorfa terränger ersatt av hornblände. Vidare finner man epidot samt obetydliga korn av zirkon och apatit. I de lerskiffrar, vilka förekomma inom mer högmetamorfa terränger, uppträder biotit i stället för klorit, kornigheten blir grövre, och bergarten skulle rätteligen benämnas grafitförande glimmerskiffer.

En stor del av fylliterna inom området äro emellertid grafitfria och ha på kartan sammanförts under beteckningen grå fyllit. Den väsentliga skillnaden från de grafitförande typerna är avsaknaden av grafit samt en viss tendens att i sig innesluta mera grovklastiskt material. Man finner sålunda övergångar till verkliga arkoser, bestående huvudsakligen av osorterat kvartsporfyr- och keratofyrgrus. Understundom kan man spåra en viss tendens till konglomeratisk utbildning, i det att kantiga fragment av skiffrar eller mer rundade bitar av kvartsporfyr uppträda i en finkornigare grundmassa (Pl. 14). En del av de sandstens- och arkosartade utbildningstyperna innehålla kalcit som bindemedel, och lokalt kan kalciten anrikas, så att benämningen oren kalksten kan vara motiverad. Dylika orena kalkstenar förekomma norr och nordost om Kotjärn i fylliterna därstädes. Den bredaste kalkstensbanken når en mäktighet av 3—4 m, men i allmänhet äro mäktigheterna betydligt mindre, och ofta uppträder kalkstenen i form av små linser i fylliten.

Ett anmärkningsvärt drag inom arkoserna är, att plagioklastavlorna ofta äro av andesinsammansättning, detta trots att det vida dominerande flertalet av kvartsporfyrerna, som man i första hand skulle vara benägen antaga ha lämnat materialet till vittringsgruset, innehåller albitisk plagioklas. Denna omständighet antyder, att man har att räkna med en viss materialtransport även vid bildningen av arkoserna.

Utanför gränsen för det stora granit- och gabbromassiv, som begränsar suprakrustalbergarterna i söder, saknas i allmänhet verkliga intrusivbergarter helt och hållet. På ett par ställen ha visserligen grönstensgångar iakttagits, men dessa göra intryck av att stå effusivbergarterna synnerligen nära och torde vara bildade i samband med den vulkaniska verksamheten. Däremot förekomma inom området kvartsgångar, ofta i tämligen riklig mängd. I en del fall förefaller kvartsdränkningen att vara lokaliserad till sulfidmalmernas närhet, i andra fall däremot har den en mer regional karaktär. Vanligen utgöras dessa gångar av ren kvarts,

någon gång med litet klorit. I några fall förekomma även karbonat, och i ett fall har iakttagits hornbländebildning i kvartsporfyr genom tillskott av CaO från en kalcitförande kvartsgång.

Stratigrafi och tektonik.

En utredning av de stratigrafiska förhållandena visar, att det ej är möjligt att för hela området genomföra en detaljerad stratigrafisk indelning. Fyllitserien överlagrar i stort sett den vulkaniska serien, men att å andra sidan den vulkaniska verksamheten fortsatt även sedan bergarter tillhörande fyllitserien börjat bildas, framgår av den omständigheten, att fragment av grafitrik fyllit i ett par fall påträffats såväl i de polymikta tuffbrecciorna som i de agglomeratiska delarna av de täta klorittufferna.

Inom den vulkaniska serien är det ej möjligt att fastställa någon lagbunden fördelning mellan olika bergartsled. Möjligen kan man spåra en viss tendens till en allmän stratigrafi, i det att tuffitiska derivat kvantitativt öka uppåt i lagerserien. De smala fyllitbäddar, vilka ofta förekomma tillsammans med tufferna i omedelbar närhet till de mäktigare fyllitstråken, torde med stor sannolikhet utgöra inlagringar. Man kan således i stratigrafiskt hänseende särskilja trenne huvudavdelningar, en understa, bestående av kvartsporfyriska till andesitiska eller basaltiska lavor och tuffer, en mellanavdelning, bestående av huvudsakligen tuffitiska avlagringar med relativt tunna bäddar av fyllit samt slutligen en översta, sedimentär avdelning, den egentliga fyllitserien.

Områdets suprakrustala bergarter förekomma aldrig i sitt ursprungliga läge utan ha alltid genom veckningar blivit starkt rubbade. Veckningen har snarast karaktären av en verklig orogenes med i huvudsak mot norr riktade tryckriktningar. På grund av undersökningsområdets relativt obetydliga utbredning och på grund av observationsmaterialets ytterligt ojämna fördelning är det givetvis synnerligen vanskligt att söka giva en klar och såväl i större som smärre drag entydig bild av tektoniken. Man får här nöja sig med att framhålla vissa drag, vilka kunna bidraga till en senare lösning av de tektoniska problemen i ett större sammanhang.

För förståelsen av områdets tektonik är det först av vikt att betona den stora skillnad, som förefinnes inom olika bergarter, med avseende på deras olika förhållande gent emot de deformerande krafterna. Särskilt stor är skillnaden mellan de normala vulkaniterna, i synnerhet lavorna, och de grafitrika fylliterna. De sistnämnda äro utan jämförelse områdets mest plastiska bergarter, varför glidningar och förskjutningar gärna utlösa sig utmed eller i fyllithorisonter. I en del fall kan den högplastiska fylliten dynamiskt pressas in utmed sprickplan i andra hårdare bergarter.

Av de delar, som medge ett mer detaljerat studium av de tektoniska detaljerna, erbjuder speciellt de väl blottade områdena omkring Bjurträskgruvan—Bjurliden samt vid Skäggträskberget vissa drag av intresse. Inom området mellan Bjurliden och Bjurträskgruvan äro lagren, såsom framgår av kartan,

starkt hopstukade och förete relativt markerade omböjningar. Såväl dessa omböjningar som småveck inreglera sig i ett veckaxelsystem stupande 30°—50° mot VSV. Inom hela detta område finner man vidare vanligen en synnerligen markerad stänglighet pekande i samma riktning. 300 m norr om Bjurträskgruvan förekommer en ytterligt starkt förskiffrad zon, som påtagligen avgränsar ett område med helt annan tektonisk stil. Norr om denna gräns äro alla bergarter nämligen utpräglat planskiffriga, och även bergartsgränserna tendera alltid att inreglera sig i de genomgående förskiffringsytorna. Skillnaden mellan de båda områdenas tektoniska stil åskådliggöres i fig. 2. Denna skillnad kommer till synes, vare sig man tar i betraktande en så liten del som en enstaka blottning, eller om man betraktar kartbilden i stort.

Vid Skäggträskberget göra lagren en stor omböjning, såsom framgår av kartbilden från detta område (Pl. 38). Genom kombination av den stora skiktpackens stupningar för olika strykningsriktningar finner man, att omböjningen har skett efter en veckaxel stupande c:a 30° mot V. I de enskilda hällarna finnes däremot intet, som antyder denna veckaxelriktning. Tvärtom finner man ofta en viss småkrusighet i bergarterna, vilken ofta kan ge ett visst intryck av stänglighet, och som stupar 50°—60° mot S eller SV. Denna riktning visar sig vara uppkommen genom interferens mellan nord—sydligt förlöpande, brantstående brott- och glidplan samt skiktplanen i den stora skiktpacken. Dessa strukturer ha sålunda ingen utslagsgivande betydelse för de stora tektoniska dragen.

Inom hela området mellan Skäggträskberget och Maurliden är det ävenledes svårt att i de enskilda hällarna finna några linjärstrukturer, vilka kunna vara av betydelse för tolkningen av de stora tektoniska dragen. I den mån, som dylika strukturer kunna spåras, stå de nämligen mycket brant, och likväl ger en kombination av iakttagelserna inom ett större område vid handen, att huvudveckaxeln här måste vara i det närmaste horisontell.

Den mest markerade tektoniska gränsen inom området förlöper i sydvästlig riktning från en punkt strax väster om Norrliden (gränsen mellan den ljusgrå rastertonen och de ofärgade ytorna i fig. 4). Här möter bergartkomplexen från öster (kvartsporfyrer med rikliga grönstenar) de från väster kommande typerna, där grönstenar spela en synnerligen underordnad roll, men där i stället keratofyrer och intermediära tuffer äro av stor kvantitativ betydelse. Härvid bli de senare bergarterna kraftigt hopstukade och omböjda, såsom är fallet vid Skäggträskberget och Storstensberget (se kartan).

Regionalmetamorfos.

De bergarter, vilka tidigare beskrivits, ha i mer eller mindre grad blivit påverkade av metamorfoserande krafter. I första hand torde det därvid ha varit en ökning av temperatur och tryck, som åstadkommit förändringarna inom bergarterna. Metamorfosen leder dels till en omkristallisation, varvid bergarternas primära textur- och i viss mån även strukturdrag utplånas, dels till en nymineralisering. För att utreda de problem, vilka stå i samband med den

metamorfos, som kan sägas ha regional karaktär, har förf. tillämpat de principer, som ursprungligen lancerats av Eskola (15) i hans faciesklassifikation. I den mån, som metamorfosen leder till bildningen av en ny mineralassociation på bekostnad av en äldre, kan man genom att fastställa de punkter, där denna mineralnybildning har ägt rum, erhålla möjligheter att jämföra olika områden med avseende på metamorfosgrad. Genom att förbinda punkter med samma metamorfosgrad erhåller man sålunda ett uttryck för »metamorfosfrontens» förlopp.

De mineralnybildningar, vilka inom föreliggande område visat sig lämpliga att välja till indikatorer för metamorfosstyrkan, äro, dels omvandlingen klorit → biotit i kvartsporfyrserien, dels omvandlingen klorit + kalcit eller epidot → hornblände inom grönstensserien. Att båda dessa reaktioner förekomma och spela stor roll blev tydligt redan vid karteringen i fält, och detta intryck förstärktes ytterligare vid mikroskopisk granskning av bergarterna.

En undersökning på grundval av ovannämnda synpunkter visar, att karteringsområdet kan uppdelas i tre huvudavdelningar, nämligen en, där reaktionen ännu ej alls är påbörjad, en, där den är fullständig samt en mellanliggande del, där reaktionen var ofullständig. I fig. 6 A beteckna de grövre streckade linjerna gränserna för begynnande och för fullständig hornbländebildning inom grönstensserien, i fig. 6 B beteckna motsvarande linjer gränsen för begynnande och för fullständig biotitbildning inom kvartsporfyrserien. För att få bättre översikt har området i dessa fall utsträckts något utanför det egentliga kartområdet. Biotitzonen, resp. hornbländezonen ligger längst i söder, kloritzonen längst i norr.

Inom kvartsporfyrerna uppträder inom de båda nordligaste zonerna ofta sericit i en omfattning som i viss mån antyder en regional sericitbildning. Zonerna skulle därför för detta fall rätteligen benämnas biotitzonen, biotit-sericit-kloritzonen och klorit-sericitzonen. I de sydligaste hällarna med kvartsporfyriska bergarter har iakttagits granat bildad på bekostnad av biotit. Här föreligger således en tendens till en association karakteristisk för ytterligare högre metamorfosgrad. Observationspunkterna räcka emellertid ej för att draga en gränslinje för begynnande granatbildning på samma sätt som för de ovannämnda mineralen. I samma metamorfa läge som de granatförande proven har vidare iakttagits grönsten förande pyroxen samt ej alldeles oväsentliga mängder av mikroklin. Detta är av intresse, då nämligen grönstenarna inom hornbländezonen i vanliga fall föra biotit, denna däremot är biotitfri. Associationen antyder, att man skulle ha att räkna med en högmetamorf association — pyroxen-hornblände-mikroklin — och en mer lågmetamorf motsvarande association — biotit-kalcit-hornblände.

Enligt Eskolas terminologi motsvara parageneserna inom den sydligaste zonen amfibolitfacies och möjligen även till en del epidot-amfibolitfacies. Den nordligaste zonen motsvarar grönskifferfacies, under det att mellanzonen huvudsakligen innehåller en blandning av dessa båda faciestyper. En viss avvikelse från den ideala mineralsammansättningen inom grönskifferfacies innebär förekomsten av anortitrik plagioklas i grönstenar tillhörande grönskifferfacies,

då man i dessa fall borde vänta sig albit. Anortitrik plagioklas torde i detta fall vara att betrakta som en relikt från den vulkaniska perioden, och ifrågavarande förhållanden antyda, att anortit är i betydligt högre grad än de andra ifrågakommande mineralen resistent gentemot denna form av metamorfos. Även förekomsten av ilmenit i stället för titanit i grönskifferfacies kan betraktas som ett undantag från de ideala jämviktsbetingelserna.

Utredningen av regionalmetamorfosen ger enligt dessa resultat vid handen, att man har att räkna med en från norr mot söder successivt stigande metamorfosgrad, d. v. s. metamorfosen intensifieras mot de väldiga massiv av Revsundsgranit, vilka begränsa Skelleftefältets bergarter i söder. Däremot finner man intet som helst samband mellan »metamorfosfronten» och den äldre graniten, Jörngraniten (jfr. fig. 6). Då Revsundsgraniten brukar betraktas som en palingen granit torde sambandet mellan granit och metamorfos bäst uttryckas så, att den metamorfos, som här beskrivits, är resultatet av samma processer som leder till granitens bildning och framträngande.

Malmförekomster.

Inom undersökningsområdet finner man flerstädes spår av en betydande sulfidmineralisering, vilken kan leda dels till utbildning av samlade sulfidmalmskroppar, dels till ekonomiskt värdelösa, men tämligen vidsträckta impregnationsstråk. I samband med infiltrationen av sulfidmaterialet blir vanligen den kvartsporfyriska eller keratofyriska sidostenen mer eller mindre omvandlad. Denna mineralbildning är senare än den mineralisering som beskrivits såsom regionalmetamorfos, och mineral bildade vid de regionalmetamorfa processerna bli åter omvandlade i samband med sulfidinvasionen. Vidare har den senare mineraliseringen alltid mer lokal karaktär. Resultatet av omvandlingarna är i första hand att fältspaten i moderbergarten förstöres och ersättes av klorit eller sericit, varvid bildas de bergarter, vilka vanligen bruka betecknas som malmkvartsiter. Vanligast äro sericit- och kloritkvartsiter, vilka dock inom här förekommande fyndigheter ofta föra ytterligare ett stort antal mineral, såsom granat, andalusit, zinkspinell m. fl.

De inom området förekommande malmkropparna nå i intet fall upp till själva jordytan, utan malmen har alltid först måst lokaliseras genom magnetiska eller elektriska mätningar. Genom grävning eller diamantborrning ha därefter indikationerna vidare undersökts. Jorddjupet varierar i allmänhet mellan en eller annan meter och 20 meter.

Bjurträskmalmen. Huvudmalmen, som ligger i det mineraliserade områdets nordöstra del, utgöres av en komplex zinkförande svavelkis-magnetkiskropp (Pl. 34). Inom smärre partier är malmen även kopparförande, men i dessa delar äro zinkhalterna mycket låga. Vissa mindre betydande delar utgöras av tämligen ren svavelkis med svavelhalter varierande mellan 30 och 45 % S. Ren magnetkismalm förekommer även och bildar t. ex. den smala svansen mot Ö.

Inom de zinkrikaste delarna förekomma halter varierande mellan 14 och 17 % Zn, men inom de partier som inräknats i zinkmalmen äro halter mellan 4 och 6 % Zn förhärskande.

Makroskopiskt iakttagbara malmmineral äro pyrit, magnetkis, zinkblände och kopparkis. Vid mikroskopisk undersökning visar sig magnetit vara tämligen allmän, vidare förekommer ilmenit. Såsom ytterligt obetydliga korn i kopparkis har valleriit iakttagits. Magnetkisen är ofta sekundärt omvandlad i markasit eller »sekundär pyrit». Såsom gångart uppträda företrädesvis kvarts, klorit, biotit, sericit och understundom hornblände. Plagioklas och epidot äro iakttagna vid mikroskopisk undersökning. Av stort intresse är, att i några fall ha i den kompakta sulfidmassan observerats runda kvartsögon av exakt samma utseende som kvartsströkornen i kvartsporfyren. Detta stöder uppfattningen, att malmen bildats genom förträngning av sidostenen, varvid i detta fall porfyrens strökorn bibehållits.

VSV om den ovan omnämnda malmkroppen förekommer en obetydlig kopparmalm bestående av kopparkis i kloritskiffer. Utom kopparkis har vidare iakttagits magnetkis, zinkblände, arsenikkis, valleriit och ilmenit.

Den berggrund, som omger de samlade malmkropparna är inom en tämligen betydande areal påverkad av malmlösningarna (jfr fig. 11). Närmast malmerna uppträda rena malmkvartsiter, där primärbergarternas fältspat är fullkomligt förstörd. Primärbergarterna ha i de flesta fall utgjorts av kvartsporfyragglomerat, och även vid synnerligen långt driven omvandling är den agglomeratiska strukturen synlig. Bergarterna inom den innersta, närmast malmerna belägna zonen äro i allmänhet utbildade som klorit- eller klorit-sericitkvartsiter, understundom som biotit-klorit- eller biotit-sericitkvartsiter. Granat är mycket vanlig, likaså zinkspinell (gahnit). Vidare förekomma i en del typer andalusit och magnetit samt i ett fall kloritoid. I enstaka fall är cordierit-gedritkvartsit även iakttagen. I den mån som kvartsen i kloritkvartsiterna träder tillbaka i mängd bildas typer, som betecknats som kloritskiffrar. Dessa förekomma gärna inemot själva malmkropparna eller som inneslutningar i desamma. I dessa typer förekommer ibland nybildad plagioklas, vilken som stora, klara tavlor växer igenom kloritmassan. Turmalin är iakttagen i några fall, och som sporadiska mineral förekomma vidare epidot, apatit och zirkon. Sulfider och ilmenit äro vidare iakttagna i de flesta fall. Vid den större malmkroppen förekommer amfibolskarn bestående av ljusgröna hornbländenålar inbäddade i en filtig talkmassa.

Utanför kvartsitzonen uppträda bergarter, vilka tydligt påverkats av de mineraliserande lösningarna, men vilka ännu föra plagioklas. Inom denna yttre omvandlingszon finner man en oregelbunden slirig växling mellan starkt sericitiserade bergartstyper och bergarter, vilka skilja sig från moderbergarten huvudsakligen genom att de äro anrikade på anortit. Anortitrik plagioklas i gryniga aggregat förekommer nämligen i synnerligen riklig mängd i dessa typer.

Grönstenarna inom det omvandlade området ha i betydligt mindre grad än kvartsporfyrseriens bergarter hemfallit åt sekundära omvandlingar. De enda

förändringar, som i dessa bergarter kunna iakttagas, äro svaga omvandlingar av hornblände till cummingtonit, en svag kloritisering samt en viss kisinfiltration.

Bjurliden. Denna malm är undersökt genom ett flertal övertvärande undersökningsgropar och kompletterande partiell avrymning av jordbetäckningen på malmens utgående samt genom trenne diamantborrhål. De aktuella delarna av malmen utgöras av zinkförande svavelkismalm med någon blyhalt. Relativt stora delar av den samlade sulfidkroppen utgöras av zinkfattig eller zinkfri magnetkis. Inom smärre partier kan dock även den rena magnetkismalmen vara zinkförande. Inom de östliga delarna av malmkroppen förekommer tämligen ren, zinkfri svavelkismalm. De zinkförande svavelkismalmsdelarna äro ofta synnerligen vackert bandade, varvid zinkbländerika och svavelkisrika band av någon cm:s mäktighet intimt växellagra.

Svavelhalterna i de renare svavelkispartierna kunna nå upp till 40 % S, men inom större delen av malmen ligga halterna mellan 30 och 35 % S. De zinkrikare delarna av malmen innehålla mellan 12 och 17 % Zn, medeltalet för hela den zinkförande delen torde dock vara c:a 7 % Zn, vartill kommer en blyhalt på 0.5—1 %. Silverhalterna följa i stort sett blyhalterna, och i de blyförande sektionerna finner man 100—250 gr/t. Guldhalterna äro däremot synnerligen låga.

De dominerande malmmineralen äro svavelkis, magnetkis och zinkblände. I ett par fall är kopparkis iakttagen i de magnetkisrika malmdelarna. Blyglans är tämligen allmän, men är oregelbundet fördelad och är i allmänhet anrikad i ådror och sliror, i vilka även ett stort antal antimonmineral förekomma. Arsenikkis i enstaka kristaller är tämligen allmän och jämnt fördelad och kan, när den är nära anknuten till blyglansådrorna, uppträda i upp till cm-stora, idiomorfa kristaller. I ett fall äro små oregelbundna fragment av tät, kompakt arsenikkismalm iakttagna i rik zinkmalm.

Den mikroskopiska undersökningen av malmerna visar ytterligt komplexa mineralassociationer. Kopparkis finnes t. ex. i allmänhet även i de zinkförande proven ehuru i ytterligt obetydliga kvantiteter. Antimonmineralen, som uppträda tillsammans med blyglans, äro ytterligt intimt sammanväxta med varandra och med blyglans. Följande antimonförande mineral äro iakttagna i förband till blyglansådrorna: Fahlerz, bournonit, boulangerit, jamesonit, geokronit, pyrargyrit, gudmundit. I ytterligt obetydliga korn äro vidare valleriit och bornit iakttagna. Av oxider förekomma magnetit och ilmenit allmänt, rutil i obetydlig mängd och i ett fall ha ytterligt små korn av hämatit påträffats.

Av de mineral, vilka uppträda som gångart i de kompaktare malmdelarna, dominerar kvarts kvantitativt. Liksom vid Bjurträskmalmen förekomma även här kvartsporfyrernas strökorn flerstädes som relikter i den kompakta sulfidmalmen. Ytterligare förekomma biotit, klorit och sericit i stor utsträckning. Plagioklas kan lokalt uppträda tämligen rikligt, liksom även hornblände, kalcit, epidot, gahnit och granat.

Omvandlingen av sidostenen är vid Bjurliden av samma karaktär som vid Bjurträskmalmen. Primärbergarterna äro kvartsporfyriska lavor och bandade

sura tuffer. I allmänhet dominerar här sericit över klorit. Grova sericit- och sericit-biotitkvartsiter med gahnit, i vissa fall även med andalusit och staurolit äro allmänna. Granat och magnetit förekomma ytterligare i dessa parageneser. Ofta föra ovan omnämnda grova kvartsiter arsenikkis såsom stora, idiomorfa kristaller. Enligt resultaten från borrhålen förekommer även här en yttre omvandlingszon, karakteriserad av en växling mellan sericitkvartsitiska och relativt anortitrika omvandlingstyper. I de anortitrika bergarterna förekomma understundom även kalcit, epidot och i några fall hornblände. Granat är vidare tämligen allmän i dessa typer. Liksom vid Bjurträskmalmen äro omvandlingarna i den grönstensbank, som förekommer inom malmen, i de flesta fall tämligen obetydliga i jämförelse med förändringarna inom kvartsporfyrerna. Endast omedelbart intill malmkontakten leder omvandlingen till utbildning av verkliga skarnbergarter med hornblände och granat.

Snåttermyran är ett mindre mineraliseringsområde, som undersökts genom gropar och tvenne borrhål. Sulfidmineraliseringen har i allmänhet endast karaktären av relativt betydelselösa impregnationer, inom vilka dock åtminstone en meterbred bank av samlad svavelkis-magnetkis-zinkbländemalm med något blyglans är iakttagen. Under mikroskopet finner man vidare något kopparkis, och i anslutning till denna förekommer även fahlerz. Pyrargyrit är iakttagen, detta trots att silverhalterna i de analyserade proven äro tämligen låga. Vidare ha små idiomorfa kristaller av arsenikkis och gudmundit påträffats. Sidostenen utgöres av omvandlad kvartsporfyr och mindre påverkad grönsten. Sericitkvartsiter och kloritkvartsiter förekomma, de senare magnetitrika, vidare kalkrika omvandlingstyper innehållande bytownit, epidot, kalcit och hornblände.

Bjurforsfältet. Bjurfors östra malm. Av Malånäsområdets malmer är Bjurfors östra malm den, om vilken man har den mest ingående kännedomen beträffande form och utsträckning. Malmens utgående i dagen är i det närmaste fullkomligt blottad genom omfattande jordavrymningar, på 30 m:s nivå under bergytan har malmen undersökts genom orter, och dessa båda nivåer kompletteras ytterligare genom ett flertal borrhål. Pl. 35—36 ge en överblick över de väsentligaste resultaten av dessa undersökningsarbeten. Malmens huvudaxel ligger i stort sett horisontellt, men företer i detalj vissa undulationer. I östliga delen stupar den sålunda mot VSV, i mellersta delen står den mot OSO, varefter den i västligaste delen åter förefaller att återtaga den västsydvästliga stupningen, dock utan att malmen besitter någon längre utsträckning efter denna riktning. Förkastningar av större betydelse saknas, men däremot finner man flerstädes en intensiv sprickbildning, vilket ger sig tillkänna genom rikligt uppträdande kvartsgångar, vilka äro i hög grad anrikade i malmens liggvägg.

Till största delen är själva malmkroppen en relativt kompakt svavelkismalm med tämligen oregelbunden kopparhalt. Vissa partier, särskilt inom östligaste delarna, äro magnetkisrikare, och lokalt kan magnetkis t. o. m. dominera över svavelkis. Den kända malmkroppen uppskattas till 250 000 ton med 31 % S

och 2.4 % Cu. Då emellertid häri är inberäknat c:a 10 % ofyndigt berg, blir värdet för den egentliga malmen 34.5 % S och 2.7 % Cu. Inom smärre delar av malmen kunna kopparhalterna nå upp till 8—10 % Cu, men stora sammanhängande delar med sådana halter förekomma icke. Inom östra delen kan man räkna med ett sammanhängande parti på c:a 50 000 ton med i medeltal 4 % Cu. Andra element av ekonomisk betydelse förekomma icke. Av intresse är, att inom denna fyndighet äro även arsenikhalterna ytterligt låga — genomsnittshalten på den i dagen utgående malmarean är endast 0.07 %.

Utom de utan jämförelse kvantitativt dominerade malmmineralen svavelkis, magnetkis och zinkblände kan man även makroskopiskt understundom iakttaga zinkblände. Detta uppträder företrädesvis i kopparfattiga delar och har även här en tendens att anrikas i cm-breda ränder. Magnetit är vidare tämligen allmän även i de kompakta malmdelarna. Vid mikroskopisk undersökning finner man i kopparkisen ofta valleriit samt i några fall cubanit. Arsenikkis är iakttagen i ytterligt obetydliga korn i enstaka fall i den samlade malmen, men uppträder i rikligare mängd i en karbonat-kopparkisförande gång, i vilken gång även gudmundit är iakttagen. Blyglans i obetydliga kvantiteter förekommer tillsammans med zinkblände. Magnetkisen är i en del fall supergent omvandlad i »sekundär» pyrit och markasit. Av oxider uppträda utom magnetit ävenledes ilmenit och rutil. Gångartmineralen utgöras av kvarts, kalcit, klorit, sericit, plagioklas och, i mindre mängd, epidot och hornblände. De renare svavelkisdelarna äro i allmänhet starkt kvartsiga, de kopparrikare malmtyperna däremot vanligen starkt kalkiga. Understundom kan kalciten anrikas så att övergångstyper till kopparkisförande karbonatgångar uppstå.

Den kompakta malmen innehåller ofta inneslutna, vanligen rundade partier av sidostenen. I enstaka fall förekomma verkliga malmbreccior. Gränserna mellan inneslutningarna och malmen äro fullkomligt skarpa och täckta med en tunn klorithinna. Samma karaktär har f. ö. även gränsen mellan kompakt malm och sidosten vinkelrätt mot strykningsriktningen. Övergången från malm till malmfritt gråberg i strykningsriktningen förmedlas däremot ofta genom en successiv övergång via impregnationer. I en del fall finner man, hur inneslutningar så att säga lösas upp av malmlösningarna, varvid bildas en ofta mycket utpräglad kloritstrimmighet i malmen. Den strimmiga och bandade strukturen torde i många fall ha intensifierats av, och är möjligen ibland orsakad av differentialrörelser i den ännu ej fullt stelnade sulfidmassan. Å andra sidan finner man även övergångar från kloritstrimmig malm till bandade malmtyper, där bankar av malmfri kvartsit och svavelkismalm växellagra.

Sidostenen utgöres av omvandlade kvartsporfyriska lavor och tuffer, samt i mindre omfattning av albit-kloritgrönstenar. Omvandlingen leder till utbildning av klorit- och sericitkvartsiter, understundom till kloritskiffer och hornbländeskarn. Rena sericitkvartsiter spela en relativt obetydlig roll, men något sericit ingår i allmänhet även i de som kloritkvartsit betecknande bergarterna. De rena kloritskiffrarna uppträda i allmänhet omedelbart intill malmkropparna eller i deras utkilande i strykningsriktningen. I liggväggen äro kloritkvartsiterna ofta oregelbundet, »vresigt» sliriga och äro intensivt genomådrade av

kvartssliror. Strukturen kan i sin mest utpräglade form påminna om ådergnejsstruktur. Den normala formen av kloritkvartsit är eljest en tämligen utpräglat skiffrig typ, i vilken kvartsögon ofta äro bibehållna, i de fall då primärbergarten haft kvartsporfyrisk struktur. Understundom blir skiffrigheten mindre framträdande och man finner en utbildningstyp, som har i stort sett tämligen massformig struktur. I en del fall ha tydligen de massformiga kloritkvartsiterna bildats genom omvandling av albit-kloritgrönsten. Omvandlingen ger i första hand upphov till en mycket karakteristisk magnetitprickighet. Förutom ovannämnda mineral förekommer ofta något biotit i kloritkvartsiterna. Kloritskiffrarna, d. v. s. de bergarter, i vilka klorit vida dominerar, äro ofta fältspatiserade och innehålla rikliga, klara plagioklastavlor. I obetydliga mängder förekomma vidare epidot, titanit, ilmenit, zirkon samt i kloritskiffer även ortit.

Av en viss betydelse äro de rikligt uppträdande kvarts- och karbonatgångarna. Vanligast äro rena kvartsgångar. Någon gång finner man sulfider i dessa eller i nära förband till dem. Anmärkningsvärt är, att i samband med dylika gångar därvid gärna uppträda zinkblände och blyglans, vilka eljest äro mycket sällsynta inom denna malm. Vidare förekomma karbonatförande kvartsgångar, och understundom ha dessa reagerat med sidostenen under intensiv hornbländeskarnbildning. Inom västra delen av malmens utgående förekommer en karbonatgång med riklig kopparkis. I denna gång ha även arsenik och antimon anrikats, vilket framgår av förekomsten av arsenikkis och gudmundit. Inom östra delen av malmens utgående förekommer exakt samma kalk-kopparmalm såsom en speciell utbildningsform av den extremt kopparrika malmbanken härstädes, men utan någon som helst gångkaraktär. Dessa förhållanden bevisa det ytterligt intima förbandet mellan de mer samlade malmerna och gångarna. Karbonat- och kvartsgångar torde vara att betrakta som en sista utsöndring av malmlösningarna, en sorts malmpegmatiter.

Bjurfors mellersta malm är undersökt endast genom borrhål, genom vilka påvisats fyra bankar av svavelkismalm med lokalt höga, men vanligen relativt låga zinkhalter (Pl. 37). De båda sydligaste malmskivorna äro relativt zinkfattiga eller zinkfria och äro ofta uppblandade med relativt riklig sericitkvartsit. Inom vissa delar av malmen, speciellt inom dess djupare delar, uppträder magnetkis rikligt och kan t. o. m. helt dominera över svavelkisen. Inom de mer samlade malmdelarna, ha svavelhalterna befunnits variera huvudsakligen mellan 35 och 40 % S. Zinkhalterna kunna inom vissa partier belöpa sig till 10 % Zn och däröver, men medelhalten för de två nordligaste malmkropparna torde vara omkring 5 % Zn, vartill kommer en blyhalt av 0.5 %. Guldhalterna äro låga, 1—2 gr/t kunna dock förekomma. Silverhalterna äro i regel 20—30 gr/t. Arsenikhalten är betydligt högre än vid Bjurfors östra malm, en genomsnittsanalys på en sektion tvärs genom malmen ger 0.28 % As.

De dominerande malmmineralen äro svavelkis, magnetkis och zinkblände. De zinkrikare malmtyperna äro i regel vackert bandade med en växellagring mellan zinkbländerika och svavelkisrika band. Tillsammans med zinkblände förekommer något blyglans samt antimonmineral. Kopparkis förekommer

tämligen allmänt men alltid i synnerligen små kvantiteter. Arsenikkis är tämligen allmänt spridd i zinkblände-magnetkismassan men uppträder här alltid i synnerligen finfördelad form. Av antimonmineral ha i malmmikroskopet följande iakttagits: Fahlerz, bournonit, boulangerit, gudmundit. I samband med bly- och antimonmineralen ha vidare gedigen vismut och elektrum observerats i obetydliga kvantiteter. Magnetit förefaller att saknas i de kompakta malmerna, däremot är rutil påträffad i zinkrika impregnationer. Av gångartmineral dominera kvarts och kalcit. Sericit och klorit äro vidare allmänt spridda, och mer sporadiskt äro plagioklas och hornblände iakttagna.

Omvandlingarna av sidostenen och de därvid bildade bergartstyperna äro av exakt samma karaktär som vid Bjurfors östra malm. Rena sericitkvartsiter äro dock vid Bjurfors mellersta malm betydligt allmännare. Ofta förekomma i sericitkvartsiterna kalcitrika sliror, inom vilka även uppträder anortitrik plagioklas. I dessa sliror ersättes sericiten av blekbrun biotit. En annan olikhet mot förhållandena vid Bjurfors östra malm är vidare, att grönstenar här spela en betydligt större roll, och att även amfibolitiska typer äro tämligen allmänna.

Bjurfors västra malm, det västligaste mineraliseringsområdet inom Bjurforsgruppen, består av en upp till 4 m mäktig malmzon av tämligen rikliga svavelkis- och magnetkisimpregnationer, inom vilka upp till halvmeterbreda kompakta bankar kunna förekomma. Svavelhalterna ligga i allmänhet under 30 % S. Zinkblände och kopparkis förekomma men aldrig i sådana kvantiteter att de kunna tillmätas ekonomiskt värde. Vid mikroskopisk undersökning äro även arsenikkis, blyglans och ilmenit iakttagna.

Norrliden, som undersökts endast genom övertvärande gropar, utgöres huvudsakligen av en pyritbreccia i sericitkvartsit. I västra delen av malmen uppträder magnetkis i rikligare mängd, och tillsammans med denna förekomma litet zinkblände, blyglans och boulangerit. Inom större delen av malmen saknas emellertid koppar, zink och bly så gott som fullständigt. Sericitkvartsitbildningen förefaller, att i detta fall ha drabbat även de grönstenar, vilka i oomvandlat skick återfinnas på malmens hängväggsida.

Österbäcken. Trenne borrhål på indikationerna vid Österbäcken ha uppvisat förekomsten av komplexa impregnationer av arsenikkis, pyrit, magnetkis, zinkblände, blyglans och antimonmineral. Av ett visst intresse är att svavelkisen under mikroskopet visar sig vara tydligt anisotrop, en omständighet, som kan innebära att själva mineralet är arsenikhaltigt. Inom impregnationszonen förekomma 2—3 dm mäktiga bankar av mer samlad, tät arsenikkis. En dylik bank har befunnits hålla 14.2 % As, 7.1 % Zn, 250 gr/t Ag och 6 gr/t Au. Av antimonmineralen är boulangerit här det vanligaste och även gudmundit förekommer relativt rikligt. I de antimonrika parageneserna äro även gedigen vismut samt litet kopparkis iakttagna. Mineraliseringen uppträder i sericitkvartsit och i omedelbar närhet till bankar av grafitfyllit.

Ö. Högkulla. Undersökningsarbetena vid denna malm ha varit av sådan omfattning, att malmens form och karaktär äro tämligen väl kända till ett djup av c:a 130 m. Malmens utgående i dagen är sålunda tämligen fullständigt blottat genom jordavrymning; på 30 meters nivå under bergytan är malmen undersökt genom ett ortsystem, varefter borrhål mot c:a 70 och 130 meters djup kompletterat kännedomen om malmens fortsättning mot djupet. Av resultaten framgår, att malmen utgöres av två separata malmkroppar, varav den nordligaste står tämligen brant och snabbt kilar ut mot djupet. Den sydliga bildar däremot en synnerligen markerad »linjal», stupande mycket regelbundet 45° mot S (se fig. 20). Mineraliseringen, som vid huvudmalmen har en ost—västlig strykning svänger öster om huvudmalmen och antar en strykning mer i NO—SV. I denna riktning förekomma smärre klumpar av kloritisk svavelkismalm med låg zinkhalt.

Huvudmalmen är en kompakt svavelkis-magnetkis-zinkbländemalm med en viss blyhalt. Zinkhalterna inom malmens övre delar variera i allmänhet mellan 15 % och 30 % Zn, och medelhalterna ligga mellan 20 % och 25 % Zn. Inom samma delar förekomma c:a 1 % Pb, 150—200 gr/t Ag och c:a 0.5 gr/t Au. Mot djupet avtaga zinkhalterna, och i de djupare delarna förekommer dels en svavelkisbandad del med omkring 16 % Zn och 1 % Pb samt en zinkfattig magnetkisdel med c:a 5 % Zn och 0.1 % Pb.

I de centrala delarna består malmen i jordavrymningen huvudsakligen av svavelkis och zinkblände, under det att i randpartierna svavelkisen nästan helt försvinner och ersättes av magnetkis. Malmen är utomordentligt vackert och regelbundet bandad, i det att svavelkis- eller magnetkisband växellagra med zinkbländeband. Banden variera i allmänhet mellan 0.5 och 1 cm i mäktighet. Bandningen följer konformt gränserna mot sidostenen eller inneslutna partier av densamma.

Utom ovannämnda mineral kan man makroskopiskt ytterligare iakttaga blyglans, och tillsammans med denna uppträda antimonmineral. Ehuru blyglansen och antimonmineralen här liksom vid Bjurliden äro anrikade i små slirror, äro dock dessa mineral i stort synnerligen jämnt fördelade inom malmkroppen. Arsenikkis förekommer likaledes tämligen jämnt fördelad i form av små kristaller här och var i den övriga sulfidmassan. På 30-metersnivån förekommer emellertid arsenikkis även såsom kompakt, tät arsenikkismalm, bildande små kantiga fragment i den zinkrika kompaktmalmen. Strukturen påminner i hög grad om vissa brecciestrukturer från Boliden (Ödman, *87*, sid. 143).

Den mikroskopiska undersökningen visar, att de blyrika slirorna bestå av ett stort antal olika mineral i ytterligt intim sammanväxning, och texturerna påminna i hög grad om de som iakttagits, i motsvarande parageneser i Bjurliden. Sålunda förekomma fahlerz, bournonit, jamesonit, boulangerit, gudmundit, pyrargyrit, ged. vismut och i ett par enstaka fall elektrum i dessa parageneser. Kopparkis är likaledes iakttagen i de flesta av de undersökta proven, ehuru alltid i synnerligen små kvantiteter, och i kopparkisen ha i två fall valleriit observerats. Av visst intresse är, att i ett par prov har påträffats tennkis i

samband med de blyrika slirorna. Detta visar sålunda, att även tenn finnes med i de mineraliserande lösningarna.

Magnetit saknas i regel i de kompakta malmtyperna. Ilmenit förekommer i enstaka fall, men är vanligare i sidostenen, där den uppträder tillsammans med hämatit och rutil. Av gångartmineral dominera kvarts och kalcit fullkomligt, i mindre mängd förekomma sericit och klorit.

Malmerna ligga huvudsakligen i en finkornig kvartsporfyr. Inom malmområdets västra del förekommer en tät, flintig kvartsporfyrtuff. Omvandlingarna av sidostenen äro vid Ö. Högkulla av betydligt mindre omfattning än vid de tidigare beskrivna fyndigheterna. I många fall är förändringen av moderbergarten även omedelbart intill malmgränsen endast markerad genom en viss ökning av klorit- och sericithalten. På liggväggsidan förekomma emellertid alldeles in mot den södra malmlinsen verkliga kloritkvartsiter och kloritskiffrar med stora fläckar av granat, kalcit och magnetit. I dylika typer har lokalt iakttagits plagioklas samt i ett fall även kloritoid. I en kloritskiffertyp förekomma epidot, titanit och ortit, en association, som mycket påminner om motsvarande typ vid Bjurfors östra malm.

Gränserna mellan den kompakta malmen och den i regel tämligen massformiga sidostenen är vanligen fullkomligt skarp. Sammalunda är förhållandet beträffande begränsningen för inneslutna fragment av sidostenen. I en del fall sänder den kompakta malmen in ådror i sidostenen, och understundom kan man iakttaga, hur dylika ådror skära varandra och sålunda avsnöra kantiga brottstycken. Vid de kompakta malmernas utkilande i strykningsriktningen bildas mera impregnationsartade partier. Dock göra även sådana områden snarare intryck av att vara breccior än impregnationer i vanlig bemärkelse, i det att berggrunden här genomdrages av ett ådernät av tämligen sammanhängande kisådror. I allmänhet äro dessa avsnitt synnerligen zinkfattiga. Kvartsporfyren är emellertid i dessa fall överförd i mycket sericitrik sericitkvartsit eller understundom t. o. m. i sericitskiffer.

Även vid Ö. Högkulla förkomma rikligt med kvartsgångar, vilka förefalla att stå i mycket nära förband till malmbildningen. I några fall äro dessa kvartsgångar f. ö. zinkbländeförande. Karbonatförande gångar saknas, men i ett fall är en flusspatrik kvartsgång iakttagen.

Skäggträskberget. På Skäggträskberget är genom äldre undersökningar en arsenikkisförande kvartsgång känd, vilken enligt äldre uppgifter skulle föra arsenikkis med betydande guldhalter. Generalprov på hela den blottade delen av gången visade emellertid endast spår av guld.

Av större intresse är ett mineraliseringsområde 300 m norr om nämnda kvartsgång. Detta har undersökts genom gropar och ett flertal flacka borrhål. Utom ekonomiskt betydelselösa impregnationer förekomma inom området åtminstone tre mer samlade malmkroppar. De äro av tämligen blygsamma proportioner — den största torde väl på sin höjd vara 100—150 m² — men ha likväl malmgeologiskt intresse. Malmen är ofta synnerligen komplex — svavelkis, magnetkis, arsenikkis, kopparkis, zinkblände kunna alla samtidigt förekomma

i tämligen riklig mängd, vartill komma smärre mängder av blyglans och jamesonit. I stora drag kan man dock se en tydlig tendens till uppdelning i kopparmalm och zink-blymalm. I den senare anrikas gärna arsenikkis, vilken då uppträder i form av finkorniga, täta sliror. Utom de komplexa malmtyperna förekommer även relativt ren svavelkismalm utan några som helst andra sulfider men relativt starkt uppblandad med sericit och kvarts.

Omvandlingarna äro tämligen omfattande, åtminstone om man tager i betraktande malmkropparnas små dimensioner. Huvudsakligen bildas kloritsericitkvartsiter och sericitkvartsiter. Intill malmerna förekommer ibland ren biotitskiffer. Slutligen förekomma även enstaka bankar av hornbländeskarn.

Sulfidfattiga mineraliseringsområden. Flerstädes inom karteringsområdet finner man omvandlingsområden, där primärbergarterna överförts i sericit- eller kloritkvartsiter, men där sulfidmaterialet är jämnt fördelat i den omvandlade bergarten i form av impregnationer. Fastän sulfidhalterna i dessa impregnationer äro låga, kan området som helhet innehålla betydliga sulfidmängder, om nämligen området i fråga har stor areell utbredning. Det intressantaste mineraliseringsområdet av denna typ ligger ungefär 500 meter N om Bjurträskmalmen och löper parallellt med den utpräglade förskiffringszon, som delar det östliga väl blottade området i två delar med olika tektonisk stil. Omvandlingsstråket är blottat i hällar och gropar och kan mellan dessa följas i form av i det närmaste kontinuerliga indikationer på en sträcka av åtminstone ett par kilometer. Den mineraliserade bergarten är huvudsakligen kvartsporfyr, vilken överförts i sericitkvartsit och klorit-sericitkvartsit, ofta småskrynklad och kvartsslirig. Sulfiden utgöres till vida övervägande delen av svavelkis. Mindre sammanhängande mineraliseringsstråk förekomma även inom områdets nordliga och nordvästliga delar, varvid omvandlingsbergarterna dock i dessa fall utgöras av tämligen rena sericitkvartsiter.

Av ett visst intresse är en mineralisering av helt annan karaktär, som förekommer på Önusberget, omedelbart öster om Önusträsket. Här uppträda kvartsgångar, 2—3 dm breda, förande arsenikkis och kopparkis och med en guldhalt, som inom sulfidrikare partier av gången är bestämd till 7 gr/t Au. Något zinkblände förekommer vidare, och i många fall är kopparkisen genomdragen av covellinådror.

Sammanfattande översikt över omvandlingarna i sidostenen i samband med malmbildningen. De bästa utgångspunkterna för en utredning av omvandlingarnas natur erhållas från Bjurlidens och Bjurträskgruvans omgivningar. I båda fallen finner man närmast malmkropparna bergarter uppbyggda av mineral, vilka innebära en anrikning av elementen järn, magnesium eller aluminium i förhållande till de oomvandlade bergarterna. Utanför denna zon finner man en övergångszon till den opåverkade berggrunden, karakteriserad av delvis samma mineral som i den inre zonen, men intensivt uppblandad med bergarter, vilka äro extremt anrikade på kalkrika mineral. Betraktar man

emellertid varje zon som helhet, finner man, att den karakteristiska avvikelsen i kemiskt hänseende från opåverkade bergarter ej är anrikningen av vissa bestämda element utan i stället de stora variationer i kemisk sammansättning, som olika bergartstyper uppvisa inom de olika zonerna.

I kristallisationsföljden de olika omvandlingsmineralen sinsemellan har man vidare en möjlighet att fastställa, i vad mån bildningen av nya mineral innebär en successiv anrikning av ett eller flera bestämda element under mineraliseringsförloppet. De funna resultaten tala här tydligt emot en sådan successiv, regelbunden anrikning. Ej heller de mineral, vilka på grund av de mikroskopiska iakttagelserna kunna antagas vara fixerade i mycket nära förband till sulfidmineralen själva, antyda en anrikning av vissa speciella element i samband med sulfidernas kristallisation.

Av ovan antydda förhållanden synes framgå, att de omvandlingar, som ha förekommit i samband med sulfidmalmsbildningen, äro i första hand förorsakade av omflyttningar i den äldre berggrunden själv, under det att en verklig tillförsel av främmande element förutom dem, som ingå i sulfidmineralen, ej behöver tillmätas så stor betydelse.

Sulfidmalmsbildningens förhållande till regionalmetamorfos och graniter. Om i första hand de fyra huvudmalmerna inom området tagas i betraktande, vilka äro tämligen väl kända, och vilka äro av i stort sett samma storleksordning, kunna vissa allmänna olikheter fastställas beträffande omvandlingarnas omfattning och karaktär. Berggrunden omkring Bjurträsk- och Bjurlidenmalmerna visar sålunda spår efter den intensivaste omvandlingen och innehåller de mest utpräglade högtemperaturparageneserna. Vid Ö. Högkulla äro omvandlingarna minst omfattande, under det att Bjurfors östra malm intar en mellanställning. En motsvarande skillnad mellan de olika lokalerna förete gångartmineralens parageneser. Vid Bjurliden och Bjurträskmalmen dominerar högtemperaturfacies, vid Ö. Högkulla förekommer endast lågtemperaturfacies, under det att vid Bjurfors östra malm en blandning av båda förekomma. Olikheterna såväl beträffande omvandlingarnas omfattning och paragenetiska karaktär som med avseende på gångartmineralens paragenser ha en viss motsvarighet i de olika malmernas läge inom olika starkt regionalmetamorfoserade terränger. Bjurliden och Bjurträskmalmen ligga nämligen i det mest högmetamorfa området, Ö. Högkulla inom det mest lågmetamorfa området, under det att Bjurfors östra malm även i detta fall intar en mellanställning. Denna parallellism mellan regionalmetamorfos och sulfidmineraliseringens karaktär har av förf. tolkats så, att de skillnader, som betingat olikheterna med avseende på regionalmetamorfosen, åtminstone i visst avseende existerat även vid tidpunkten för sulfidmalmernas bildning.

Tages sulfidmineraliseringen som helhet i betraktande, visar även förhållandet mellan färglös glimmer och kalkmineral ett påtagligt olikartat uppträdande inom olika metamorfoszoner. Inom kloritzonen samt inom delar av klorit-biotit-sericitzonen är sulfidinvasionen sålunda ofta åtföljd av en samtidig utbildning av sericit och kalcit, inom biotitzonen förekomma kalcit och sericit

nästan aldrig tillsammans. I de kalcitförande proven utgöras ingående glimmermineral nästan alltid av blekbrun biotit.

För frågan om malmernas magmatiska ursprung är sambandet mellan malmbildning och regionalmetamorfos av fundamental betydelse. Vid diskussionen av de regionalmetamorfa processerna har redan framhållits, att det icke kan fastställas något förband mellan regionalmetamorfos och den äldre graniten, medan man däremot kunde konstatera en viss samhörighet mellan den yngre graniten, Revsundsgraniten, och regionalmetamorfosen. Då förutom ovan anförda samband mellan regionalmetamorfos och sulfidmalmsbildning den sulfidmalmerna åtföljande mineralbildningen visat sig vara senare än regionalmetamorfosen, föreligga påtagliga grunder för det antagandet, att sulfidmalmerna härstamma från samma magmatiska ursprung som skapat Revsundsgraniterna.

Sulfidmalmsbildning och tektonik. Inom Skelleftefältet synas de tektoniska förutsättningarna vara av utslagsgivande betydelse för malmernas framträngande och fixering, under det att bergarternas kemiska egenskaper spela en betydligt mindre roll. I tidigare publikationer, vilka behandla malmbildningen inom Skelleftefältet, har ofta framhållits, att de samlade malmkropparna gärna förekomma tämligen nära fyllithorisonter, och att malmbildningen således företer en viss grad av horisontbeständighet. Detta torde i första hand ha sin grund i de stora olikheterna i plasticitetshänseende mellan fylliter och vulkaniter, vilka bidraga att vid tektoniseringen skapa brottlinjer i fylliternas närhet, av vilka malmlösningarna kunna begagna sig. Sålunda ligga t. ex. Ö. Högkulla-malmen och Skäggträskberget båda på en ost—västlig linje, sannolikt bildad vid spänningar uppkomna i samband med den stora omböjningen vid Skäggträskberget.

Det malmmaterial, som tillföres fylliterna själva, ger däremot i allmänhet ej upphov till samlade malmkroppar utan blandas tämligen jämnt ut i fyllitmassan och bildar impregnationer. Över huvud taget synas förutsättningarna för utbildningen av samlade malmkroppar vara relativt små inom högplastiska bergarter.

Ett exempel på hur olika tektonisk stil kan inverka på sulfidmineraliseringens karaktär utgör området omkring och norr om Bjurträskmalmen. Närmast omkring Bjurträskmalmen förekomma huvudsakligen stängliga bergarter, och denna stänglighet har åstadkommits genom de veckningar, vilka på kartan framträda såsom kraftiga omböjningar av lagren. Själva kartbilden antyder, att en dylik tektonisk utbildning måste vara ägnad att »luckra upp» berggrunden och skapa öppningar, av vilka malmlösningarna kunna begagna sig. Inom den nordligare zonen däremot, där planskiffrighet är det dominerande strukturdraget, uppträda sulfiderna endast som impregnationer, men dessa bilda i stället synnerligen uthålliga och långsträckta stråk.

Malmdifferentiation och elementfördelning. Följande huvudmalmtyper kunna särskiljas inom området: Svavelkismalm, magnetkismalm, zink-

malm (komplexmalm med zinkblände och mer eller mindre svavelkis och magnetkis), kopparmalm (kopparkis med mer eller mindre svavelkis eller magnetkis) samt arsenikkismalm. Mellan dessa olika malmtyper existera givetvis övergångar, men redan vid karteringen får man ett starkt intryck av, att mellan vissa av typerna äro övergångarna successiva och övergångsleden kvantitativt rikligt representerade, under det att mellan andra typer övergångsled äro ytterligt sällsynta. Sålunda förefaller det att existera successiva övergångar mellan ren magnetkis- och ren svavelkismalm samt mellan koppar- eller zinkrika malmtyper och rena svavelkis- eller magnetkismalmer. Övergångstyper mellan kopparkisrika malmtyper och zinkbländerika malmtyper äro däremot betydligt sällsyntare, liksom även övergångstyper mellan tät arsenikkismalm och övriga malmtyper. En statistisk undersökning av tillgängligt analysmaterial bestyrker till fullo detta redan i fält funna förband mellan de olika malmtyperna.

I ovan förda diskussion ha endast elementen järn, koppar, zink, arsenik beaktats. Av övriga i malmerna ingående element visar sig bly vara nära anknutet till zinkmalmerna, och samtidigt med bly anrikas även antimon, vismut och silver. Guld synes vara starkast anrikat i arsenikkismalmerna. Vad beträffar Malånäsfältet gäller vidare, att när arsenikkis bildar självständiga malmklumpar, uppträda dessa alltid tillsammans med zinkmalm, även i sådana fall då kopparmalm även finnes tillstädes.

Den mikroskopiska undersökningen av malmerna visar, att kristallisationsföljden de olika sulfidmineralen sinsemellan, skulle väl kunna förklara övergångarna från ren svavelkis- eller magnetkismalm till kopparkis- eller zinkbländerika malmer. Man finner nämligen alltid följande succession: Svavelkis → magnetkis + zinkblände → kopparkis → blyglans. Genom en kristallisation i denna ordning är det emellertid omöjligt att förklara det intima förbandet mellan zinkblände och blyglans. Då sålunda denna association måste ha förorsakats av andra faktorer än dem, som reglera kristallisationen, ligger det nära till hands att antaga, att zink-koppardifferentiationen även skulle ha orsakats av andra faktorer än kristallisationsföljden, och att den troligen hade utbildats, innan den egentliga kristallisationen började. På grund av arsenikkismalmens självständiga uppträdande förefaller det sannolikt, att även denna är bildad genom en differentiation jämförbar med koppar-zinkdifferentiationen.

En anrikning av vissa element i vissa elementgrupper kan således fastställas, vilken uppdelning med stor sannolikhet inträffade i malmlösningarna, redan innan kristallisationen av malmmineralen började. Av dessa grupper karakteriseras en genom anrikning av koppar tillsammans med järn och svavel, en andra genom en anrikning av elementen zink, bly, antimon, silver, vismut tillsammans med järn och svavel och en tredje genom anrikning av arsenik och guld tillsammans med järn och svavel. I den malmgeologiska litteraturen ha sulfidernas transportmöjligheter ingående diskuterats, och man har sökt att i faktorer av skilda slag se förklaringar till sulfidmineralens uppträdande, differentiation och kristallisationsföljd. I de flesta fall finner man emellertid intet, som skulle kunna förklara en gruppindelning i enlighet med den ovan

beskrivna. Ett undantag utgör dock teorin om att metallerna skulle transporteras som dubbelsulfider med Na_2S. Allt efter dessa dubbelsulfiders förhållande till vatten kan man göra en gruppering av olika element, vilken visar stora överensstämmelser med den i naturen funna elementfördelningen. Förekomsten av dubbelsulfider ger alltså en m ö j l i g förklaring till differentiationen inom malmbildningens tidigare skede. Sedan kristallisationen börjat, kommer dock givetvis denna att i huvudsak reglera den fortsatta utvecklingen.

Tidigare har framhållits, att de fyra huvudmalmerna Bjurträskmalmen, Bjurliden, Bjurfors östra malm och Ö. Högkulla bilda en serie, i vilken i nämnd ordning de olika förekomsterna uppvisa fallande omvandlingsintensitet av den omgivande berggrunden, och där gångartmineralens parageneser tyda på högre bildningstemperaturer vid de förstnämnda lokalerna i förhållande till de senare. Med avseende på malmkropparnas förhållande till sin sidosten, kan man även fastställa en viss parallell skillnad de olika lokalerna sinsemellan. Vid Bjurträskmalmen och vid Bjurliden tyda strukturerna på att malmrummet skapats huvudsakligen genom förträngning av tidigare existerande silikatbergarter. Vid Ö. Högkulla har malmrummet till största delen tydligen bildats genom brecciering av sidostenen, efter sprickor, vilkas sidor skjutits isär, under det att verklig förträngning spelar en kvantitativt synnerligen underordnad roll. Vid Bjurfors östra malm förekomma strukturer, vilka visa att båda dessa fenomen med stor säkerhet förekommit sida vid sida. Vilkendera av dessa faktorer, som varit av dominerande betydelse, har ej kunnat avgöras med säkerhet.

En statistisk undersökning av det tillgängliga analysmaterialet från ovannämnda fyra malmförekomster antyder, att elementen äro betydligt jämnare fördelade inom malmer av breccietyp än inom malmer av förträngningstyp. Särskilt framträdande blir denna olikhet vid en jämförelse mellan Bjurliden och Ö. Högkulla, vilka såväl mineralogiskt som strukturellt äro varandra synnerligen lika, och här framträder den kanske tydligaste skillnaden i blyhalternas betydligt större oregelbundenhet inom Bjurliden i förhållande till Ö. Högkulla. Förutsättningarna för dessa olikheter torde vara desamma, som bidraga att förklara sambandet mellan sulfidmineralisering och regionalmetamorfos, nämligen att malmmineralen vid förträngningsmalmerna deponerats i en mer utpräglad högtemperaturmiljö än vid brecciemalmerna, varigenom den termiska verkan blir intensivare, och malmdifferentiationen kommer att överspänna längre tid.

Jämförelse med andra sulfidmalmsområden. Skelleftefältets övriga sulfidmalmsförekomster äro ännu i det stora hela tämligen ofullständigt kända, och det stöter därför på svårigheter att på nuvarande stadium giva en klar överblick över, hur föreliggande områdes fyndigheter förhålla sig i relation till fältet i dess helhet. Ehuru sericit- och kloritkvartsiter äro mycket vanliga, vill det emellertid synas, som om mineraliseringen här understundom leder till mer utpräglade högtemperaturparageneser, än vad som vanligen är fallet inom Skelleftefältet. Sålunda uppträda vid Bjurträskmalmen och Bjurliden

granat, andalusit, gahnit, staurolit och delvis även cordierit i en omfattning och utbildning, som eljest ej är vanlig inom fältet. Dessa parageneser förete i stället vissa likheter med Bergslagens kvartsitiska sulfidmalmer, varest nämnda mineral ofta spela en stor roll, och vissa av de vid nämnda förekomster anträffade typerna skulle väl kunna återfinnas i Bergslagen. Tages emellertid mineraliseringen som helhet, framträder en tydlig skillnad, i det att klorit och sericit även vid Bjurliden och Bjurträskgruvan spela en kvantitativt betydligt större roll, än vad vanligen är fallet inom Bergslagsmalmerna. Vidare förekomma inga verkliga motsvarigheter till Bergslagens skarnmalmer. Vid Bjurträskmalmen och vid Skäggträskbergets kisfyndighet uppträder likväl hornbländeskarn av liknande typ, som ofta förekommer inom Bergslagen.

De största överensstämmelserna beträffande mineraliseringens mineralogi och allmänna karaktär inom Fennoskandias urberg finner man eljest inom Finland och de ha redan tidigare påtalats av t. ex. Saksela i beskrivningen av Ottravara (68). Av sulfidmalmerna inom den kaledoniska fjällkedjan erbjuda de typer, vilka enligt Carstens terminologi (7) benämnas Rödhammar- och Flöttumtyperna, vissa analogier.

Från den ytterligt omfattande litteratur, som behandlar sulfidmalmer utanför Fennoskandia, skulle man kunna uppräkna ett synnerligen stort antal, vilka uppvisa stora likheter av ett eller annat slag med Malånäsfältets malmer. I detta sammanhang skall endast omnämnas de stora, och relativt nyupptäckta malmerna inom Quebec och Manitoba i Kanada. Dessa uppvisa ytterligt stora likheter, såväl beträffande malmmineralens som silikatmineralens mineralogi och även beträffande texturella och strukturella egenheter. Härtill kommer, att de äro belägna inom en bergartsmiljö, som i utomordentligt hög grad påminner om Skelleftefältets, och som tillhör en urbergsavdelning, vilken brukar parallelliseras med det äldsta svenska urberget.

Stockholm 1939. Kungl. Boktr. P. A. Norstedt & Söner 391136.

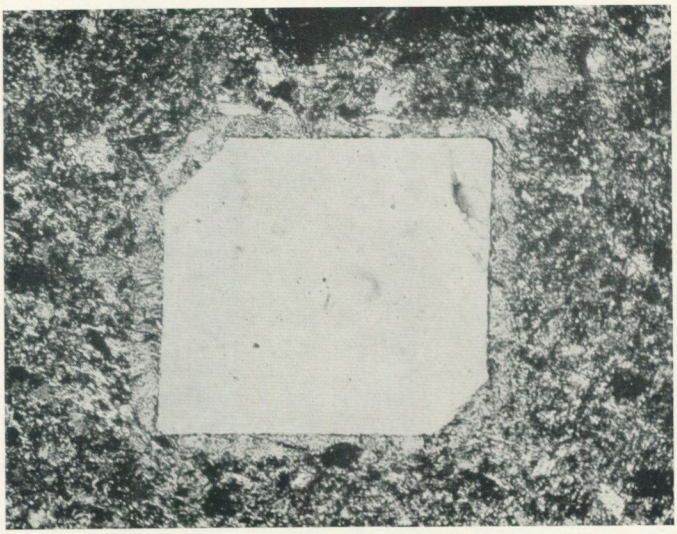


Fig. a. Idiomorphic quartz phenocryst surrounded by a marginal zone of granophyric plagioclase. Quartzporphyry 2 km WSW of Lake Maurträsket. Thin section. Nic+. × 100.

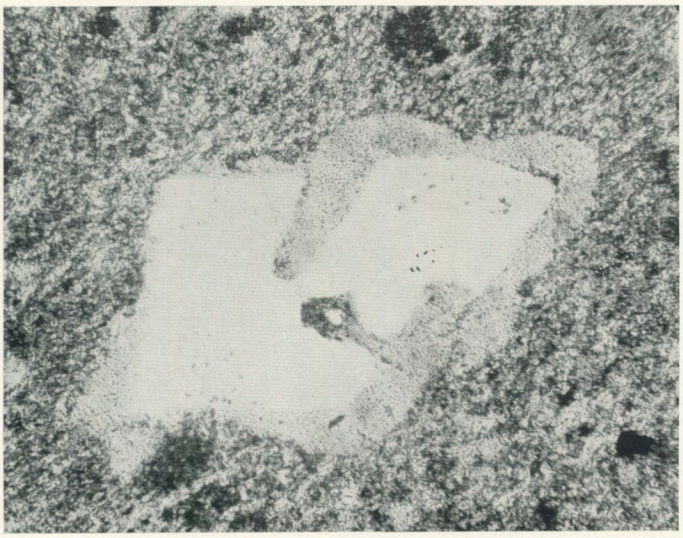


Fig. b. Corroded quartz phenocryst. Quartzporphyry 2 km WSW of Lake Maurträsket. Thin section. Nic.+. × 100.

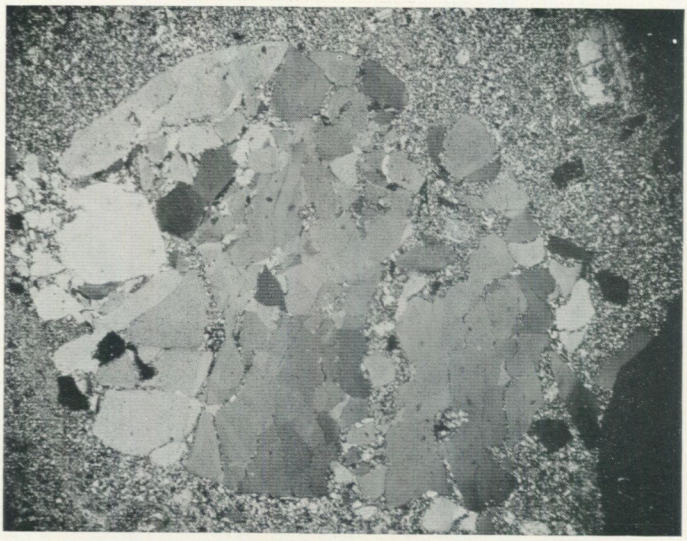


Fig. a. Granulated quartz phenocryst. Quartzporphyry 2 km NW of Ö. Högkulla. Thin section. Nic.+. × 14.

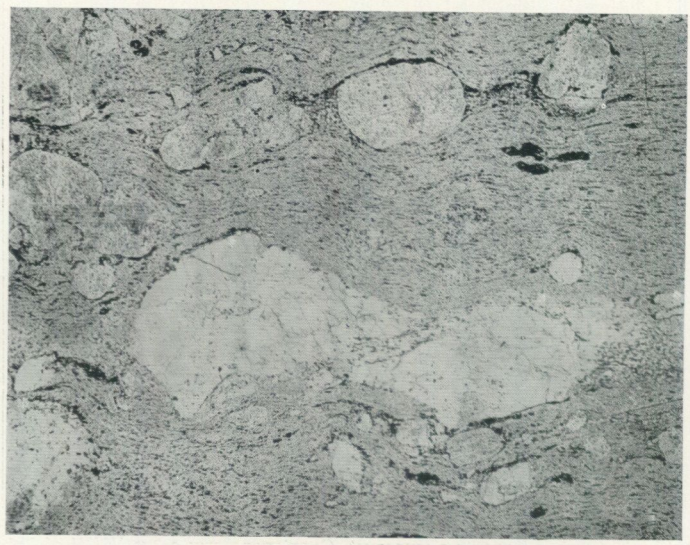


Fig. b. Sheared quartzporphyry. 300 m SE of the Bjurträsk ores. Thin section. Ord. light. × 9.

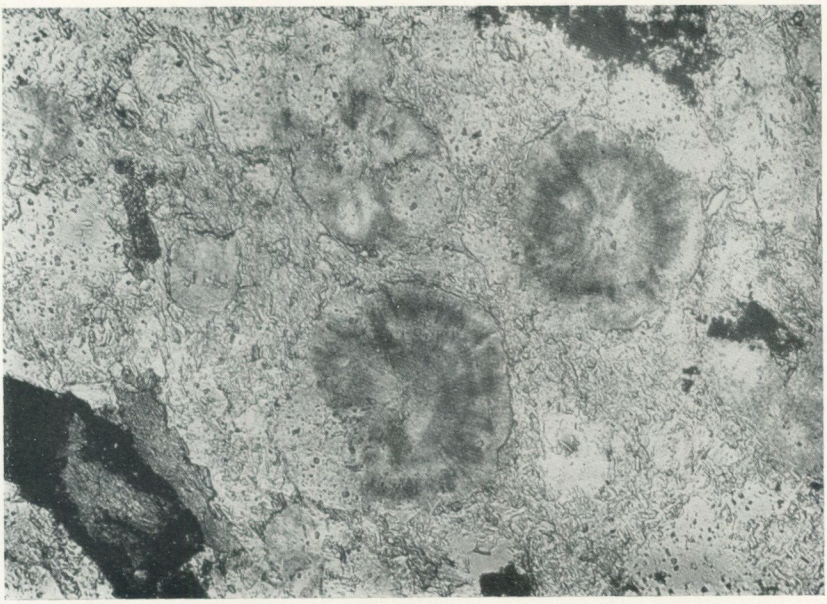


Fig. a. Quartzporphyry with spherolites containing a black powder, probably graphite, displaying a radial and concentric arrangement. 1,5 km SW of Lake Maurträsket. Thin section. Ord. light. × 40.

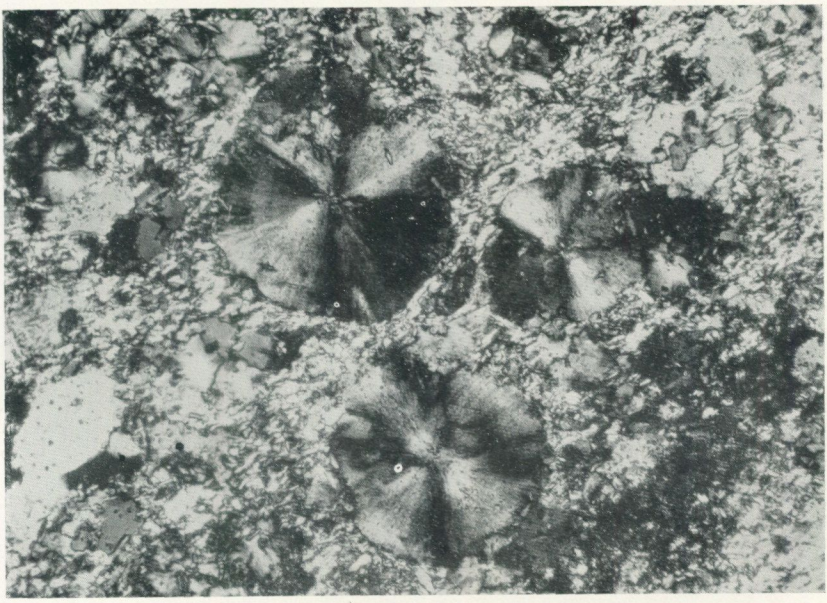


Fig. b. The same as Fig. a. Nic.+.



Fig. a. Quartzporphyry agglomerate NW of the Bjurträsk ores. (The scale is 16 cm).



Fig. b. Strongly sheared quartzporphyry agglomerate. 800 m N of the Bjurträsk ores. (The scale is 16 cm.)

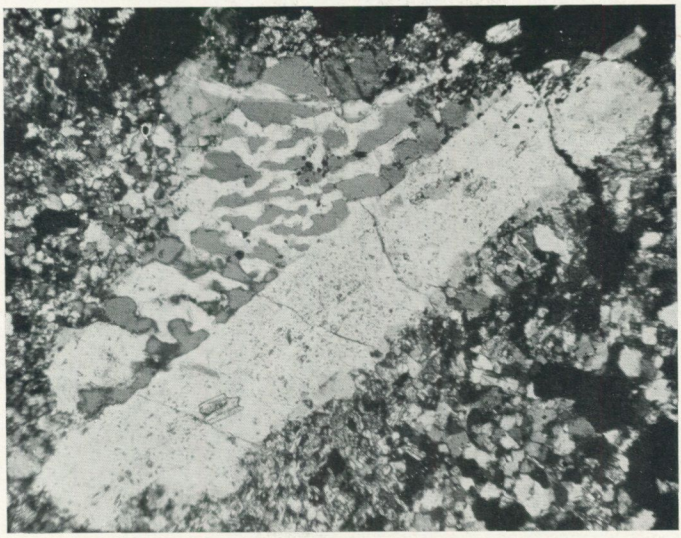


Fig. a. Plagioclase phenocryst, partly in myrmekitic intergrowth with quartz. Quartzporphyry from Skäggträskberget. Thin section. Nic.+ × 60.

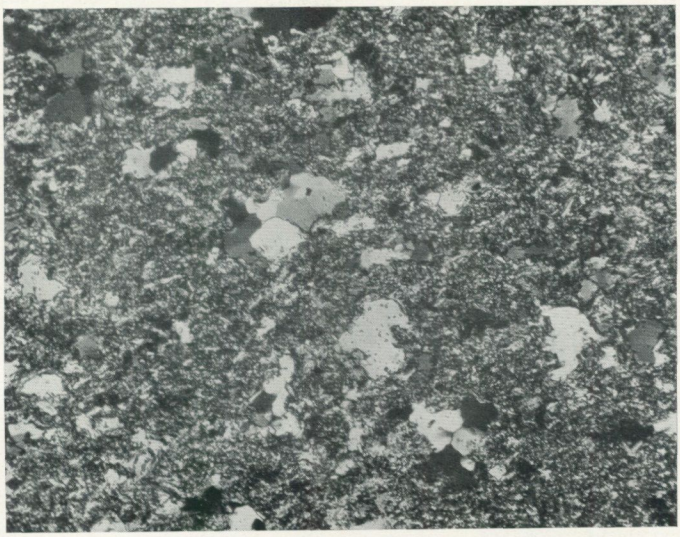


Fig. b. Fine-grained massive quartzporphyry tuff, with irregular-shaped, larger quartz grains. Ö. Högkulla. Thin section. Nic.+. × 60.

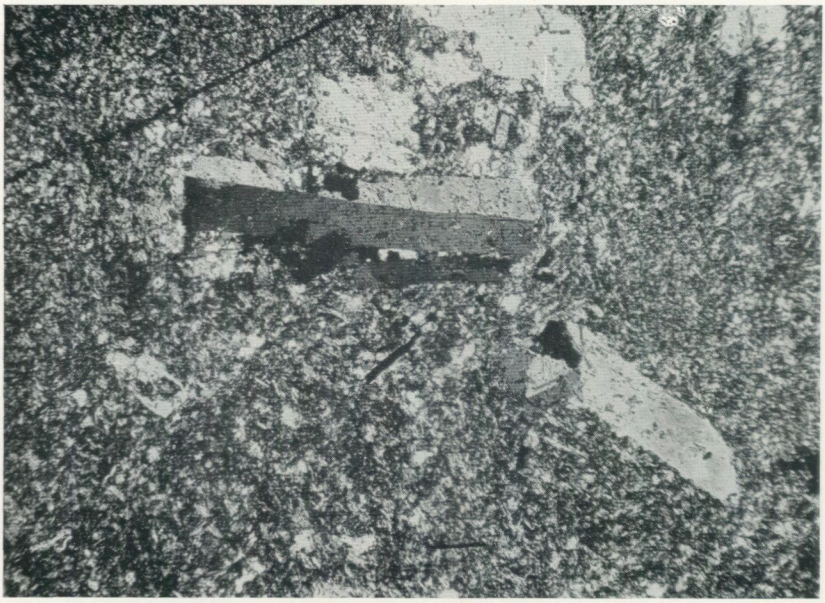


Fig. a. Keratophyre. Fragment in volcanic breccia from Skäggträskberget. Solitary albite phenocrysts in the keratophyric groundmass consisting chiefly of albite and chlorite. Thin section. Nic.+. × 40.

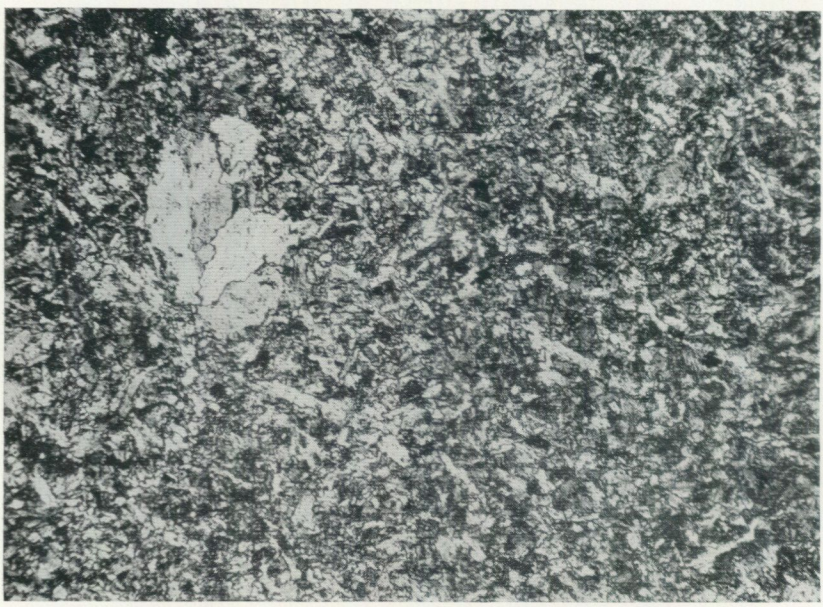


Fig. b. Quartzkeratophyre. 1.5 km NE of Ö. Högkulla. Albite phenocrysts in the keratophyric groundmass consisting chiefly of albite, chlorite, and probably some quartz. Thin section. Nic.+. × 40.

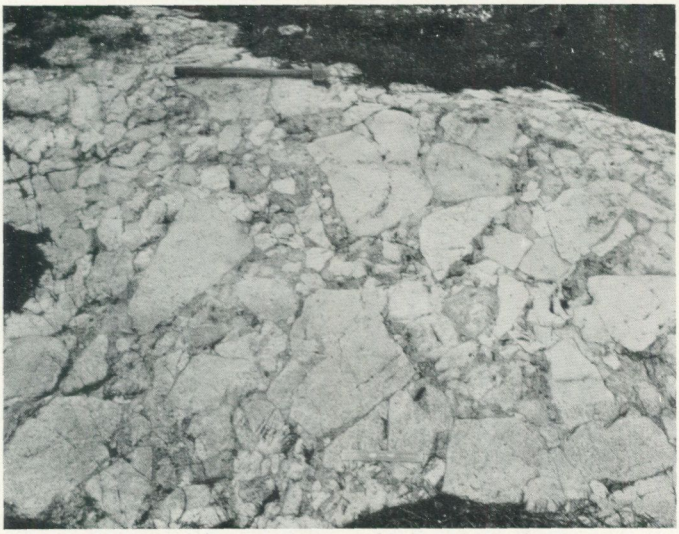


Fig. a. Volcanic breccia, 1 800 m SE of Lake Maurträsket. Large angular fragments of quartzporphyry and keratophyre in a groundmass rich in chlorite and calcite.

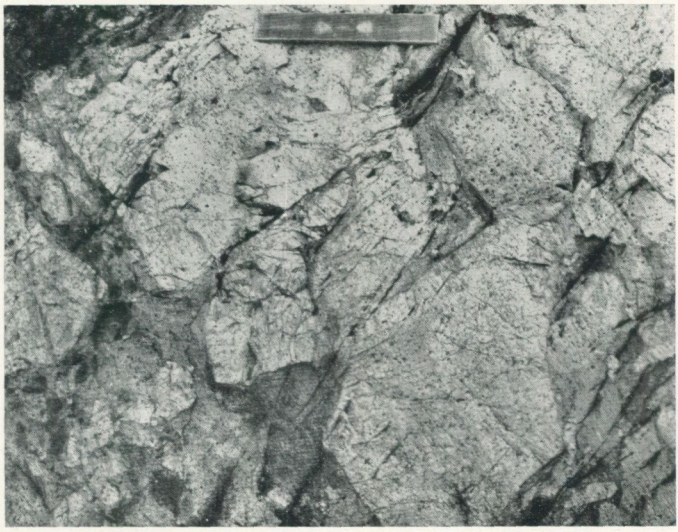


Fig. b. Volcanic breccia, SE of Maurliden. (The scale is 16 cm).



Fig. a. Volcanic breccia, SE of Maurliden. (The scale is 16 cm).

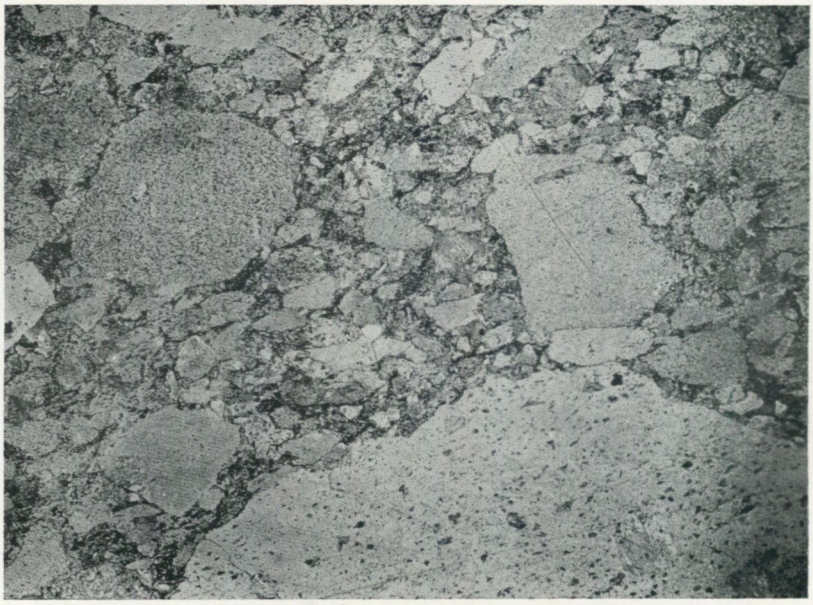


Fig. b. Micro-structure of the groundmass of volcanic breccia. 1.5 km NW of Lake Kotjärn. Irregular-shaped fragments of various volcanic rocks. Thin section. Ord. light. × 9.

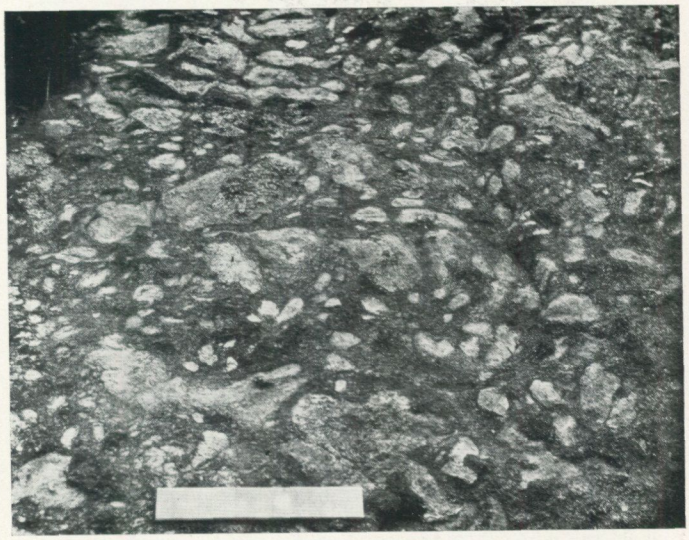


Fig. a. Greenstone agglomerate W of Norrliden. (The scale is 16 cm).

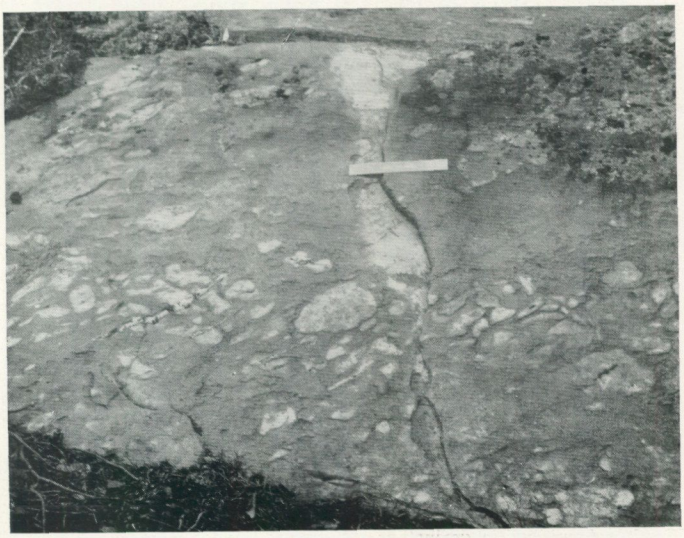


Fig. b. Agglomeratic bed in otherwise homogeneous greenstone. W of Norrliden. (The scale is 16 cm).



Fig. a. Greenstone agglomerate with angular fragments. W of Norrliden. (The scale is 16 cm).

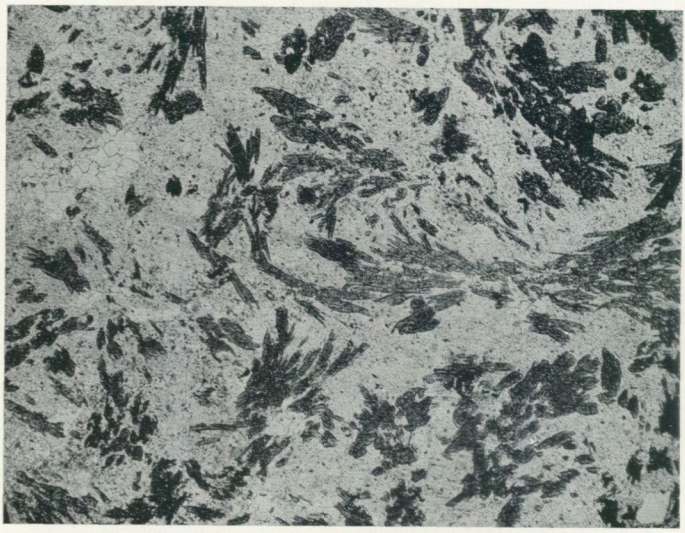


Fig. b. Amphibolitic greenstone. Hornblende needles in a fine-grained groundmass of plagioclase, chlorite, and sometimes quartz. 1 km NW of the Bjurträsk ores. Thin section. Ord. light. × 18.

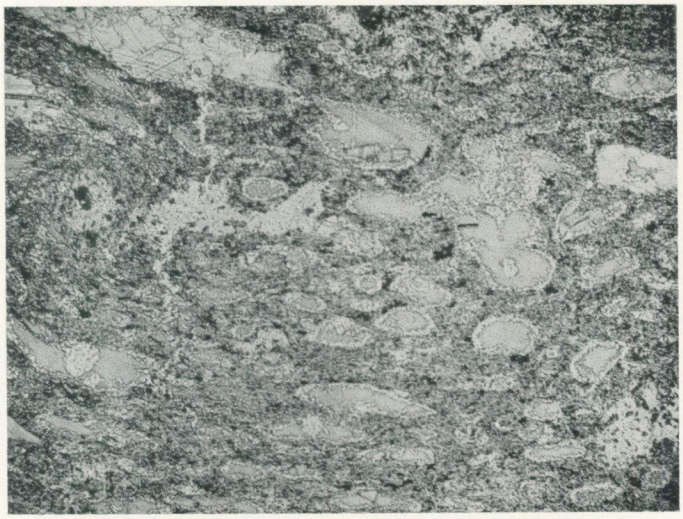


Fig. a. Amygdaloidal greenstone. The elongated vesicles are filled with chlorite (in the centre) and quartz (the outer zone). 400 m NE of Örträsk village. Thin section. Ord. light. × 16.

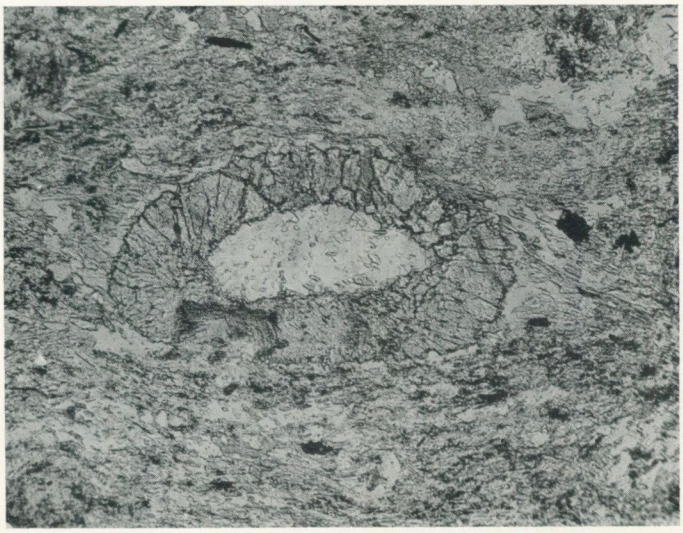


Fig. b. Greenstone with vesicle filled with quartz in the centre, surrounded by zoizite. 400 m NE of Örträsk village. Thin section. Ord. light. × 60.

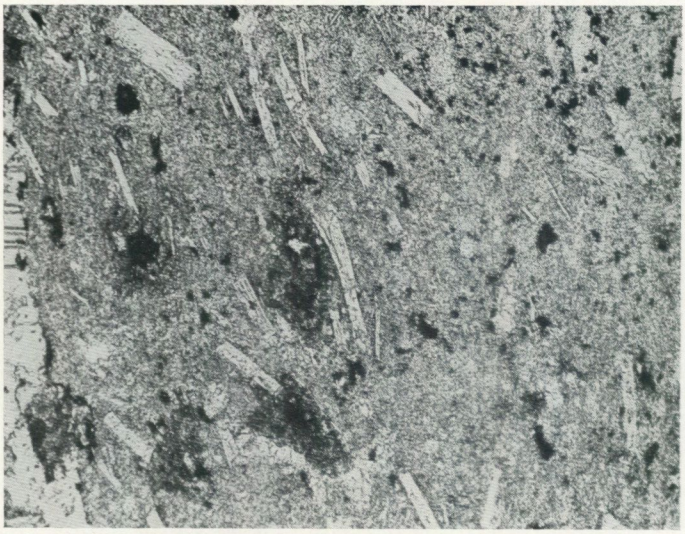


Fig. a. Basaltic greenstone. Laths of plagioclase showing a tendency towards fluidal arrangement in the fibrous groundmass. 600 m N of Lake Kotjärn. Thin section. Ord. light. × 60.



Fig. b. Albite-greenstone. Laths of albite in a chlorite-rich groundmass. Middle Bjurfors ore. Thin section. Nic.+ × 100.

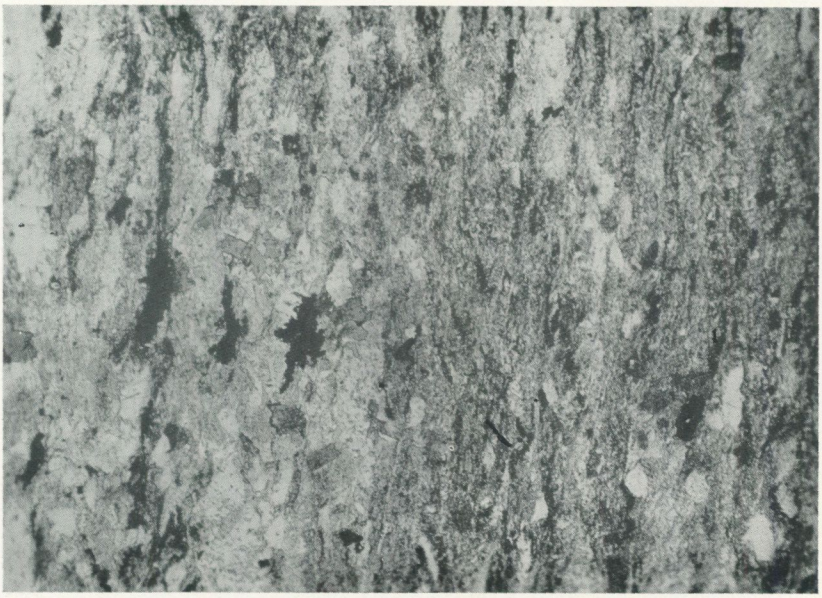


Fig. a. Graphite-phyllite. 1 km W of Norrliden. Thin section. Ord. light. × 50.

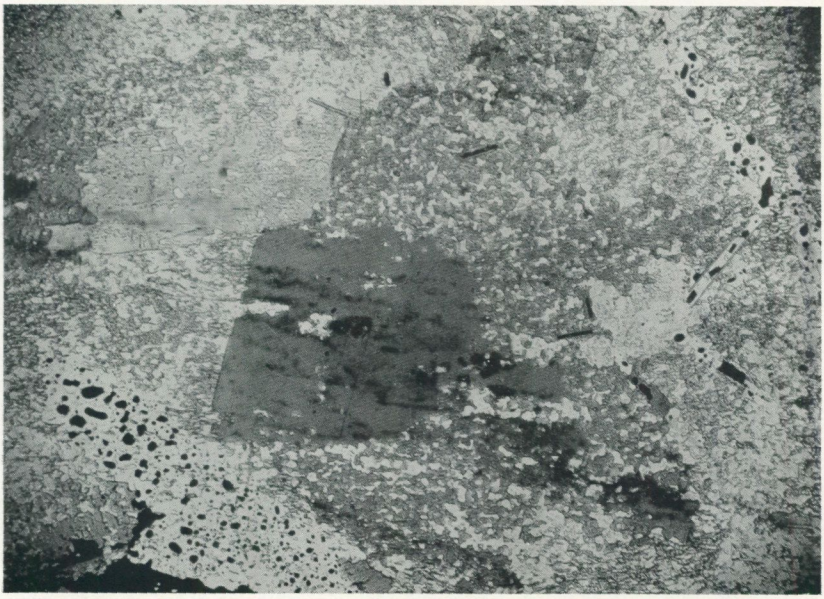


Fig. b. Biotite poikiloblasts in chlorite-quartzite. The Bjurträsk ores. Thin section. Ord. light. × 18.

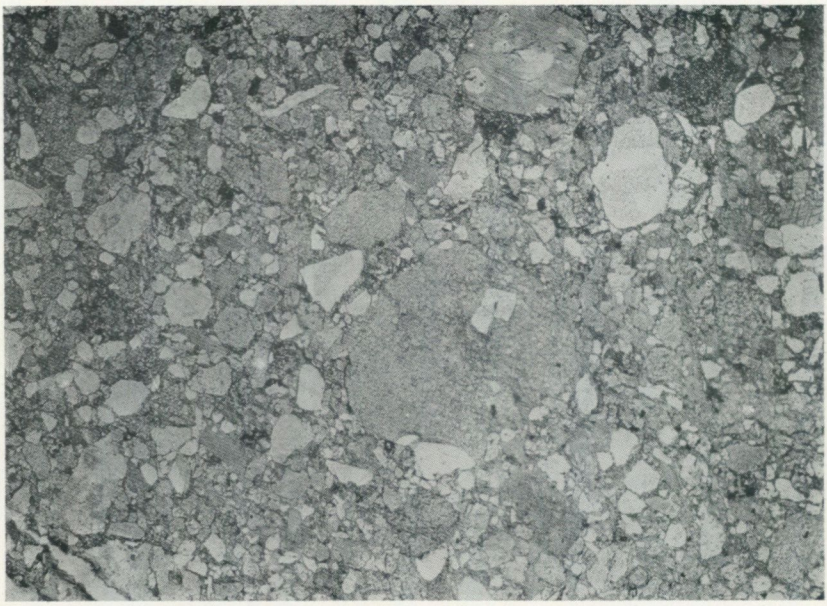


Fig. a. Arkose with abundant quartzporphyry material. In the middle a minute rounded fragment of porphyry. 1 km NE of Kotjärn. Thin section. Ord. light. × 9.

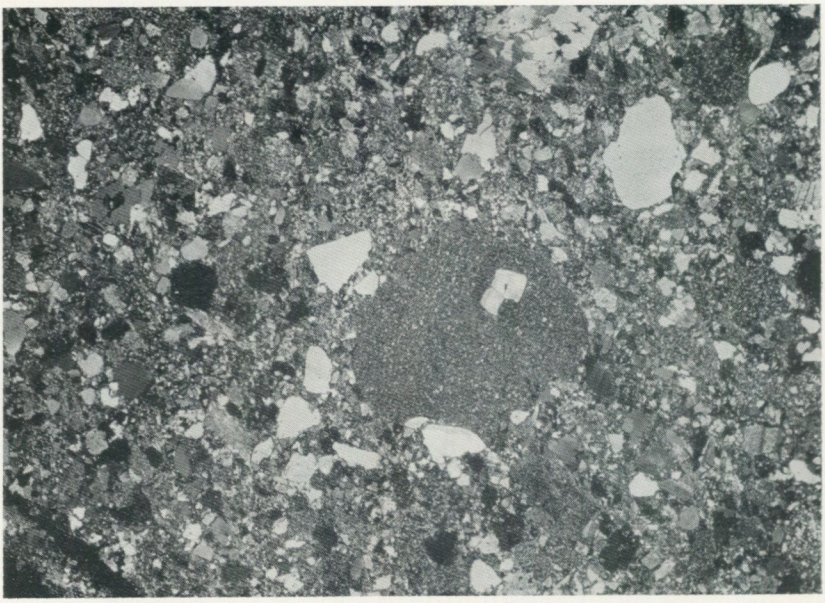


Fig. b. The same as fig. a. Nic.+.

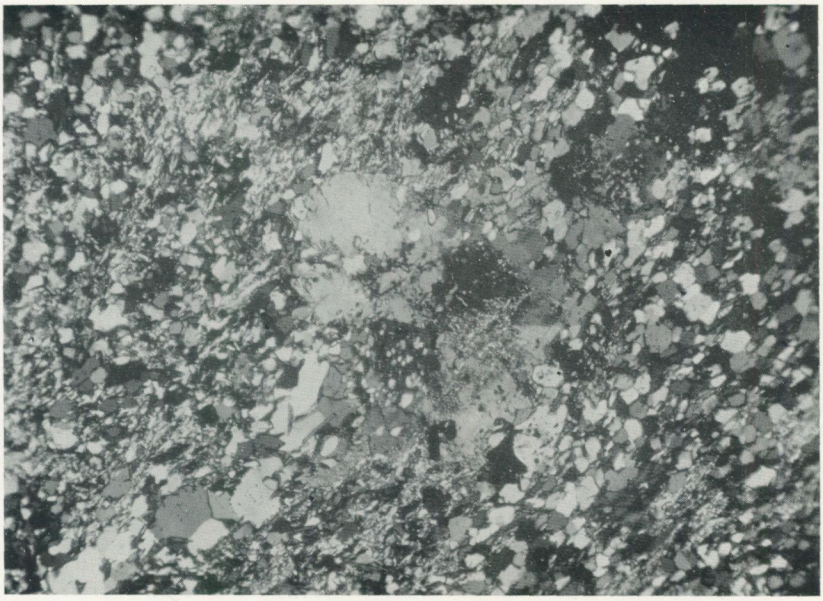


Fig. a. Penetrations-twins of plagioclase in altered quartzporphyry. Immediately W of the Bjurträsk ores. Thin section. Nic.+. × 140.



Fig. b. Zonal orthite minerals in clorite-rock. Eastern Bjurfors ore. Thin section. Ord. light. × 140.

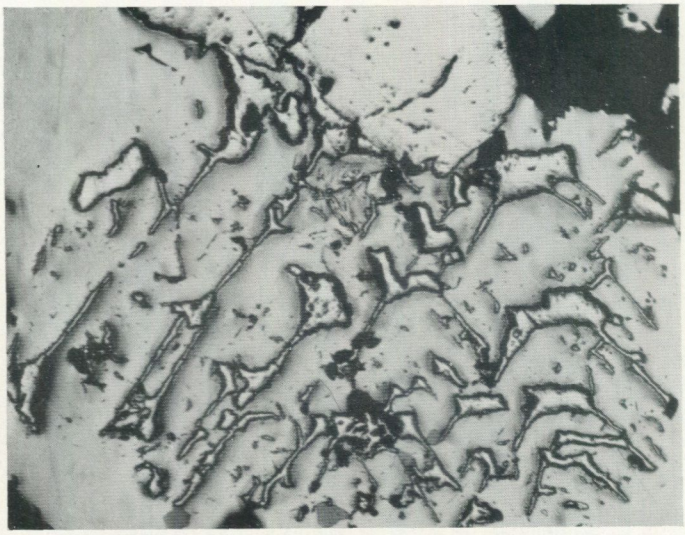


Fig. a. Zonary replacement of pyrite (white, relief) by the chalcopyrite (light grey). Eastern Bjurfors ore. Polished section. Ord. light. × 155.

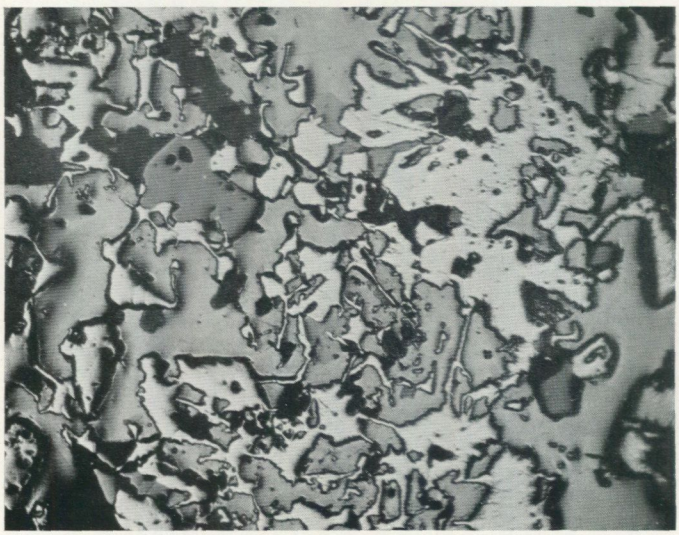


Fig. b. Skeleton-shaped remainders of pyrite (white, relief) in chalcopyrite (light grey). Eastern Bjurfors ore. Polished section. Ord. light × 110.

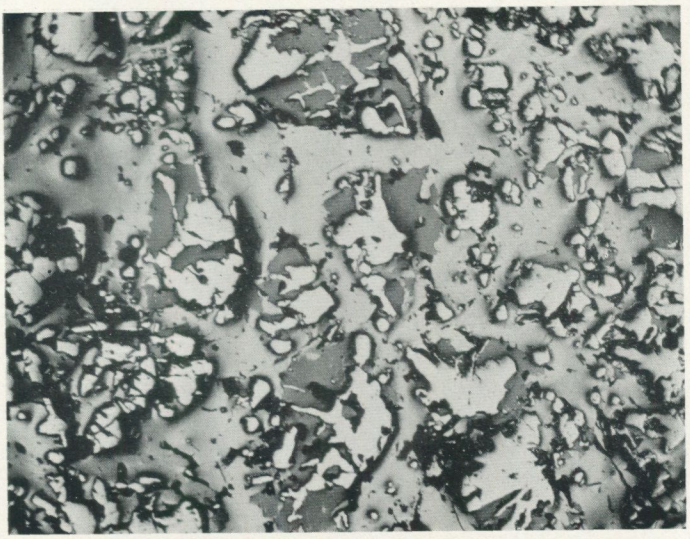


Fig. a. Pyrite (white, relief) replaced by sphalerite (grey) and pyrrhotite (grey-white). The skeleton-shaped pyrite is mainly surrounded by sphalerite. Ö. Högkulla. Polished section. Ord. light. × 110.



Fig. b. Irregular, broken translation lamellae in pyrrhotite. Bjurliden. Polished section. Nic.+. × 110.

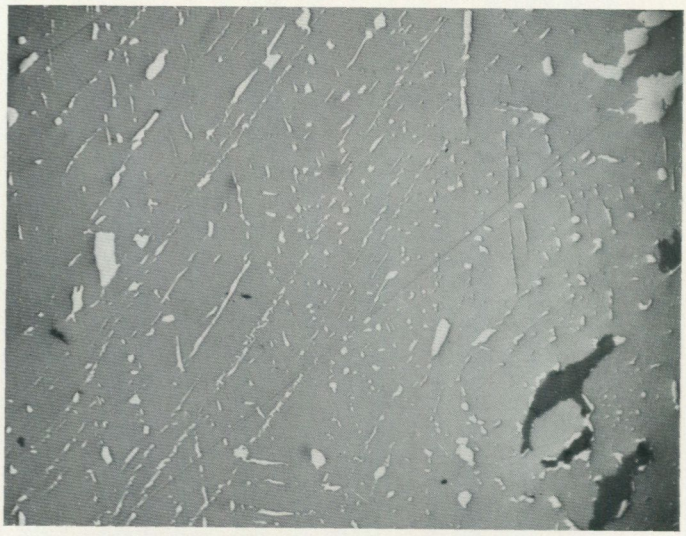


Fig. a. Sphalerite (grey) with regularly arranged pyrrhotite (white). Ö. Högkulla. Polished section. Ord. light. × 110.

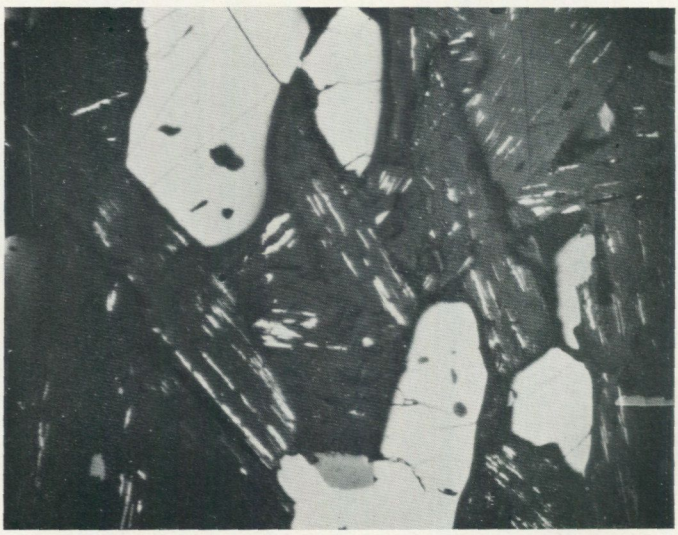


Fig. b. Galena (narrow white stringers) on the cleavage planes of mica. Large homogeneous grains of pyrrhotite (white). Bjurliden. Polished section. Ord. light. × 110.

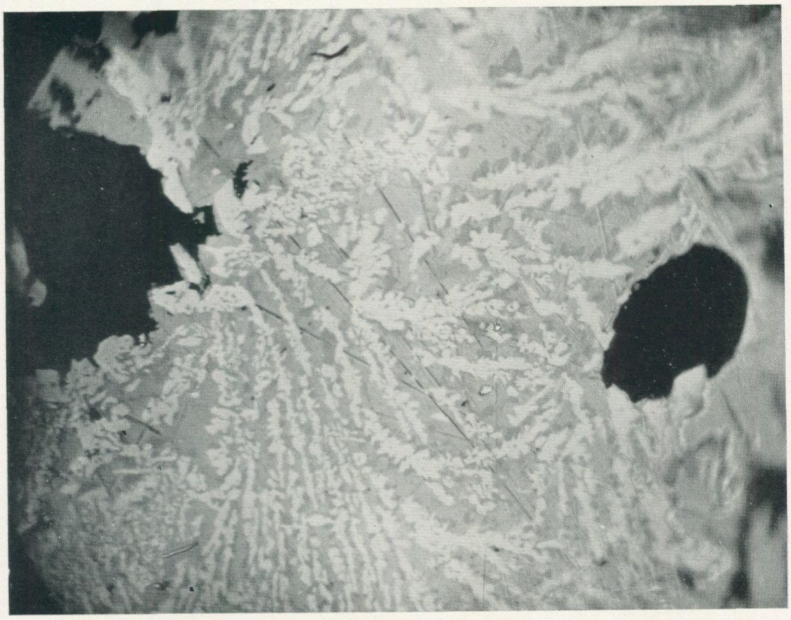


Fig. a. Gudmundite forming ramiform crystal-aggregates in galena (light grey). Small grains of pyrrhotite (darker grey). Bjurliden. Polished section. Ord. light. × 400. Immersion.



Fig. b. Intergrowth of gudmundite (white) and pyrrhotite (light grey, M) surrounded by galena (light grey). Corroded grains of tetrahedrite (F). Bjurliden. Polished section. Ord. light. × 400. Immersion.



Fig. c. Intergrowth of galena (white) and tetrahedrite (grey). Bjurliden. Polished section. Ord. light. × 110.



Fig. a. Intergrowth of galena (grey-white) and tetrahedrite (grey). Small white spots of native bismuth. Bjurliden. Polished section. Ord. light. × 260. Immersion.

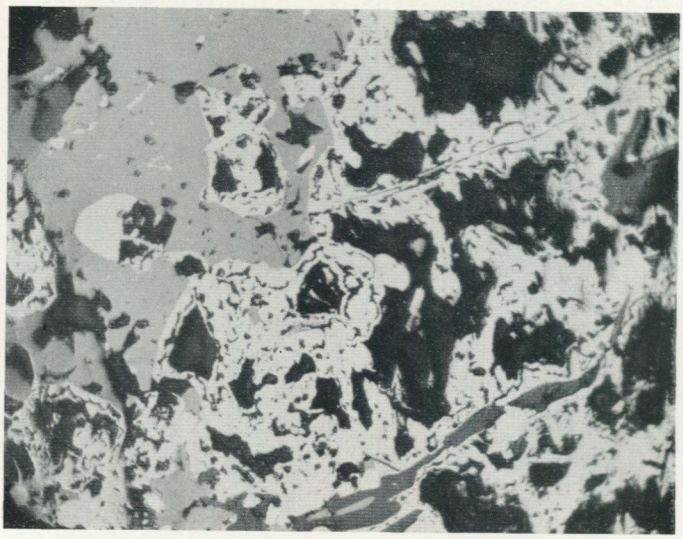


Fig. b. Marcasite-like alteration products of pyrrhotite as zonal garlands. Sphalerite (grey) containing a small, preserved grain of pyrrhotite. (white; to the left). Skäggträskberget. Polished section. Ord. light. × 110.

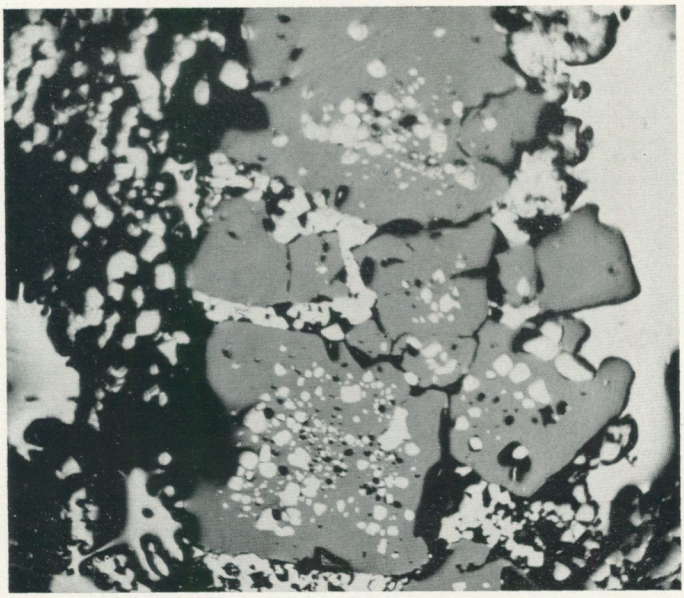


Fig. a. Magnetite (grey) enclosing small grains of pyrite (white). Large homogeneous mineral to the right = chalcopyrite. Eastern Bjurfors ore. Polished section. Ord. light. × 110.

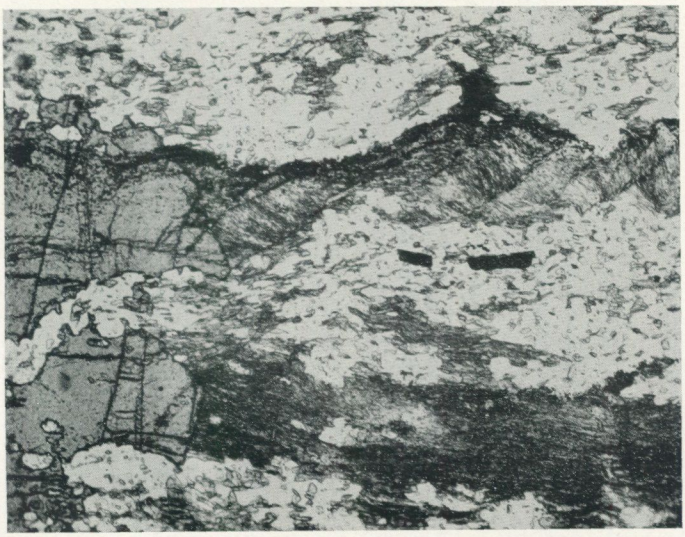


Fig. b. Chloritoid-bearing chlorite-quartzite. Winding rows of ore minerals traversing the chloritoid porphyroblasts. The Bjurträsk ores. Thin section. Ord. light. × 40.

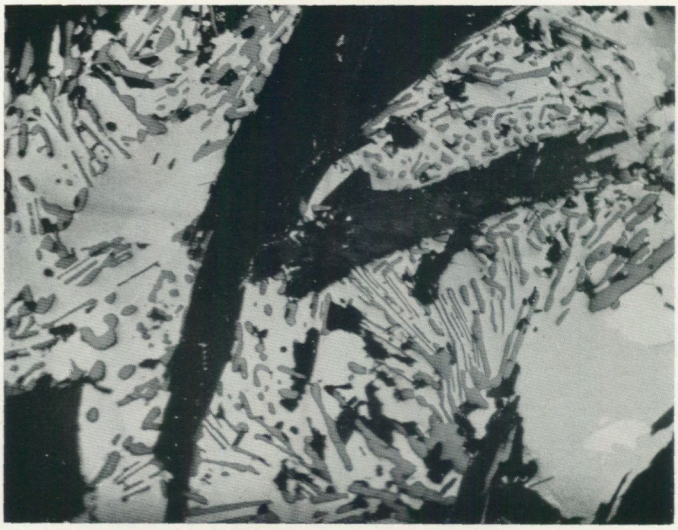


Fig. a. Regular arrangement of ilmenite (grey, relief) in pyrrhotite (light grey). Bjurliden. Polished section. Ord. light. × 100.

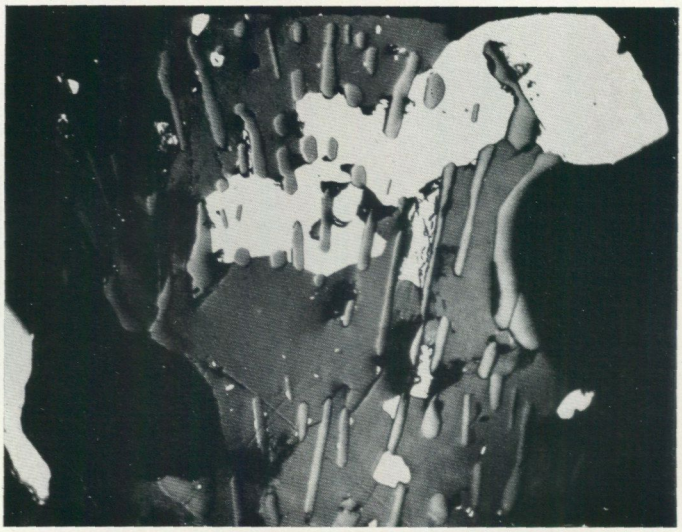


Fig. b. Group of regularly arranged ilmenite grains (grey, relief) traversing the contacts between pyrrhotite (white) and sphalerite (dark grey). Bjurliden. Polished section. Ord. light. × 400. Immersion.



Fig. a. Chlorite-quartzite with chloritoid as black bundles in the groundmass. The Bjurträsk ores. 3/4 of natural size.



Fig. b. Chlorite-quartzite with swarms of parallel biotite bands in two directions. Eastern Bjurfors ore. 1/2 of natural size.

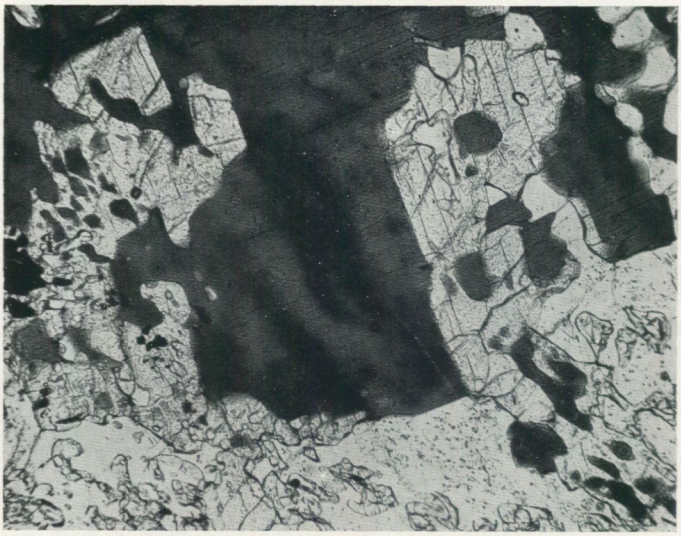


Fig. a. Andalusite replacing biotite in chlorite-biotite-quartzite. Bjurliden. Thin section. Ord. light. × 70.

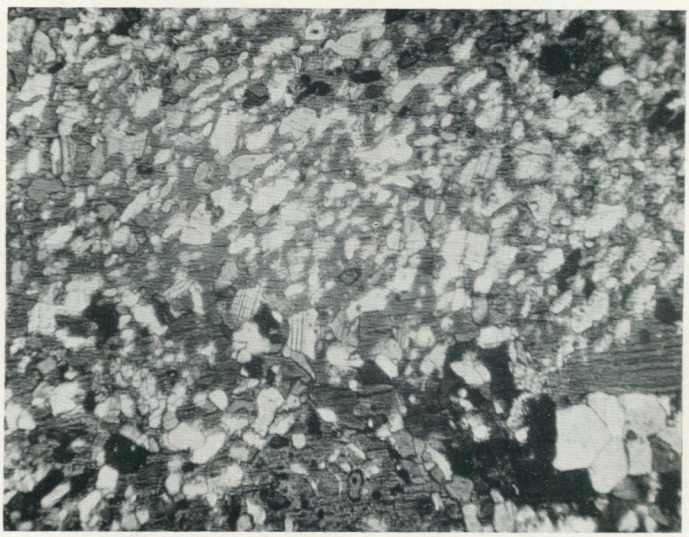


Fig. b. Hornblende with abundant inclusions of plagioclase. Altered quartzporphyry. Bjurliden. Thin section. Nic.+. × 70.

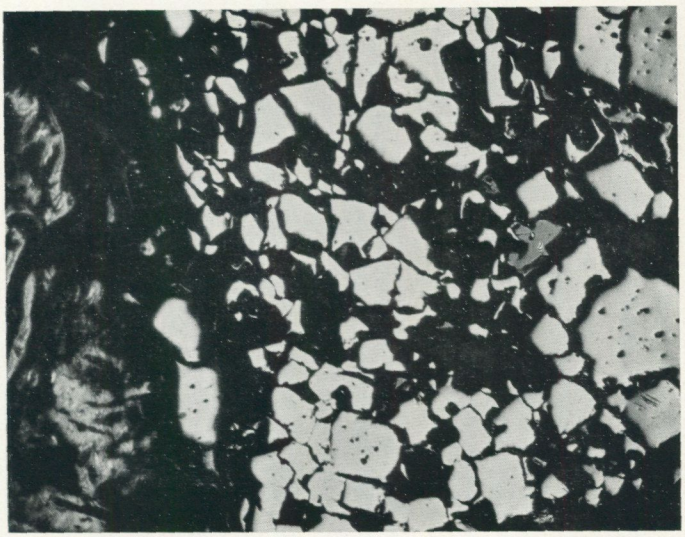


Fig. a. Cataclastically deformed pyrite ore. Bjurliden. Polished section. Ord. light. × 110.

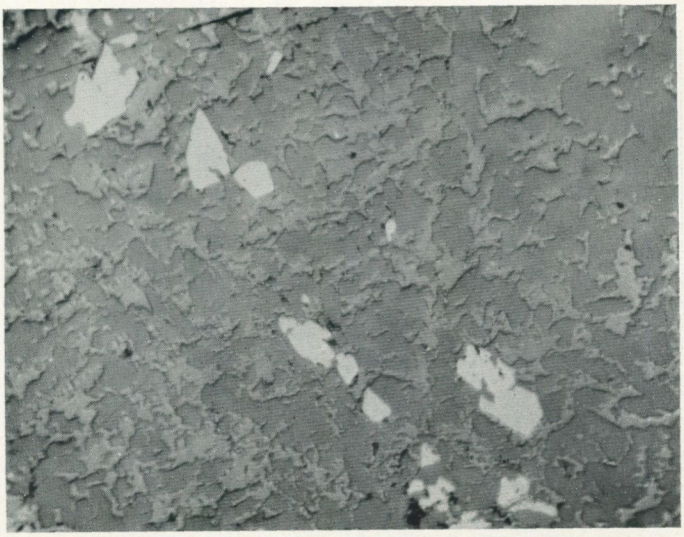


Fig. b. Pyrrhotite (darker grey, relief) intensely brecciated and replaced by galena (lighter grey). Idioblastic grains of gudmundite (white). Bjurliden. Polished section. Ord. light. × 300.



Fig. a. Bent quartz grains in chlorite-quartzite (Cf. fig. 13). 500 m N of the Bjurträsk ores. Thin section. Ord. light. × 18.

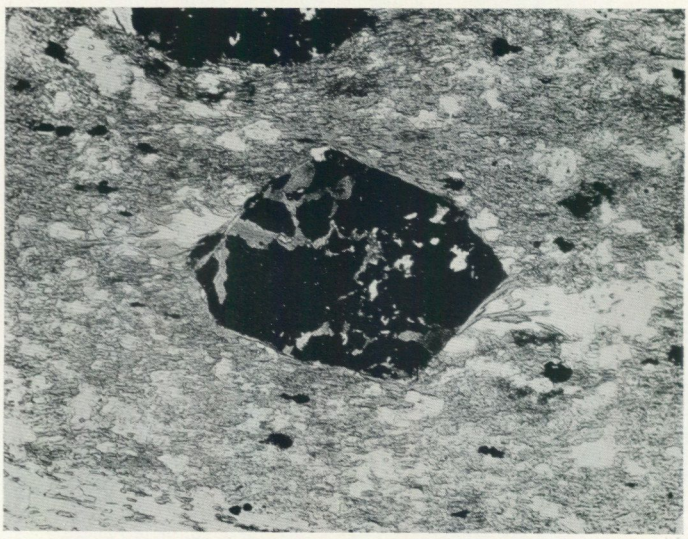


Fig. b. Idioblastic magnetite in chlorite-quartzite replaced by biotite. Eastern Bjurfors ore. Thin section. Ord. light. × 60.



Fig. a. Contact between an extremely dense pyrite streak and pyrite ore of »the »normal» type. Eastern Bjurfors ore. Polished section. Ord. light. × 110.

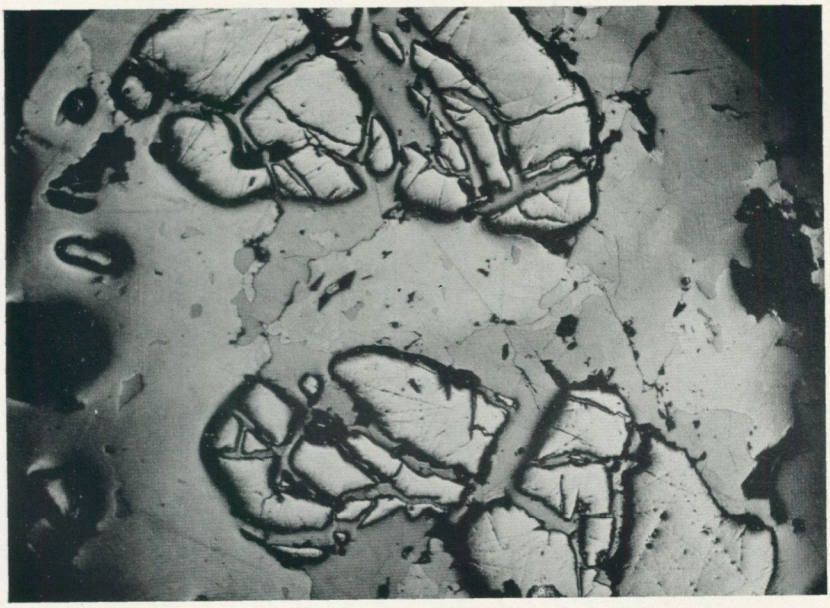


Fig. b. Pyrite (high relief) replaced by pyrrhotite (darker grey) and chalcopyrite (white-grey). Eastern Bjurfors ore. Polished section. Ord. light. × 110.



Fig. a. Vermicules of pyrrhotite (relief) in chalcopyrite. In the upper right corner a lamella of cubanite. Eastern Bjurfors ore. Polished section. Ord. light. × 130.

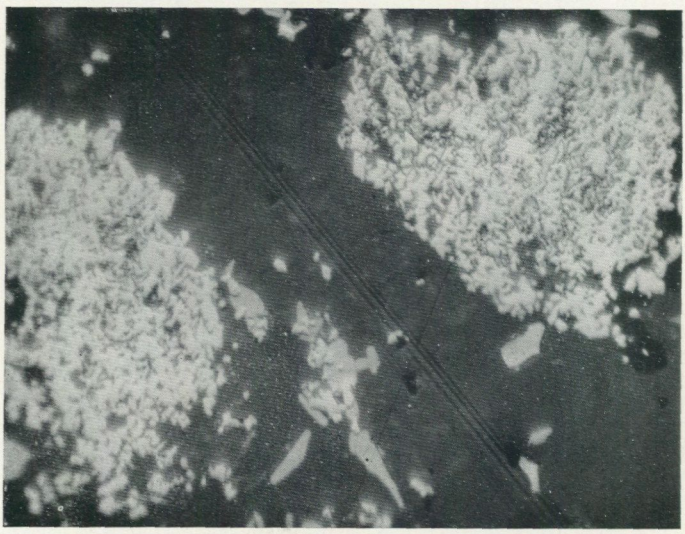


Fig. b. »Drusy» spots of arsenopyrite (white, relief) with interstitial galena (somewhat darker than arsenopyrite) in sphalerite (almost black). Middle Bjurfors ore. Polished section. Ord. light. × 800. Immersion.

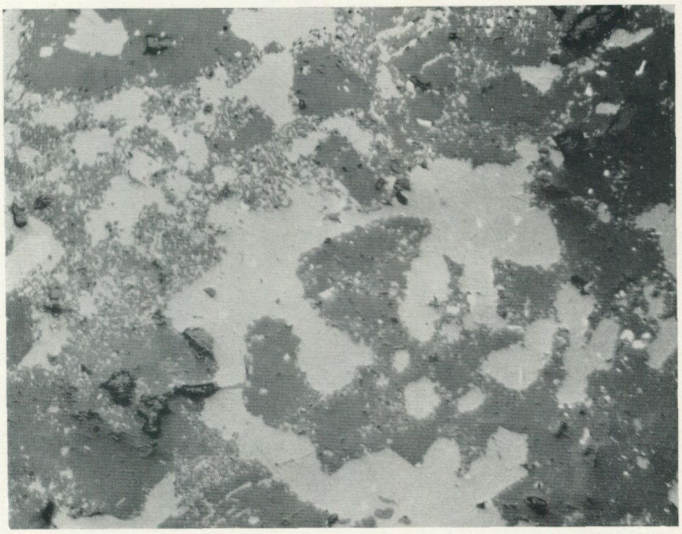


Fig. a. Plagioclase (dark grey) »powdered» with sphalerite (light grey). Western Bjurfors ore. Polished section. Ord. light. × 130.



Fig. b. Irregular-shaped grains of pyrite (P) in arsenopyrite (A). Österbäcken. Polished section. Ord. light. × 200.

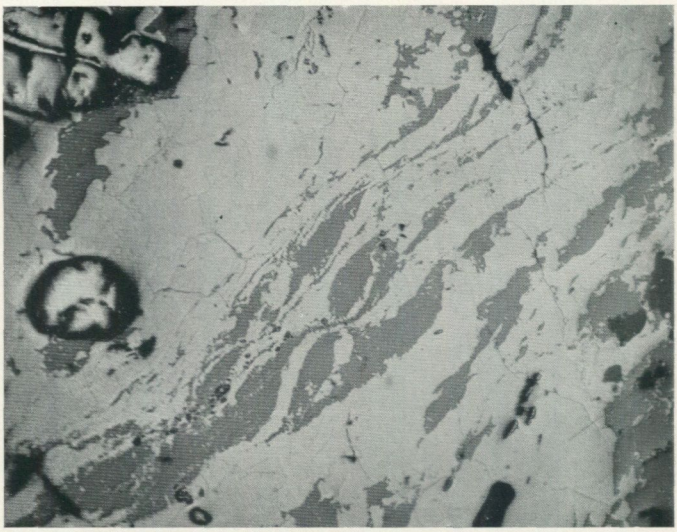


Fig. a. Pyrrhotite (light grey) and sphalerite (dark grey) with a fluidal arrangement. Solitary pyrite crystals (high relief). Ö. Högkulla. Polished section. Ord. light. × 110.

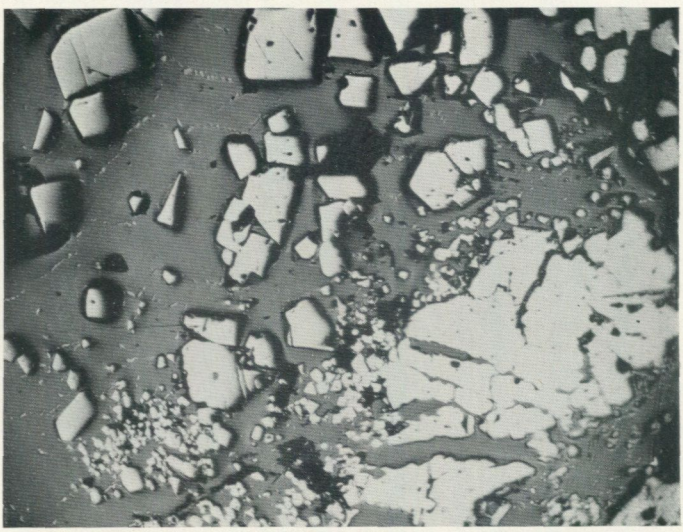


Fig. b. Older pyrite (white; the lower right-hand part) »flows apart» in the sphalerite mass (grey) and well-defined pyrite cubes are regenerated. Ö. Högkulla. Polished section. Ord. light. × 110.

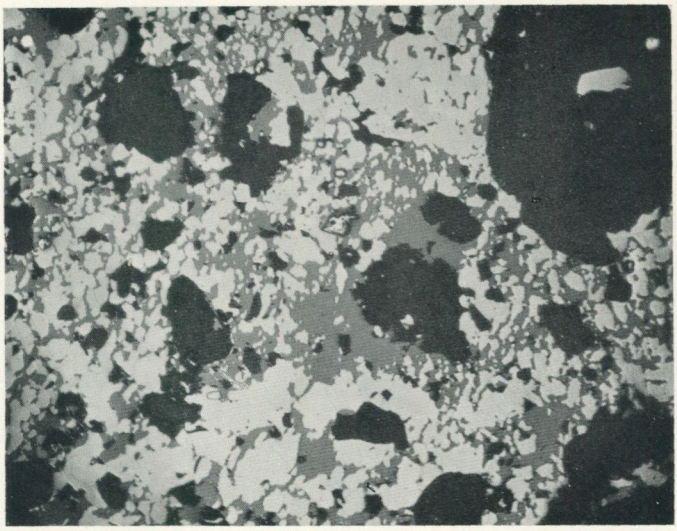


Fig. a. Dense pyrrhotite (white)–sphalerite (grey) ore with rounded inclusions of gangue minerals. Ö. Högkulla. Polished section. Ord. light. × 110.

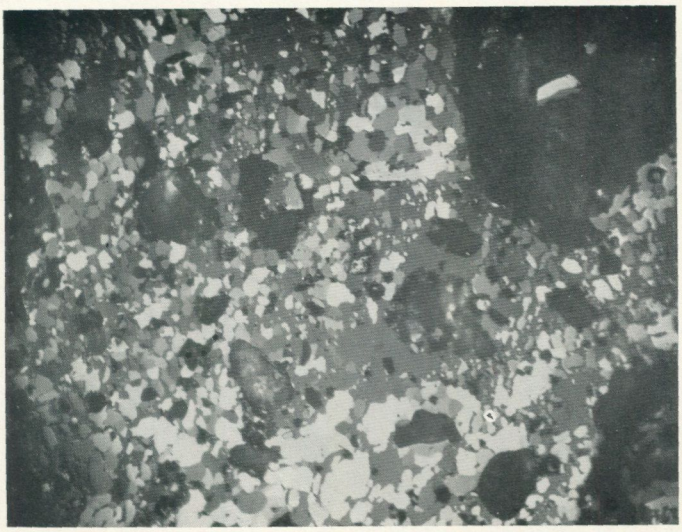


Fig. b. The same as fig. a. Nic.+.

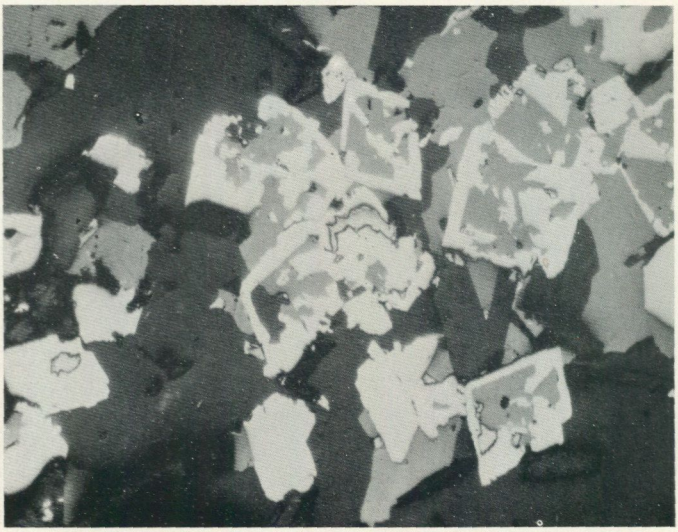


Fig. a. Zonary replacement of arsenopyrite (white) by sphalerite (grey). Skäggträskberget. Polished section. Ord. light. × 200.

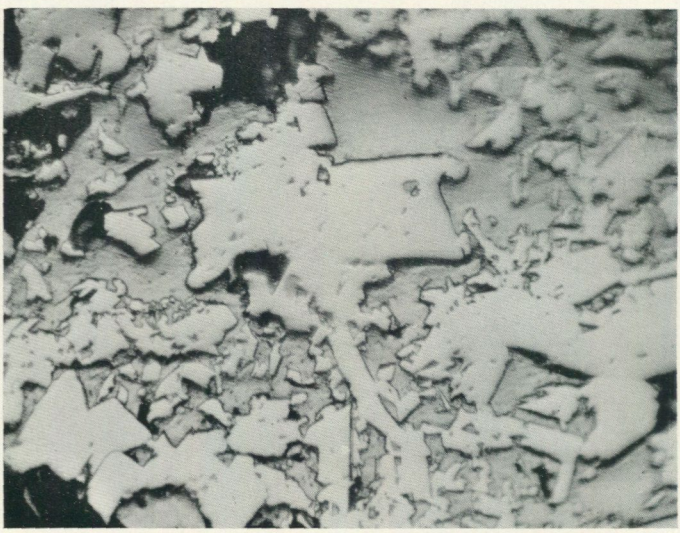


Fig. b. Framework of arsenopyrite crystals (white, relief) with interstitial galena (light grey). Skäggträskberget. Polished section. Ord. light. × 500. Immersion.

TECKENFÖRKLARING TILL PL. 34-37
LEGEND TO PLATES 34-37



Kvartsporfyr (med plagioklas)
Quartzporphyry (with plagioclase)



Effusiv grönsten
Effusive greenstone

Altered volcanic rocks, originally mainly of quartzporphyry composition



Kloritkvartsit med relikta kvartsströkorn
Chlorite-quartzite with residual quartz phenocrysts



Skiffrig kloritkvartsit
Schistose chlorite-quartzite



Slirig kloritkvartsit
Veined chlorite-quartzite



Massformig kloritkvartsit
Massive chlorite-quartzite



Sericitkvartsit med bibehållna kvartsströkorn
Sericite-quartzite with residual quartz phenocrysts



Sericitkvartsit
Sericite-quartzite (sericite-schist)



Malmkvartsit med spinell, andalusit, staurolit, granat eller magnetit
Ore quartzite with spinel, andalusite, staurolite, garnet or magnetite



Kloritskiffer
Chlorite-rock



Amfibolskarn
Amphibole-rock, skarn



Kalksten
Limestone



Förskiffringszon, biotitsköl
Strongly schistose zone, biotite-rock



Svavelkismalm (innehållande mer eller mindre koppar eller zink)
Pyrite ore (containing more or less copper or zinc)



Extremt kopparrik malm
Extremely copper-rich ore



Kloritbandad svavelkismalm
Chlorite-banded pyrite ore



Svavelkismalm med sericitkvartsiträndер
Pyrite ore with sericite-quartzite



Magnetkismalm (innehållande mer eller mindre koppar eller zink)
Pyrrhotite ore (containing more or less copper or zinc)



Sulfidmalm med relikta kvartsströkorn
Sulphide ore with residual quartz phenocrysts



Konturer för hällar och undersökningsgropar
Outlines of outcrops and prospecting trenches



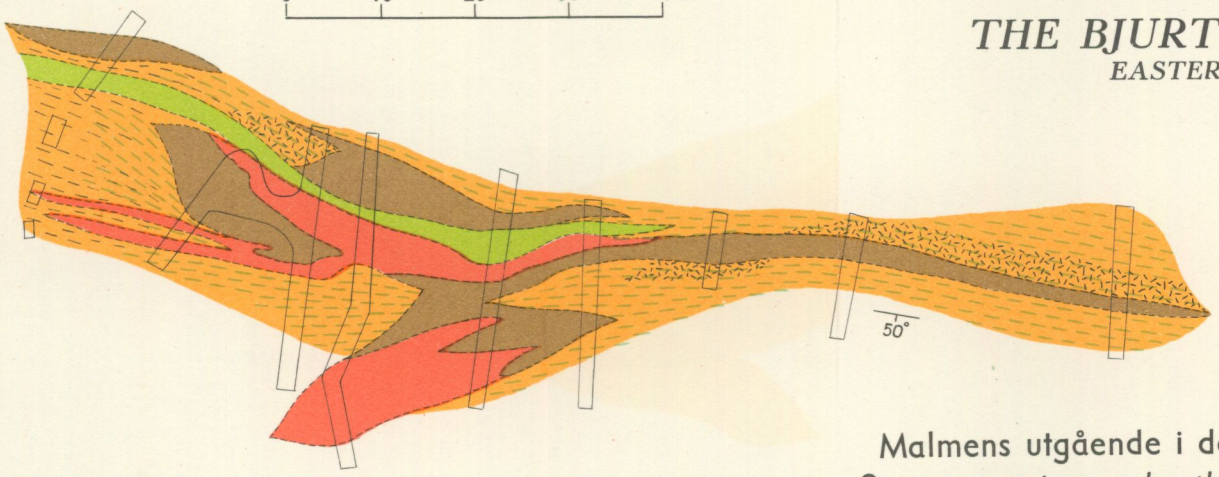
Borrhål
Drill hole

BJURTRÄSKMALMEN
ÖSTRA MALMEN

THE BJURTRÄSK ORE
EASTERN ORE

1:800

0 10 20 30 40 m



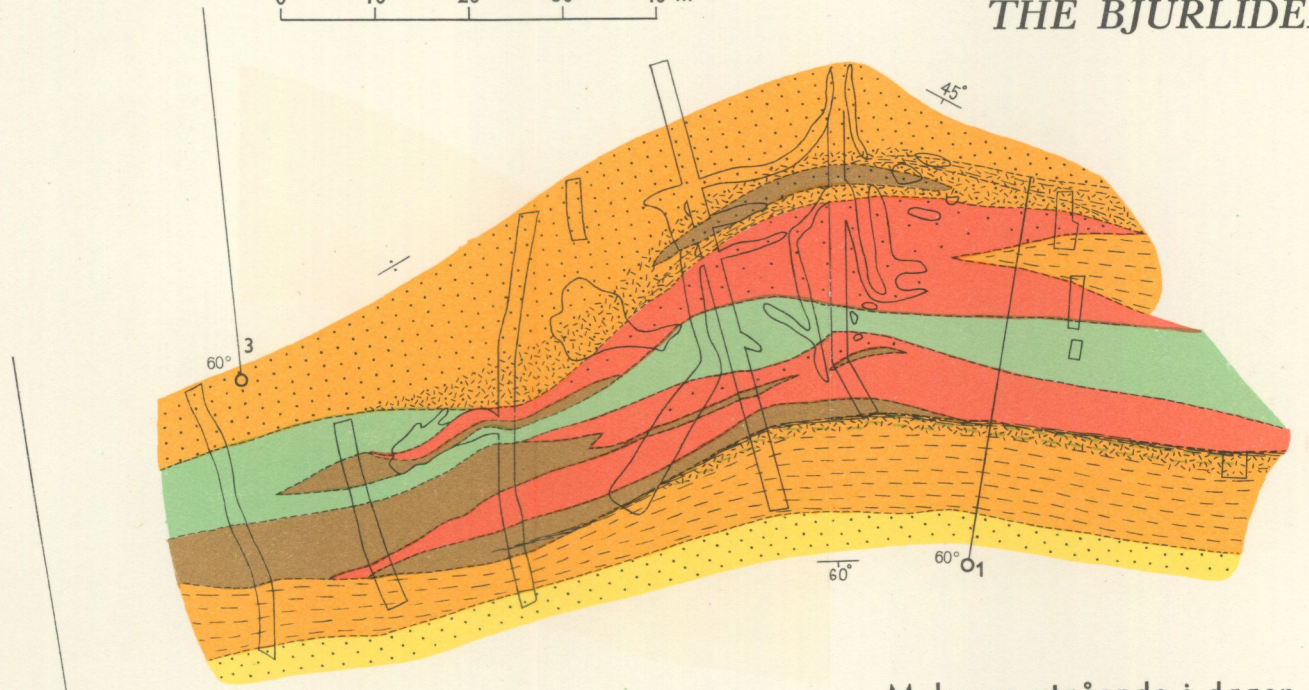
N

Malmens utgående i dagen
Ore outcropping under the drift

BJURLIDENMALMEN
THE BJURLIDEN ORE

1:800

0 10 20 30 40 m



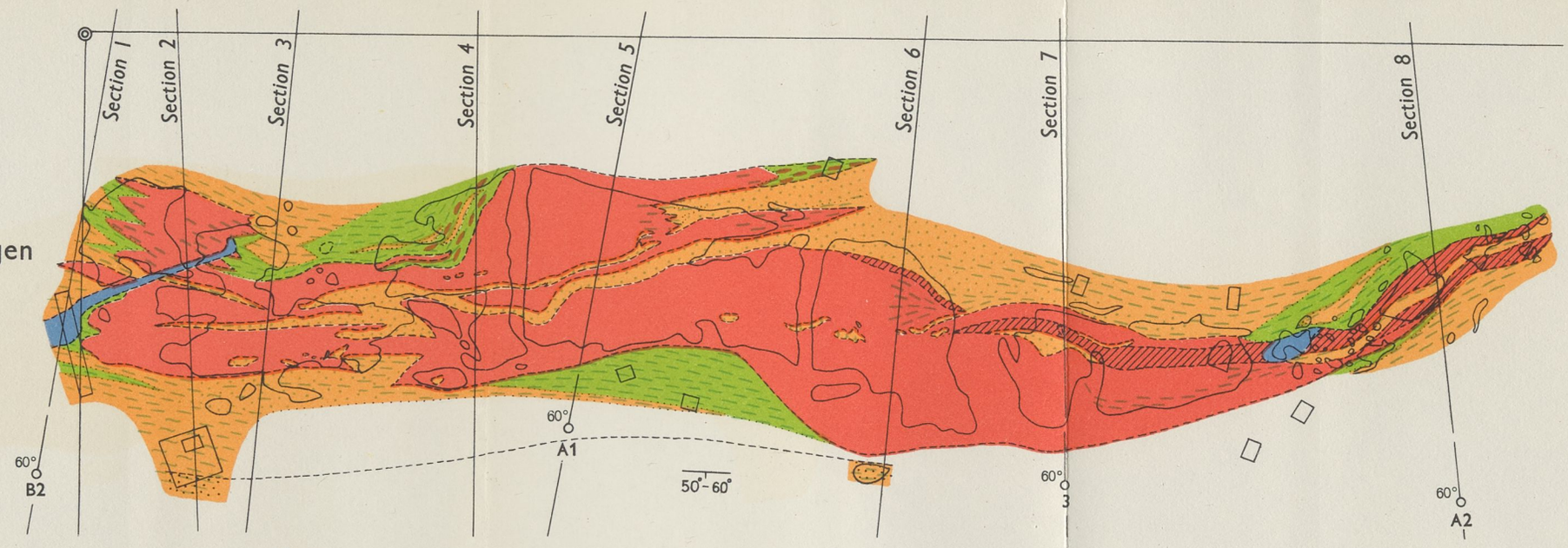
N

Malmens utgående i dagen
Ore outcropping under the drift

A.-B. KARTOGRAFISKA INSTITUTET
ESSELTE AB. STOCKHOLM 1939

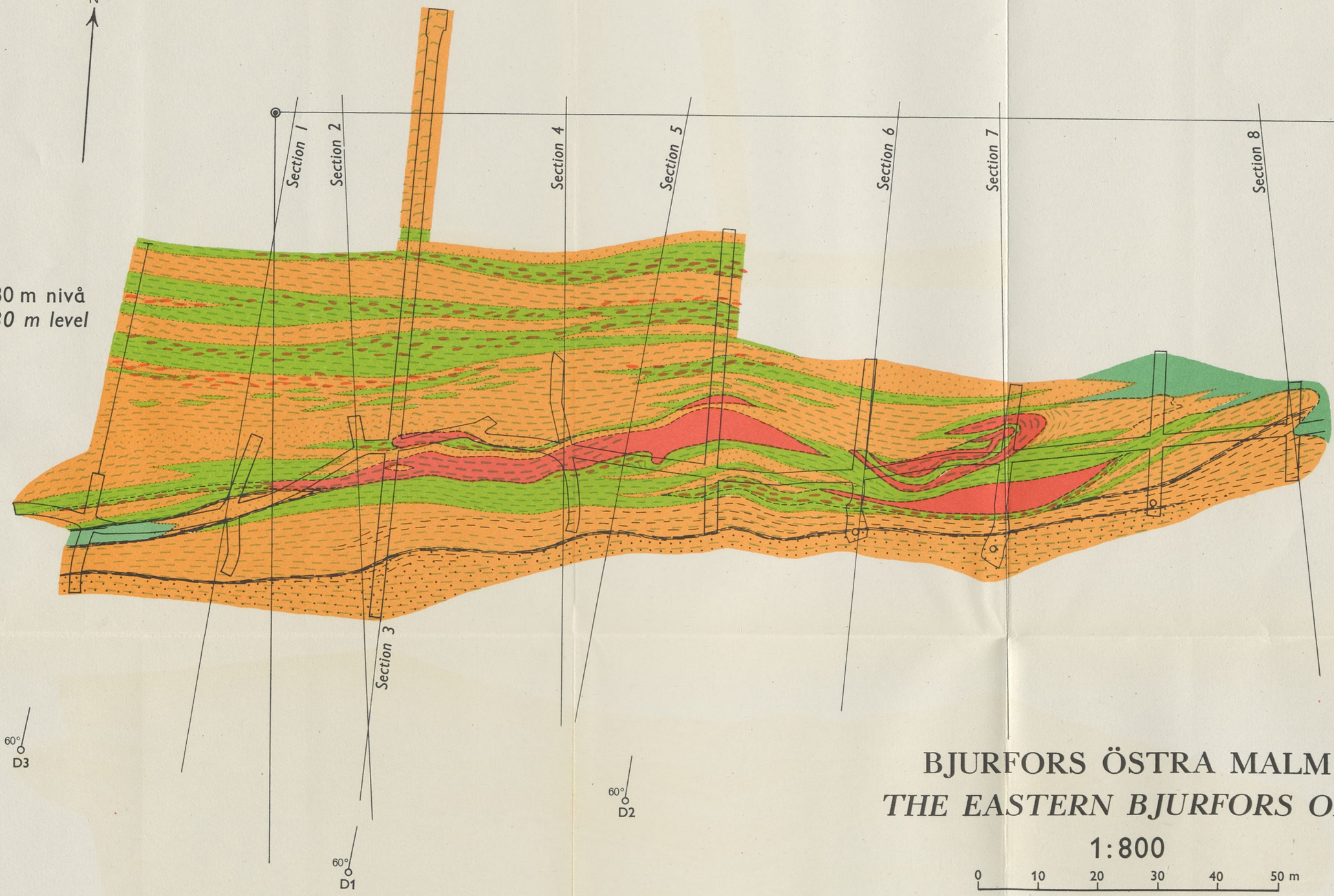
Malmens utgående i dagen

Ore outcropping under the overburden



N

30 m nivå
30 m level



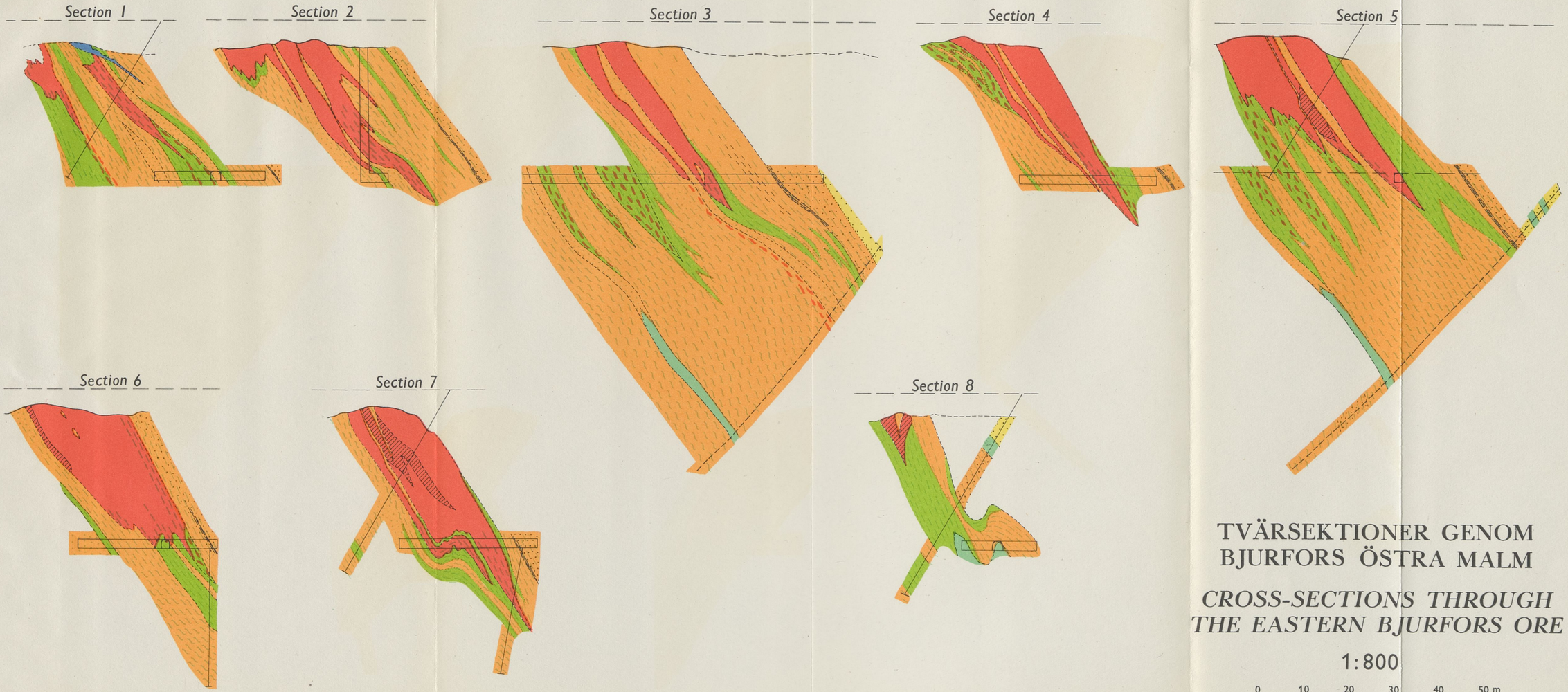
BJURFORS ÖSTRA MALM

THE EASTERN BJURFORS ORE

1:800

0 10 20 30 40 50 m

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ESSELTE AB. STOCKHOLM 1939



TVÄRSEKTIONER GENOM BJURFORS ÖSTRA MALM

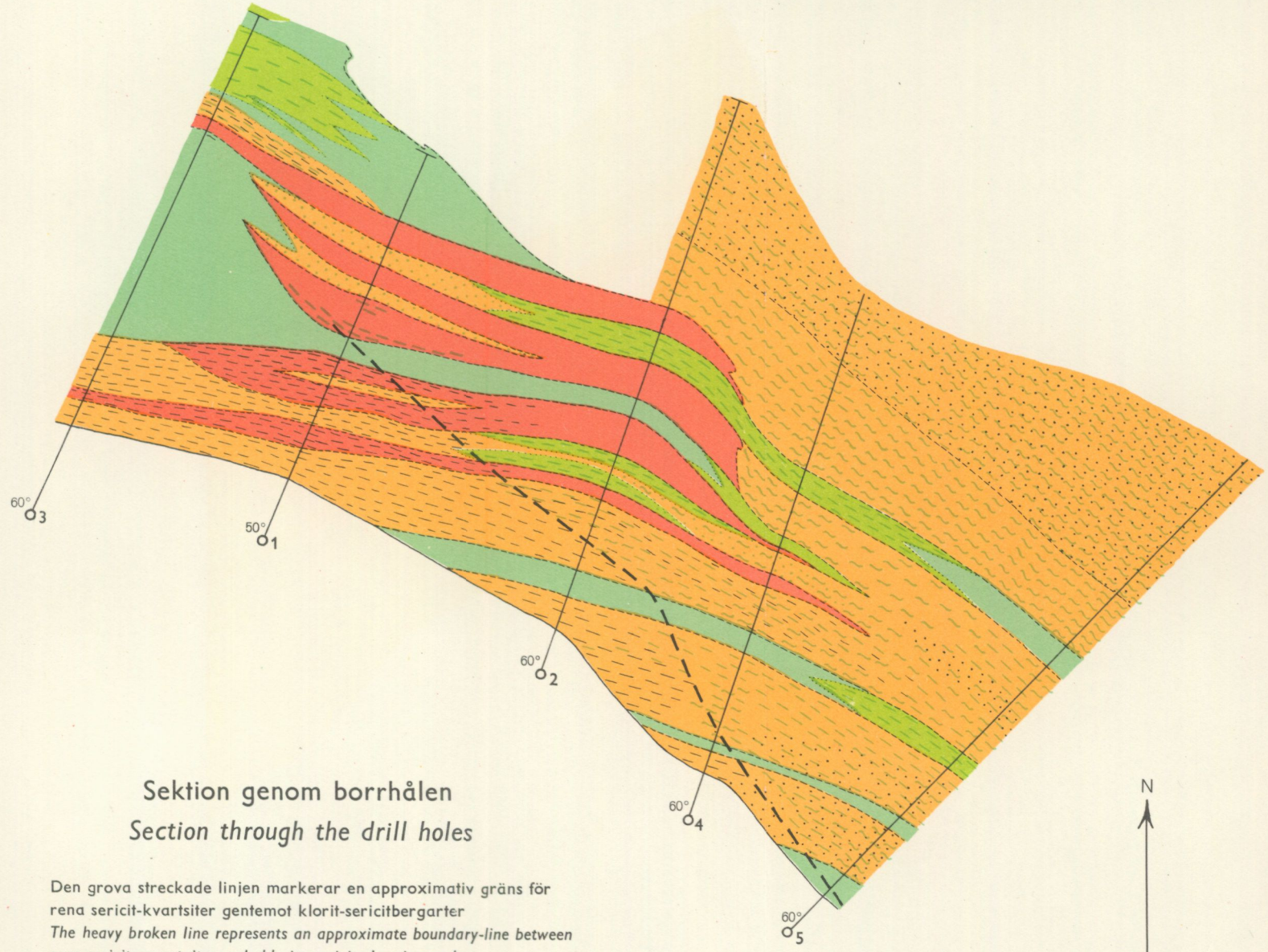
CROSS-SECTIONS THROUGH THE EASTERN BJURFORS ORE

1:800

0 10 20 30 40 50 m

A.-B. KARTOGRAFISKA INSTITUTET
ESSELTE AB. STOCKHOLM 1939

BJURFORS MELLERSTA MALM
THE MIDDLE BJURFORS ORE



Sektion genom borrhålen
Section through the drill holes

Den grova streckade linjen markerar en approximativ gräns för rena sericit-kvartsiter gentemot klorit-sericitbergarter
The heavy broken line represents an approximate boundary-line between pure sericite-quartzites and chlorite-sericite-bearing rocks

1:800

0 10 20 30 40 m

A.-B. KARTOGRAFISKA INSTITUTET
ESSELTE AB. STOCKHOLM 1939

BERGGRUNDSKARTA ÖVER MALÅNÄSOMRÅDET

GEOLOGICAL MAP OF THE MALÅNÄS DISTRICT

Av
Sven Gavelin 1939

N

Svansele

Skellefteälven

Malån

Malånäsudden

Maurträsket

Maurliden

Maurträsket

Ortjärn

Kotjärn

Önusberget

Önusträsket

Önusbäcken

Norrliden

Österbäcken

Ortjärn

Örträsk

Örträsket

Örträskgruven

Rutselet

Bjurträskmalmen

Bjurliden

Snättermyran

Bjurforsfältet

Storstensberget

Kaffeheden

Ö. Högkulla

Skäggträskberget

Fromheden

Västmyrbäcken

Malån

Bjurträsket

Bjurberget

Bjurträsket

Bjurbäcken

Fäboträsket

Malån

Sulfidmalmförekomst med malmens utgående i dagen
Sulphide ore deposit with outcropping ore

Kvartsgångar med arsenikkis
Quartz veins with arsenopyrite

Hällkonturer
Outlines of outcrops

Undersökningsgrop
Prospecting trench

Myrkonturer
Outlines of swamps

Borrhål
Drill holes

Strykning och stupning
Strike and dip

Stänglighet
Linear structure

Kvartsporfyr med stora strökorn
Quartzporphyry with large phenocrysts

Kvartsporfyr med små strökorn
Quartzporphyry with small phenocrysts

Kvartsporfyrogglomerat
Quartzporphyry agglomerate

Bandad kvartsporfyrtuff
Banded quartzporphyry tuff

Jämnkornig kvartsporfyrtuff
Even-grained quartzporphyry tuff

Kvartskeratofyr, keratofyr, täta tuffer, huvudsakligen av intermediär sammansättning
Quartzkeratophyre, keratophyre, dense tuffs, mainly of intermediate composition

Polymikt agglomerat, vulkanisk breccia
Polymict agglomerate, volcanic breccia

Effusiv grönsten
Effusive greenstone

Grafitfyllit
Graphite-phyllite

Grå fyllit, gråvacka, arkos
Grey phyllite, greywacke, arkose

Grå fyllit med talrika inlagringar av grafitfyllit
Grey phyllite with numerous interstratified beds of graphite-phyllite

Kalksten
Limestone

Revsundsgranit
Revsund granite

"Revsunds"-gabbro
"Revsund" gabbro

1:20 000

0 500 m 1 2 3 km

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