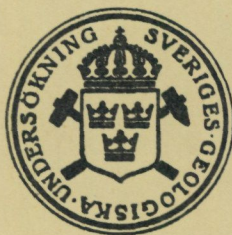


HANS ZWEIFEL

AITIK –
GEOLOGICAL DOCUMENTATION
OF A DISSEMINATED
COPPER DEPOSIT

A PRELIMINARY INVESTIGATION



STOCKHOLM 1976

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ABSTRACT

The Aitik Copper Deposit is situated about 15 km east of Gällivare, Norrbotten County, Sweden (lat. $67^{\circ}07'N$ /long. $21^{\circ}E$). The country rock consists of Precambrian meta-sediments which occur in a zone about 40 km long, parallel to the general $N20^{\circ}W$ strike and about 5 km wide. This zone of metasediments is surrounded by the younger Lina granite which has an age of 1540 ± 90 million years.

The eastern part of the Aitik area is dominated by meta-arenites which occur in a syncline. The grade of metamorphism and alteration in this part is low and primary sedimentary features such as conglomerates and cross-bedding can easily be recognized.

In the western part metamorphism and alteration is more intense and the country rock consists of gneisses, schists, quartzites and amphibolites. Primary sedimentary features cannot be recognized. The Aitik ore occurs in this part of the area on the western flank of an antiform and dome structure. Biotite schists, gneisses and quartzites partly with garnet, sericite schists and quartzites and gneisses with skarn schlieren form the main part of the bedrock.

Chalcopyrite is the only mineral of economic importance and occurs together with pyrite, magnetite and pyrrhotite. The following minerals can be observed occasionally but are quantitatively without importance: bornite, chalcocite, malachite, molybdenite, sphalerite, galena, arsenopyrite, scheelite, uraninite.

The mineralization occurs mainly as disseminations and stringers in the bedrock. Different types and stages of mineralization can be recognized.

The ore has a length of about two kilometres and the surface area is $380,000 \text{ m}^2$ with an average grade of 0.4 % Cu and a cut-off grade of 0.22 % Cu.

The genesis of the Aitik ore is explained by primary sedimentary preconcentration and later mobilization in connection with metamorphism and pneumatolytic activity.

PREFACE

The author has worked on the geology of the Aitik area during 1957—1958 and again from 1965 up to the present. During these investigations he has received valuable help from several colleagues.

The former chief geologist and head of the prospecting department of the Boliden Co, Dr E. Grip, has shown continued interest and has always stimulated the investigations. The management of the Boliden Co has shown a very positive attitude and has made the publication of the present paper possible.

Prof. O. Ödman had already been investigating the area between 1931 and 1933 and had collected valuable information.

Mr Åke Wirstam, mining geologist of the Boliden Co, has mapped most of the drill-holes and he has been responsible for the calculation of ore reserves. He has always been very helpful and has contributed with valuable information.

Dr Nils Edelman, now professor in Åbo, Finland, mapped in the area between 1959 and 1963 and has summarized the results in the company reports.

Fil. lic. C. A. Nilsson, now working for the Geological Survey of Sweden has worked with the Aitik mineralization between 1963 and 1964.

Mr Klaus Vesterberg, mineralogist of the company, has been helpful in producing the photographs of the thin and polished sections.

Dr D. Malmqvist and Dr D. S. Parasnis, geophysicists of the company, have worked for many years with the geophysical investigations and interpretations of the Aitik

mineralization and area. Their investigations have been published in *Geoexploration*. As the geological picture presented here is heavily based on the geophysical results, this co-operation has been of great value.

The geology of the area has been frequently discussed with P. Padget, K. A. Sandahl and F. Ros of the Geological Survey of Sweden. This co-operation has been very important for the interpretation of the geological setting.

For due permission to publish this paper I am indebted to the management of the Boliden Co.

INTRODUCTION

The Aitik copper deposit is situated about 15 km east of Gällivare, Norrbotten County, lat. 67°07'N and long. 21°E. The mineralization consists mainly of disseminated chalcopyrite and pyrite in Precambrian gneisses and schists. To the north the formations strike into the Liikavaara — Nautanen region where similar mineralizations are known (Geijer 1917). The country around the mine is flat and covered with extensive swamps and moraine (5—10 m). Outcrops are very rare with the exception of a section along the Lina river north of the mine.

The drilling has been concentrated to the mineralized zones and we have no direct geological observations in large parts of the mapped area. Magnetic maps have therefore been freely used for reconstructing the geology. The present investigations have to be regarded as preliminary, the development of the mine and drilling in parts of the area, where until now no direct geological information is available, will probably reveal facts which can modify the picture presented in this paper. As the Aitik mineralization certainly will be of interest to ore geologists and prospectors this paper is published now, even if certain investigations still are lacking and some geological interpretations doubtful.

Only the part of the zone that lies south of the Lina river has been mapped and studied by the author, as the area north of that river is protected by special concessions of the Government. However, the geological problems have been intensively discussed with the geologists of the Geological Survey (P. Padget and K. A. Sandahl) who have mapped the area north of the river, as well as the whole region.

DISCOVERY AND DEVELOPMENT OF THE AITIK DEPOSIT

Glacial boulders with disseminated chalcopyrite were found in the area by personnel of the Boliden Co in 1930. Geological investigations resulted in 1932 in the discovery of additional boulders and a small mineralized outcrop at the south end of the zone, where the Aitik mine has been developed. It was found, that an area around this outcrop had been claimed about 1900 by the private prospector Björkqvist, who in that period had localized several prospects 10—20 km north of Aitik. An electromagnetic survey started in 1932 and went on until 1933. Two

zones of interest were indicated and examined by drilling between 1933 and 1936, one in the Aitik area (at that time called Liikavaara W) and another zone 5 km to the east, called Liikavaara East. The first deposit early showed to be the larger, and later investigations were concentrated to that zone.

As the grade of the mineralization was not attractive at that time, there was a period of inactivity until 1948. Between 1948 and 1956 loop frame (slingram) surveys were carried out and minor geochemical investigations. In 1957 started a new period of more activity, including geological mapping, airborne EM (electro magnetic) and magnetic survey and later diamond drilling, especially on the deeper levels of the mineralizations. Resistivity surveys carried out between 1960 and 1962 showed that this method was superior to the EM methods to indicate the disseminated mineralization in the Aitik zone and pointed out that the mineralization should extend further to the north than was known at that time. Diamond drilling proved this to be correct and the whole ore zone was mapped by resistivity and magnetic methods. By 1963 the drilling had outlined so extensive an area of low grade mineralization that a feasibility study for an open pit mine was started, which later showed that the project was economically reasonable. The development work started in 1965 and ore production in 1967.

Project Aitik No. 1 was to develop the mine for a 2 million ton/year open pit operation, with an average content of 0.5 % Cu and a cut-off grade of 0.37 % Cu. The open pit was only planned down to 50 m below the surface and the calculations made on an ore reserve of 30 million tons. In project No. 2 the mine was developed for a 5 million ton/year output with an average grade of 0.4 % Cu. The deeper parts of the mineralization, to some extent known by a few drillholes, will be examined by mining investigations. A shaft will be sunk down to the 600 m level. The purpose of this investigation is to examine if an underground operation could be of interest in the future.

THE MINERALIZATIONS OF THE AITIK — NAUTANEN AREA

Geijer (1917) describes in his paper on Nautanen the mineralizations of the area. Aitik and Liikavaara East are not discussed in this paper as they had not been discovered at that time. All the mineralizations mentioned by Geijer are situated north of the Lina river. The most important mineralizations, namely Nautanen, Liikavaara (not to be confused with Liikavaara East) and Sorvanen, occur in the northern part of the area, 10—20 km NNW of Aitik in the direction of the general strike. They also have a very similar position geologically. The other occurrences, Nietsajokki, Fridhem, Snålkok, Juoikama and Sakakoski, are situated in the central and eastern parts of the zone of metasediments (see general geological map, Fig. 1).

It must be mentioned here at once, that these mineralizations are far from the size of Aitik and even Liikavaara East. They were mined between 1902 and 1907, but these attempts resulted in an economic failure. The total production from this area was about 150 000 t of ore and waste.

The mineralizations of the Nautanen — Liikavaara — Sorvanen zone consist of disseminated chalcopyrite in connection with skarn zones (garnet, epidote, amphibole), scapolite-amphibole fels, magnetite and tourmaline. Beside chalcopyrite there occurs even some bornite, chalcocite, pyrite, magnetite and pyrrhotite. Some molybdenite can be observed occasionally. The bedrock is a fine-grained gneiss or schist, partly rich in microcline and often with skarn bands or veins. The bedrock partly shows extensive scapolitization and tourmalinization. Scapolite occurs especially in the eastern part of the mineralized zone, tourmaline in the western part. Apatite is frequently met with in the northern part and zeolites have been observed.

The mineralizations occur in several lenses, 0.3—2.0 m wide and up to 40 m long. Exceptionally, the width can go up to 4.0 m (Liikavaara). Between the lenses generally no Cu mineralization occurs. The Cu content of the ore lenses is about 1—1.5 %.

The mineralizations in the central and eastern parts consist of quartz veins with chalcopyrite and bornite. The occurrence of native gold has been reported from the Fridhem quartz veins.

The Aitik ore and even the Liikavaara East mineralization, which will be described in this paper, are of quite a different size than the small deposits of the Nautanen area which are known up to present. However, the type of mineralization is partly very similar. We have the same mineralogical components — chalcopyrite, magnetite, pyrite, pyrrhotite — as the main minerals, bornite and chalcocite in quartz veins, molybdenite occurring occasionally. Even the bedrock is very similar — fine-grained gneisses and schists, rocks with skarn bands and lenses, scapolitization and tourmalinization. However, the large scale low grade Cu dissemination, characteristic of Aitik, is lacking in the Nautanen area.

GENERAL GEOLOGICAL SETTING

The rock units of the area are of Precambrian age and consist of metamorphosed sediments occurring in a zone 40 km long parallel to the general N 20°W strike and with an average width of about 5 km. This zone of metasediments is surrounded by the younger Lina granite, migmatites and gabbro.

It is not within the scope of this paper to study the general stratigraphic relationships between this area and other parts of Norrbotten. The Geological Survey of Sweden is at present mapping the region and trying to solve the stratigraphic problems. The Aitik — Nautanen zone of metasediments is to a large extent

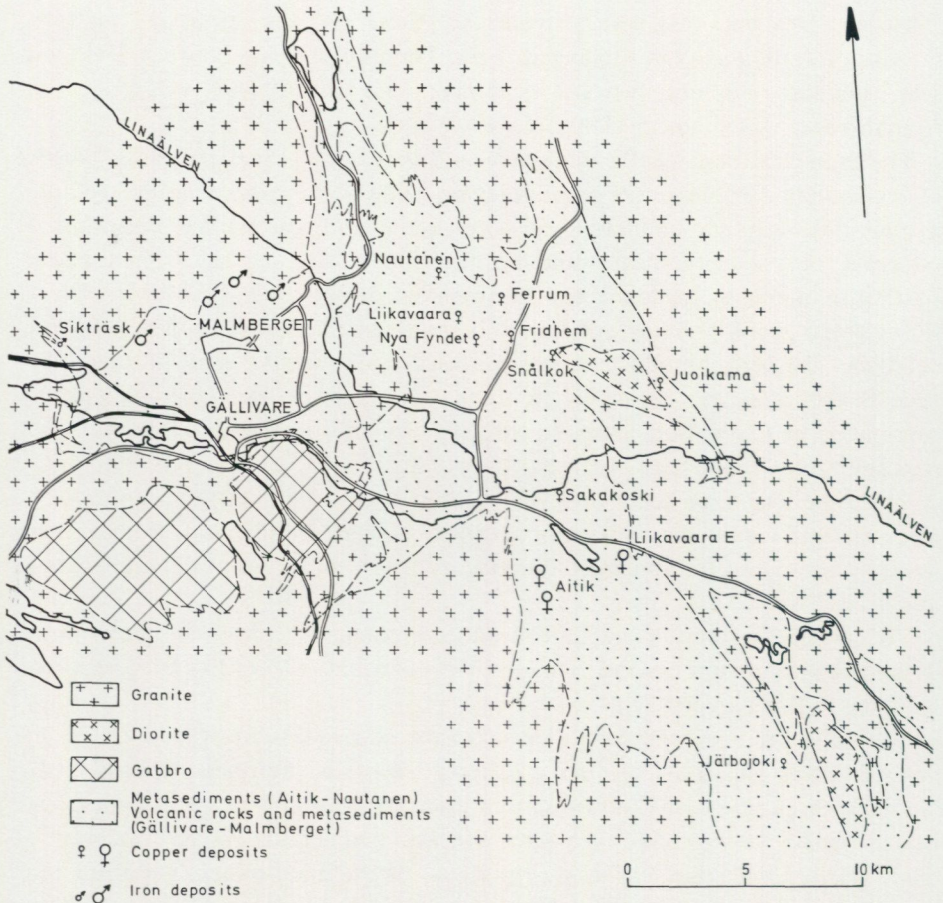


Fig 1. Generalized geological map of the Aitik - Nautanen - Gällivare area, mainly based on the geological map of the Swedish Geological Survey (Gällivarebladet, in preparation).

surrounded by the younger Lina granite and it is therefore difficult to establish direct relationships with other formations of Norrbotten. It would be very important and interesting to connect the formations of the Aitik - Nautanen area with those of the Malmberget area, where the large iron ore deposits occur (see Fig. 1). However, due to the lack of outcrops in the border zone between the two areas, it has not been possible to make observations which could definitely establish the relationship. Geijer (1930) describes the bedrocks of the Malmberget iron ores as metamorphosed porphyries. However, as primary volcanic textures only can be observed occasionally, because of metamorphism and alteration, it is possible that at least part of the bedrock consists of metasediments.

According to K. A. Sandahl (verbal communication) it has been observed

in an outcrop near Malmberget, that porphyry cuts through rocks similar to those which occur in the Aitik area. This could indicate that the porphyries of the Malmberget are younger than the metasediments of the Aitik area. As this porphyry is probably of the same age as the Kiruna porphyries, this would mean that the metasediments of the Aitik — Nautanen area are of comparable age to the Kurraavaara conglomerate. However, we have at present not enough direct observations to determine definitely the stratigraphic position of the formations which occur in this area.

The Lina granite, that is obviously younger than the metasediments, has been determined by the Rb/Sr method to an age of 1540 ± 90 million years and the Kiruna porphyry to 1605 ± 65 million years (Welin 1970).

The geology of the Nautanen area, north of the Lina river, which is the direct continuation of the Aitik zone to the north has earlier been studied by P. Geijer (1917). In his description of the country rocks he uses the term leptite and regards most of the rocks as metasediments of generally clastic origin. Concerning the tectonics of the area he recognized the anticlinal structure of Nautanen and the synclinal structure in the Huivijokk valley as well as some other minor synclines.

To describe the geology of the area, it is best to distinguish between an east and a west part. The eastern part is characterized by low grade metamorphism and weak pneumatolytic or hydrothermal alteration. Sedimentary features of the rocks can still be easily recognized. In the western part the metamorphism and recrystallization is much more intensive, as well as pneumatolytic and hydrothermal alteration. Tourmalinization, scapolitization and the formation of rocks with skarn schlieren and veinlets is widespread. The Aitik deposit and the Nautanen mineralizations occur in the western zone, the mineralization of Liikavaara East in the eastern zone.

The difference in the grade of metamorphism and alteration between the two zones will be discussed later.

Tectonically we can recognize a syncline in the eastern part and an antiform structure in the western part.

In the eastern part we can distinguish between a lower rock unit of meta-arenites and a higher unit of meta-arenites with amphibolitic layers (centre of the syncline).

These rocks of the syncline in the eastern part will in this paper be summarized as the Liikavaara group.

To the north, outside the area mapped by the author, there appears below the meta-arenites a group of rocks consisting of skarn-banded rocks, mica schists and banded metasediments.

The meta-arenites have in this paper been summarized as Liikavaara group, as the village Liikavaara, as well as the deposit Liikavaara East are situated within the occurrence of this rock unit.

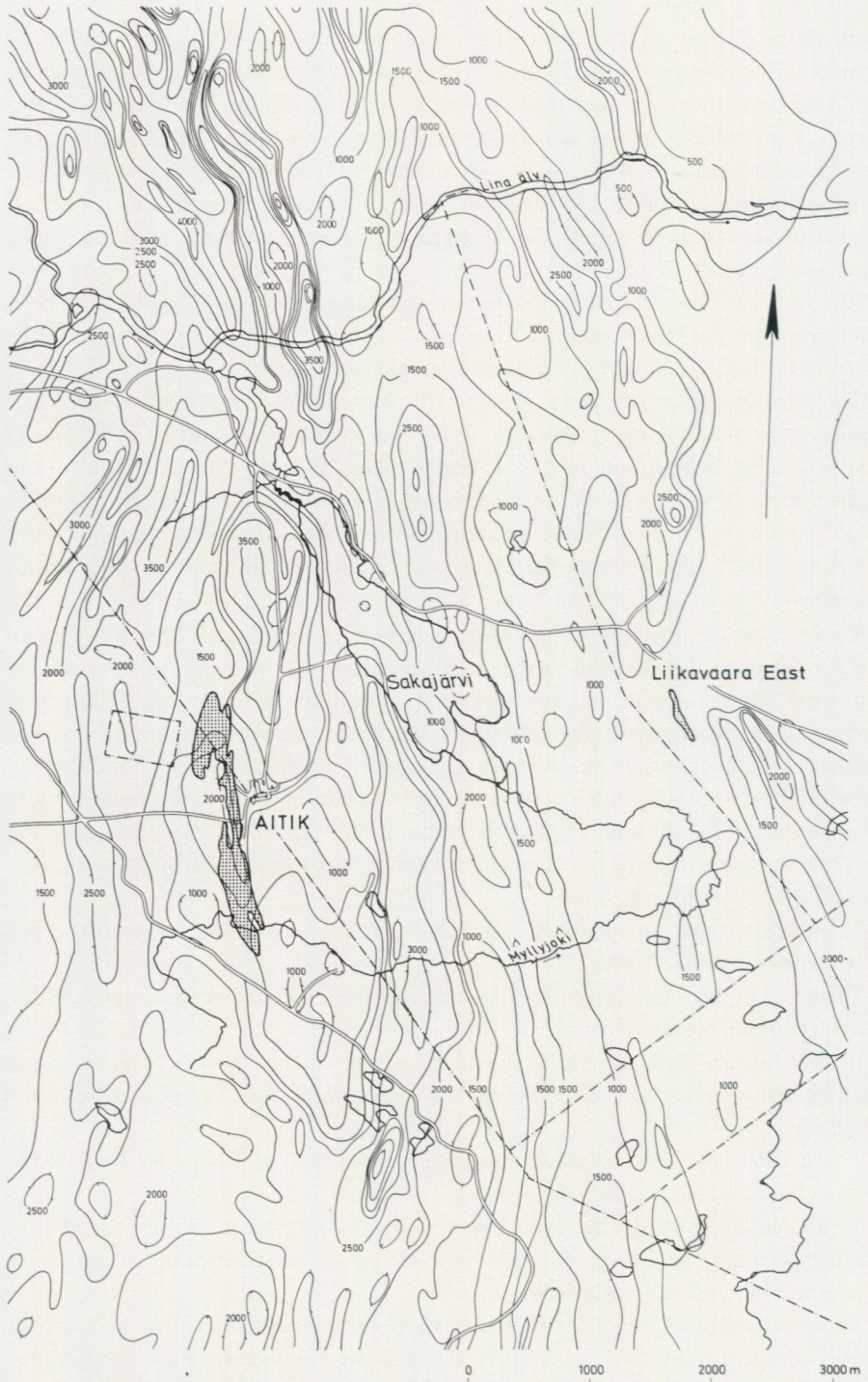


Fig. 2. Aero-magnetic map of the Aitik area.

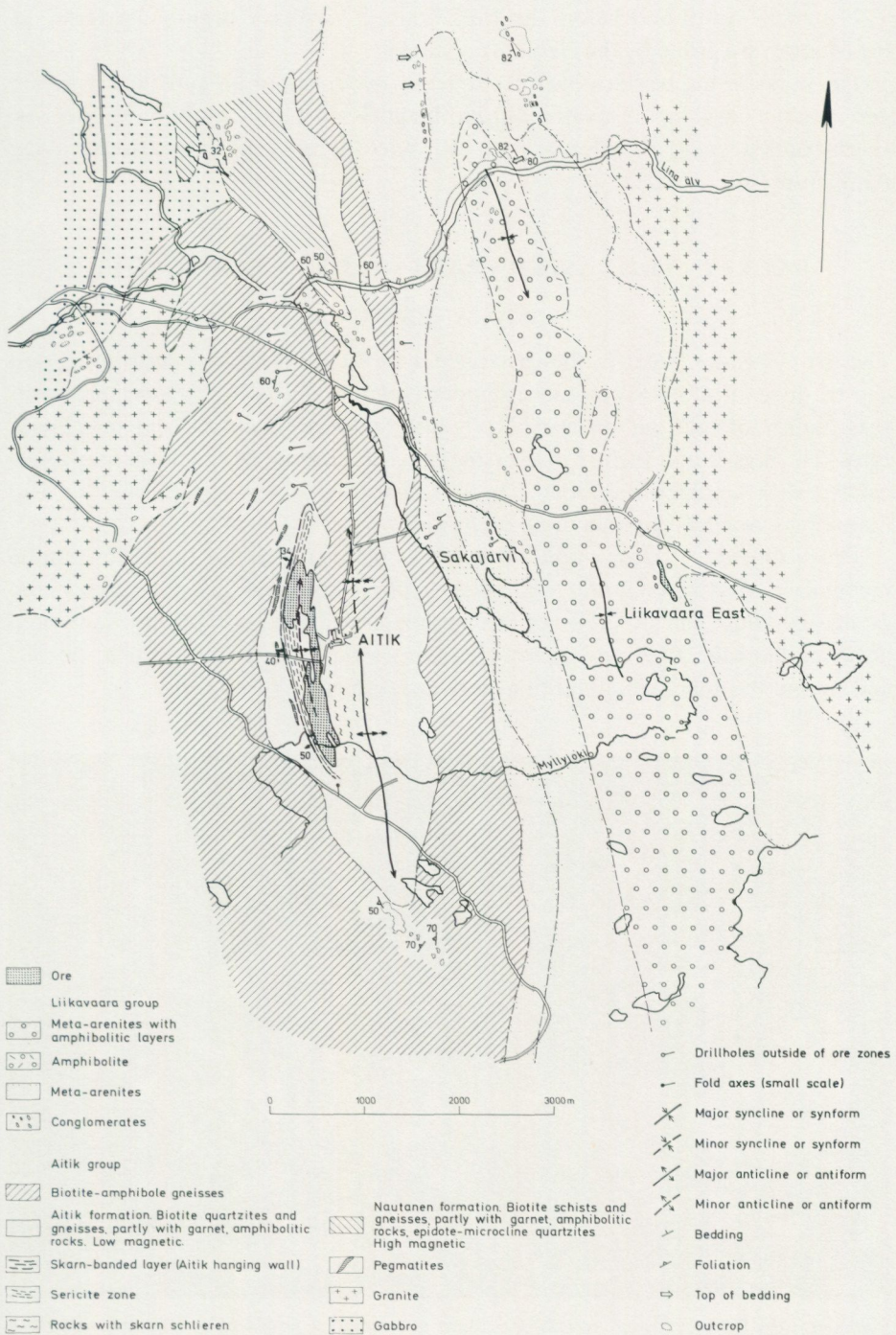


Fig. 3. Geological map of the Aitik area.

The rocks north and below the Liikavaara group have been summarized as the Muorjevare group by the Geological Survey.

The rocks in the western part, tectonically occurring in an antiform structure and mostly consisting of a variety of biotite gneisses, biotite-amphibole gneisses, skarn-banded gneisses, mica schists etc. have here been summarized as the Aitik group.

ROCKS IN THE EASTERN PART — LIIKAVAARA GROUP

META-ARENITES

The meta-arenites occur in the eastern part of the Aitik—Liikavaara zone, and can be divided into a lower and an upper formation. The lower formation consists mainly of feldspar quartzites, phyllitic feldspar quartzites and conglomerates. The higher unit (centre of syncline) is characterized by meta-arenites intercalated with amphibolitic rocks. The meta-arenites of the upper zone are also more of greywacke type than those of the lower zone.

The sedimentary clastic origin of the rocks belonging to this formation can be recognized as conglomerates and other sedimentary features, e.g. cross- and graded bedding, can be observed. Conglomerates are most typically developed north of the Lina river and in some drillholes on Lake Sakajärvi (e.g. dh 50) and west of the mineralization Liikavaara East (dh 65).

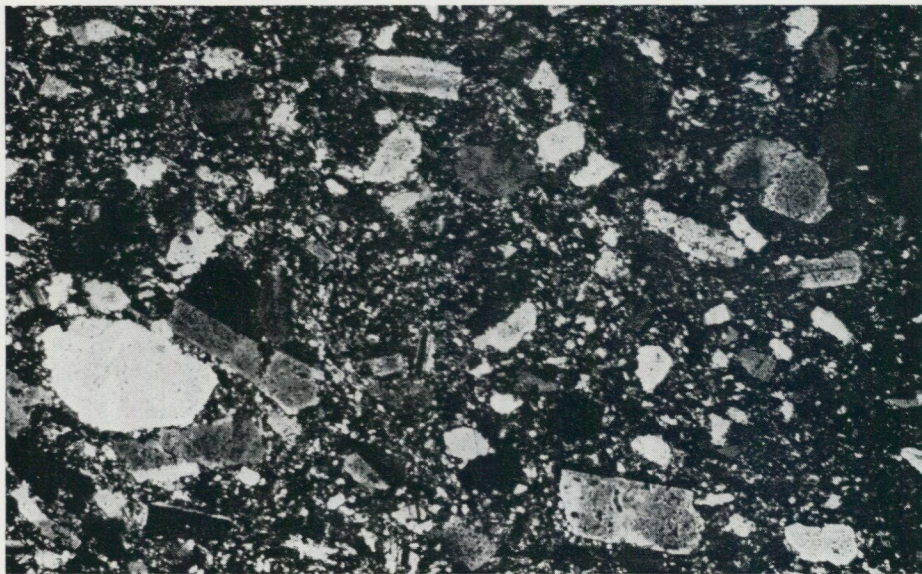


Fig. 4. Arenite from the Lina river. Sharp edged and rounded grains of quartz and oligoclase in a fine-grained matrix of quartz, feldspar, sericite, chlorite and magnetite. Sp 6660. Crossed nicols. Magn. 25x.



Fig. 5. Arenite from Sakkajärvi. Main constituents are quartz, oligoclase and biotite of even grain size. Amphiboles (lower part of the picture) are more porphyroblastic. Sp 11388, dh 53. Crossed nicols. Magn. 25x.

The rocks consist mainly of quartz and feldspar (generally oligoclase) with varying amounts of sericite, biotite and chlorite. Microcline may occur but is not abundant, calcite is often present and partly also some epidote. The plagioclase shows often sericitization, the microcline seems to be formed late and does not show any alteration.

Magnetite is quite abundant in parts, tourmaline and apatite occur as accessories. The rocks consist of a matrix with a grain size for quartz and feldspar between 0.01 and 0.05 mm, with scattered rounded or angular grains of plagioclase with a grain size of 0.1—0.6 mm.

The fabric is only slightly crystalloblastic and generally not lepidoblastic. Original sedimentary features can still be recognized.

The difference in metamorphism between the eastern zone and the western zone, mentioned in several parts of this report, is not so much a difference of the metamorphic facies but a difference of recrystallization. The minerals in the rocks of the eastern and the western zones are about the same with the exception of those obviously belonging to pneumatolytic or hydrothermal alteration. An exception are carbonates, which are common in the eastern zone, but occur in the western zone only as intrusive or mobilized veinlets. That amphiboles are more abundant in the western zone is probably due to the primary difference in the composition of the rocks.



Fig. 6. Arenite. Sericitized pebbles and grains of feldspar in a fine-grained matrix of quartz, feldspar, sericite and calcite. Sp 11405, dh 252. Crossed nicols. Magn. 25x.

Towards the amphibolitic rocks the arenites have a more phyllitic aspect. The arenites in the centre of the syncline are very little known as both outcrops and drillholes are very scarce. In the Lina river section only amphibolitic rocks are exposed, but dh 25 and dh 65 indicate, that the amphibolites only occupy part of the centre of the syncline and that the rocks mostly consist of meta-arenites. Dh 252 shows, that at least part of the rocks are meta-greywackes.

The name arenite has been used as it is difficult to give these rocks a well defined term. In the field the terms meta-arkose and meta-greywacke have been used, but the chemical analyses show that these classifications are not appropriate.

TABLE 1

Meta-arenites Average 15 analyses		Greywacke, average (Pettijohn 1957)		Arkose, average (Pettijohn 1954)	
SiO ₂	56.1		68.1		76.37
Al ₂ O ₃	17.1		15.4		10.63
MgO	2.9		1.8		0.23
CaO	4.9		2.3		1.30
K ₂ O	2.8		2.2		4.99
Na ₂ O	4.6		2.6		1.84
Fe _{tot}	5.3	Fe ₂ O ₃	3.4	Fe ₂ O ₃	2.12
FeII	3.0	FeO	3.4	FeO	1.22

(Samples from drillholes 50, 51, 52, 53)

The comparison of these analyses shows that there is a considerable difference between the arenitic rocks and those of arkoses and greywackes respectively. The SiO_2 content is considerably lower, the Al_2O_3 content higher, due to the fact that the rocks contain more feldspar and less quartz than arkoses and greywackes. The Na_2O content is higher and the K_2O content lower, as plagioclase is much more abundant than microcline.

The most appropriate term would probably be feldspathic quartzite.

The clastic origin of the arenite formation has been proved by the observation of the various above named sedimentary features. However, it is not clear from what kind of rock the material originated. The high sodium content does not suggest that the material originated from a granite. The chemical composition is rather similar to some volcanic rocks, but then one could expect to observe some volcanic fragments and not only well separated grains.

AMPHIBOLITIC ROCKS

Amphibolitic rocks occur in the Lina river section in the centre of the syncline. However, from drill core observations south of the river (dh 252, 25, 65), one can conclude that the centre of the syncline does not only consist of amphibolites, but rather of meta-arenites with amphibolitic layers.

Sedimentary structures, e.g. crossbedding, can be observed at some places along the Lina river section. These observations indicate that the rocks also have been formed at least partly by sedimentary clastic deposition.

The mineralogical composition is hornblende, biotite, plagioclase and quartz with magnetite, apatite and titanite as accessories.

The quartz appears in fine-grained lenses (0.02—0.1 mm), the plagioclase in rounded grains (0.2—0.8 mm), filled with sericite.

Hornblende and biotite occur as porphyroblasts 0.2—1 mm long.

TABLE 2

Analysis	
SiO_2	53.6 %
Al_2O_3	13.8 %
MgO	7.8 %
CaO	6.6 %
MnO	0.37 %
TiO_2	0.85 %
K_2O	2.4 %
Na_2O	2.0 %
Fe_2O_3	8.8 %
FeO	3.0 %

(Sample from outcrop near the Lina river, centre of syncline)

The sedimentary structures mentioned above, as well as the connection between amphibolitic rocks and rocks of greywacke type in dh 252, suggest that these rocks originally have been dolomite-rich clastic sediments. This means that during the formation of the arenites we had periods of more calcareous deposition, probably minor transgressions.

ROCKS IN THE WESTERN PART — AITIK GROUP

The rocks which we here call the Aitik group, have been divided into two different formations:

1. Biotite to biotite-amphibole gneisses
2. Aitik formation

Beside the petrographic differences which will be described below, there exists a difference in the magnetic intensity between the two rock units, the Aitik formation showing considerably lower magnetic properties.

The Aitik ore is situated in the western and upper part of the Aitik formation. The hanging wall of the Aitik ore is a typical skarn-banded layer.

THE AITIK FORMATION

The term Aitik formation has been applied to summarize different rock types which occur within the Aitik antiform structure. However, it is uncertain if these rock types belong to one or several stratigraphic units. The uncertainty is due to the following facts:

1. Alteration (sericitization, scapolitization, tourmalinization, the formation of skarn schlieren etc.) have changed the original composition of the rocks.¹
2. The area is extensively covered by overburden. The rocks can only be studied in drillholes and in the open pit. As the drilling has been concentrated to the ore zone, only a few observations can be made outside the mineralization.

Excluding those rocks that are obviously much influenced by alteration, one can conclude that the main rock type consists of quartz, plagioclase and biotite, with or without amphiboles (hornblende). The mineralogical composition is thus not very different from the rocks of the arenite formation, but the structure is more crystalloblastic and sometimes lepidoblastic. The average grain size of quartz and feldspar is 0.1—0.2 mm, compared with 0.02—0.1 mm in the arenite formation.

¹ The term skarn has in this paper not only been used for Ca-Mg-silicate rocks, but also for amphiboles and biotite. Skarn means here therefore a concentration of mafic minerals.

Microcline can often be observed, but is obviously a late product of infiltration.

Biotite is somewhat more abundant than in the arenite formation. Except for different types of banding, which probably are sedimentary in origin, no obvious sedimentary structures have been observed in the Aitik formation, probably because of more intensive alteration and lack of outcrops. The mineralogical composition and chemical similarity to the arenite formation suggests though, that the Aitik formation originally consisted of clastic sediments, with varying amounts of carbonates and clay minerals.

The rocks in metamorphic character alternate between quartzites, feldspar quartzites, biotite gneisses and biotite-amphibole gneisses. The term gneiss might not be correct, as the rocks are rather fine-grained. However, the author does not want to use the term leptite as it is not very well defined, and granulite is generally not used in Swedish literature. Micro-gneiss would probably be a proper term for rocks of this type.¹

The bedrock of the Aitik ore is a specific layer within the Aitik formation, mainly consisting of fine-grained biotite to biotite-garnet gneisses.

Within the zone of the Aitik mineralization these rocks have been partly altered to sericite quartzites, scapolite feldspar quartzites, gneisses with skarn schlieren, microcline epidote fels etc. These rocks will be described in the chapter describing the bedrock of the ore.

In summary we can say that the Aitik formation includes a variety of different metamorphic and altered rocks, probably of originally sedimentary clastic origin. It may or may not be a stratigraphic unit. No obvious observations of volcanic rocks have been made, but this might of course be difficult, as metamorphism and alteration have changed the original character of the rocks.

The hanging wall of the Aitik mineralization is formed by a layer of skarn-banded rocks, up to 20 m thick. Similar layers occur to a distance of about 200 m from the hanging wall, where the limit is drawn between the Aitik formation and biotite to biotite-amphibole gneisses. Even if partly skarn-banded rocks may occur together with the upper gneisses, they are not very frequent and not so typically banded as in the hanging wall zone.

The typical skarn-banded layers (5—30 m thick) consist of a fine-grained biotite gneiss with bands of skarn minerals, mostly hornblende, epidote, biotite, chlorite and sometimes garnet. These bands are from some millimetres up to 5 cm thick and the distance between the bands can vary between some centimetres up to 2 dm.

The most typical skarn-banded layer occurs generally in the hanging wall of the mineralization, towards the limit of the sericite zone. Sometimes the skarn-banded rocks are somewhat affected by alteration. Microcline infiltration can

¹ Definition of microgneiss, see Neues Jahrbuch f. Min. und Petr. 1963, p. 163: Ein Vorschlag zur qualitativen und quantitativen Klassifikation der kristallinen Schiefer, Alker et al.

partly be observed. The contact between the sericite zone and the skarn-banded rocks is sometimes obscured by the intrusion of pegmatites.

The hanging wall layer of skarn-banded rocks can be observed in all the drill-holes along the mineralized zone and is actually the only typical horizon in the western part of the Aitik area.

There has obviously been a change in the facies of sedimentation between the deposition of the rocks of the Aitik bedrock and the rocks now skarn-banded. This is also reflected in the chemical composition.

TABLE 3

	Typical skarn-banded rock	Aitik bedrock
SiO ₂	55.2 %	57.0 %
Al ₂ O ₃	14.9	16.1
MgO	5.7	1.9
CaO	9.9	3.1
K ₂ O	2.6	4.8
Na ₂ O	0.9	2.4
Fe _{tot}	5.7	6.4
FeII	0.9	3.8

Most typical are the higher CaO and MgO contents, which suggest a more calcareous-dolomitic deposition (the low Na₂O content is due to some microcline infiltration).

The skarn-banded rocks are generally not affected by alteration, apart from the above named sericitization close to the mineralized zone. Tourmaline occurs in connection with intruding pegmatites.

The grain size of quartz and feldspar is 0.1—0.5 mm, hornblende porphyroblasts have a size of about 1 mm.

BIOTITE — BIOTITE-AMPHIBOLE GNEISSES

These gneisses have been observed in drillholes east of the mineralization and in some outcrops south of the Aitik ore. The main rock type is a fine-grained biotite gneiss, which, through increasing content of hornblende, can go over into a biotite-amphibole gneiss and even to amphibolite. Epidote occurs sometimes as small nodules in the otherwise quite acid type of rocks. The gneisses are somewhat banded, due to the concentration of biotite and amphiboles, as distinct from quartz and feldspar. However, there is a difference in respect to the skarn-banded gneisses, which have more typically developed and wider bands consisting only of hornblende, epidote, biotite and chlorite.

The feldspar is generally oligoclase, sometimes oligoclase-andesine. The grain

size of quartz and feldspar changes between 0.1 and 0.5 mm. Biotite and hornblende occur as porphyroblasts but the grain size is generally not more than 0.5 to 1 mm. Epidote is sometimes an accessory and sometimes a main mineral. Otherwise apatite, titanite, magnetite and tourmaline occur as accessories. Microcline has infiltrated the gneisses and can locally be an important constituent. Scapolitization, tourmalinization and sericitization can not generally be observed, with the exception of an outcrop south of the Aitik ore, where scapolite occurs. The following analyses show the chemical compositions of various gneiss types:

TABLE 4

	Dh 534 14—19 m	Dh 534 139—144 m	Dh 534 189—194 m
SiO ₂	52.2 %	56.8 %	51.0 %
Al ₂ O ₃	15.7	16.1	17.2
MgO	2.3	2.5	4.2
CaO	7.2	4.6	10.8
K ₂ O	3.0	3.1	2.4
Na ₂ O	4.7	3.5	3.0
Fe _{tot}	8.5	7.6	6.9
FeII	1.5	1.8	0.8

These gneisses are interpreted as metamorphic, originally sedimentary rocks, even if no sedimentary structures can be observed. They can originally have been feldspar sandstones with changing amounts of calcareous, dolomitic and clay material.

NAUTANEN FORMATION

This formation occurs mainly north of the investigated area and will therefore not be described here in detail. The rocks of this formation are not very different from those of the Aitik group, and especially of the Aitik formation. There occur mica schists and gneisses, often with garnet, skarn-banded and amphibolitic rocks, as well as red, microcline-infiltrated micro-gneisses (leptites) with epidote. This combination of rocks is very similar to the rocks summarized as the Aitik formation. The main difference between the two formations is the dissimilarity of the magnetic characteristics. The magnetic intensity of the Nautanen formation is considerably higher. The aeromagnetic map shows 2000—5000 γ for the Nautanen formation and 400—2000 γ for the Aitik formation. Regarding the problems of the stratigraphic connection of the two formations and the structural interpretations, see the chapter on stratigraphic relationships p. 21 and the chapter on the pyrite — pyrrhotite — chalcopyrite — magnetite assemblage p. 67. The Nautanen formation is probably the equivalent or part of the Muorje-vare group (term used by the Geological Survey of Sweden to summarize different rock types which occur stratigraphically below the Liikavaara group).

GENERAL REMARKS REGARDING THE RELATIONSHIP OF THE DIFFERENT METASEDIMENTS

The rocks in the eastern part of the Aitik zone still show clastic sedimentary features and are evidently metasediments. In the western part the rocks are more recrystallized, metamorphic and altered. The macroscopic aspect between the eastern zone and the western zone is therefore often different.

If we take a look at the average chemical composition of the rocks from different parts of the Aitik zone, we see that variations in fact are rather small, with the exception of the ore zones Aitik and Liikavaara East (see Table 15).

The average SiO_2 -content is around 56 %, Al_2O_3 16—17 %, MgO 3—4 %, Fe_{tot} 5—6 %. The relation between Na_2O and K_2O is also very similar. CaO is slightly higher in the biotite-amphibole gneisses, and especially in the skarn-banded layers.

This indicates that the original sedimentation was quite uniform, with certain variations in the deposition of calcareous material. This explains why typical stratigraphic horizons are almost lacking, and the difficulty of producing stratigraphic relationships. It seems that the deposition on the western side was more variable, with changes of the CaO and partly the MgO content (change between biotite gneisses and biotite-amphibole gneisses and skarn-banded rocks).

GRANITE

The granite is a medium-grained reddish rock, macroscopically generally without metamorphic textures. It is, in the literature, generally called the Lina granite, widespread in Norrbotten. This granite surrounds the whole zone of metasediments, from south of Aitik to Nautanen. In the mapped area the granite occurs 1 km west of the Aitik ore and only 100—200 m east of the mineralization Liikavaara East.

The granite is obviously younger than the metasediments which have been intruded by the granite. The age of the Lina granite has been determined by Welin (1971) to be 1545 ± 80 million years (Rb/Sr method).

The main mineralogical constituents are quartz, microcline and albite-oligoclase. The microcline is more abundant than the plagioclase. Biotite can be observed but is only a minor constituent, often transformed into chlorite. Sericite is mostly only an alteration product of the plagioclase. Titanite, apatite, magnetite and zircon occur as accessories.

PEGMATITES

The pegmatites occur mostly on the western side of the Aitik zone, between the granite and the ore, and are obviously connected with the granite. Their frequency and thickness diminishes from west to east. In the upper parts of the

Aitik mineralization there occur a number of pegmatites generally not more than 1 m wide. West of the mineralization they can be 20 and more metres wide (their exact thickness is difficult to determine as the strike and dip in relation to the drillholes cannot be determined exactly). In the eastern part of the ore and in the footwall, pegmatites do not generally occur.

The frequency and thickness also increases with depth. Between 400 and 600 m depth pegmatites up to 40 m have been encountered.

Many pegmatites follow more or less the general strike, but they can also cut right through the bedrock, as can be observed for example in the southern part of the open pit.

Mineralogically they consist of quartz, microcline and albite; black tourmaline is a characteristic constituent and is seldom absent.

Most pegmatites have a slight pink colour and the main feldspar is microcline. Some pegmatites are white and albite is more abundant than microcline.

Apart from tourmaline, only muscovite can be a more important constituent. Spots of magnetite occur sometimes. Molybdenite, scheelite and uraninite have been observed occasionally, but are obviously very rare and rather a curiosity.

STRATIGRAPHIC RELATIONSHIPS AND TECTONIC PROBLEMS

As the mapped area is largely covered by moraine and swamps, the results of the geophysical surveys have been extensively used for reconstructing the geology. The magnetic map has especially been of great help.

As the interpretation of the stratigraphic relationships and the tectonic structure are intimately connected, the two subjects will be treated together.

The magnetic map shows on the eastern side of the area, where the meta-arenitic rocks of what we call the Liikavaara group occur, a large scale fold structure (see magnetic map). Way-up determinations based on crossbedding observations north of the Lina river indicate that this is a syncline with an axis dipping SSE (observations made by K. A. Sandahl and P. Padget of the Geological Survey). This means that the meta-arenites in the centre of the syncline are the youngest rocks in this part of the area. Older rocks do not occur in the east zone within the mapped area south of the Lina river, but further to the north, below the feldspar quartzites, a formation of banded metasediments and mica schists appears and in between a zone of skarn-banded rocks (Muorjevare group).

On the western side the following observations were made:

1. The dip in the zone of the Aitik mineralization is about 45° W.
2. The dip according to observations in drill cores is steeper to the east.
3. Folding axis in the southern part of the Aitik zone dips $20\text{--}30^{\circ}$ SSE, in the northern part $20\text{--}35^{\circ}$ NNW.

These observations together with the shape of the magnetic picture indicate an antiform and a culmination, this means a dome structure. The antiform is interpreted to be double folded. The Aitik mineralization occurs on the western flank of the antiform.

The rocks of what we call the Aitik formation, in the centre of the antiform, therefore have to be regarded as older than the biotite-amphibole gneisses.

The question is then how the eastern and the western parts of the area, i.e., the Liikavaara group and the Aitikgroup, can be connected tectonically and stratigraphically, and what is the relationship between the Aitik group and the rocks of Nautanen.

The syncline can be followed to the north, where older formations appear below the feldspar quartzites. The limit of this structure to the west is abrupt and marked by a low magnetic zone, which can be followed from the Sakajärvi to the Nautanen area.

The Geological Survey interprets the Nautanen zone as an antiform structure, where older rocks have been moved upwards. The age of the rocks of the Nautanen area could then be the same as those which appear in the syncline below the feldspar quartzites.

The Aitik formation disappears to the north below biotite-amphibole gneisses because of the NNW-plunge of the fold axis.

The eastern limb of the antiform, including both the Aitik formation and the biotite-amphibole gneisses, can be followed on the magnetic map somewhat north of the Lina river (see geological map Fig.3). However, north of the Lina river these formations are substituted by the higher magnetic rocks of the Nautanen formation along a distinct line. The relationships between the rocks of the Nautanen formation and those of the Aitik group are not quite clear. No very important petrographic difference exists between the rocks of these formations. In both we can distinguish gneisses, mica schists, skarn-banded rocks, amphibolitic rocks and red microcline-infiltrated rocks with epidote. The latter are generally more usual in the Nautanen formation than in the rocks of the Aitik group. However, there is a remarkable difference in the magnetic properties of the two formations, the magnetic intensity of the Nautanen formation being considerably higher. This could be explained in different ways:

1. The Nautanen formation and the rocks of the Aitik formation are stratigraphically identical, but there exists a primary difference in the facies of these formations.
2. The rocks of the Nautanen formation are slightly older than those of the Aitik formation and have been pushed upwards tectonically.
3. The differences between the two formations are due to metamorphism only and not to primary features.

Tentaviley I want to propose that the Aitik formation and the Nautanen formation should belong to the same stratigraphic unit and that there existed a primary difference between the respective facies. Tectonic movements have probably occurred along the border zone between the Liikavaara group in the east and the Aitik-Nautanen group in the west. We call this zone the Sakajärvi zone. We do not know how important these tectonic movements have been. The Sakajärvi zone marks in any case also a difference in the grade of metamorphism and alteration between the two groups.

Tentatively I propose the following stratigraphic model for the area:

TABLE 5

Liikavaara group

Upper meta-arenites with amphibolitic layers.

Lower meta-arenites, quartzites in the Huivijokk valley.

Aitik group

Biotite-amphibole gneisses

Aitik formation

Skarn-banded rocks, sericite schists and quartzites, biotite schists and gneisses, gneisses with skarn schlieren, amphibolitic rocks

Nautanen group

Biotite-amphibole gneisses (?)

Nautanen formation

Skarn-banded rocks, biotite-garnet, schists and gneisses with microcline and epidote, amphibolites

Muorjevare group

(definition page 19)

Skarn-banded rocks, mica schists, banded metasediments

If this interpretation is correct, the rocks of the Liikavaara group which occur within the eastern syncline are the youngest in the area. The rocks of the Aitik formation in the centre of the western antiform represent the oldest rocks. The Aitik group, the Nautanen group and the Muorjevare group are of similar age.

It must be mentioned here, that the geological interpretation of the magnetic map is based on the assumption that the magnetic isoanomaly curves indicate the stratigraphic units of the area. On the eastern side (Liikavaara group) we have enough geological information and observations of primary sedimentary features to demonstrate that this is correct. However, on the western side (Aitik-Nautanen formation) observations of primary sedimentary features are lacking and it is difficult to connect different zones on a geological basis, due to metamorphism and alteration. It is therefore quite possible that the magnetic picture on the west side is influenced by metamorphism and alteration. In this case the geological picture presented here would be only partly correct. However, we have no alternative at present for producing a possibly better geological picture — we are forced to use the magnetic map, and we would need more sophisticated geological investigations to interpret the magnetic isoanomaly curves in certain parts of the area as "isostratigraphic" and other parts as "isometamorphic".

POSSIBILITY OF VOLCANIC ROCKS

The rocks of the Aitik—Liikavaara—Nautanen area have all been described as metasediments. For most of the meta-arenites the sedimentary character is well established by the observation of sedimentary textures. Regarding the amphibolitic rocks of the Liikavaara group they have been interpreted as metamorphosed dolomitic sediments which still show sedimentary textures e.g. cross bedding. The possibility of partly tuffitic origin must be considered, however.

In the western part where we have the Aitik group, it is more difficult to establish the original character of the various rock types. It should be clear though that also here most of the rocks are metamorphosed sediments, e.g. the biotite and biotite-garnet schists, quartzites and gneisses, the skarn-banded rocks and the biotite-amphibole gneisses. Also here most of the amphibolitic rocks have been interpreted as somewhat dolomitic, metamorphosed sediments. However, we have to admit that it is possible that volcanic rocks could occur among all the different rock types whose original textures have been obscured by metamorphism. Some of the metasediments could for example contain volcanic material and originally have been tuffs, and certain amphibolitic rocks might originally have been basic dikes. Certain rock types within the biotite-amphibole gneisses have some features which could originally have been agglomeratic, and porphyrites and quartz diorites are reported from the area north of the Lina river.

THE AITIK DEPOSIT MINERALOGY

The only ore mineral of any economic importance is chalcopyrite. Beside the chalcopyrite the mineralization includes pyrite, magnetite and pyrrhotite. Malachite occurs occasionally in the weathering zone. Chalcocite and bornite are rare and especially concentrated in quartz veins, where they often coat the chalcopyrite. Quantitatively these minerals are of no importance but they can locally raise the Cu content of the concentrates. Sphalerite, galena and arsenopyrite have only been observed occasionally. The chalcopyrite contains sometimes small inclusions of fahlerz. Ilmenite occurs sometimes together with the magnetite, and hausmannite has been observed in a few polished sections. Uraninite, scheelite and molybdenite occur now and then as isolated grains in the pegmatite veins.

The grain sizes of the ore minerals are as follows:

TABLE 6

	Max.	Min.	Most frequent
Chalcopyrite	1.5 mm	0.01 mm	0.05—0.1 mm
Pyrite	7.0 „	0.01 „	0.05—0.1 „
Magnetite	3.0 „	0.02 „	0.05—0.2 „
Pyrrhotite	5.0 „	0.01 „	0.05—0.5 „



Fig. 7. Aitik; disseminated chalcopyrite and pyrite in sericite schist. Pp 5595, dh 124. Polished section. Magn. 10x.

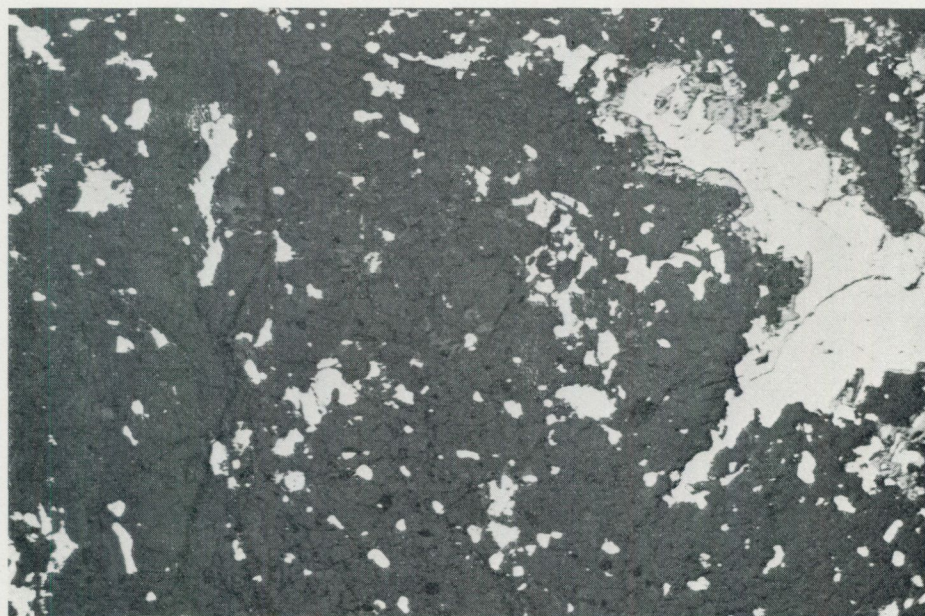


Fig. 8. Aitik; chalcopyrite and magnetite in biotite gneiss. Magnetite forms a border around the large chalcopyrite crystals to the right. Pp 4564, dh 32. Polished section. Magn. 10x.

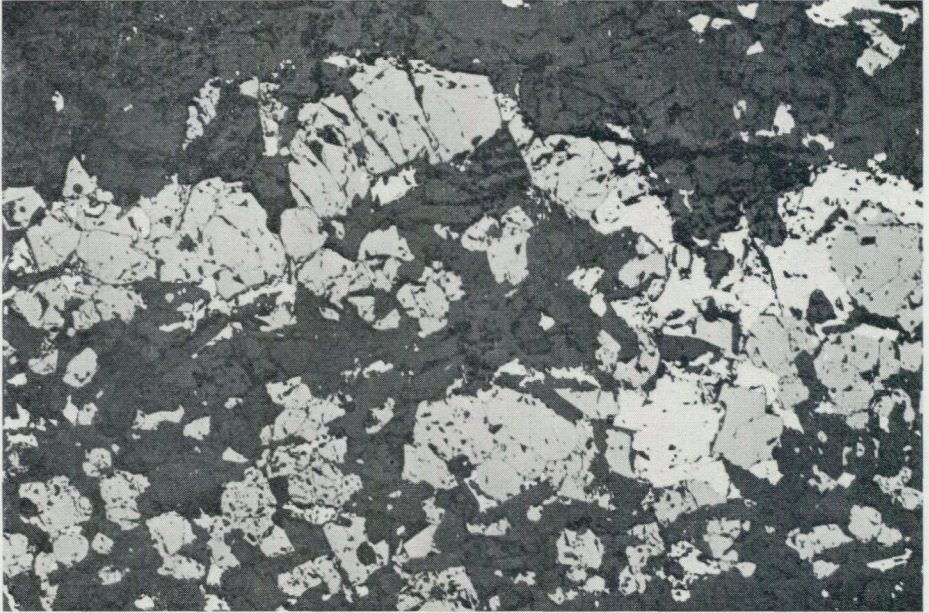


Fig. 9. Aitik; veinlets of chalcopyrite and magnetite. Pp 4569, dh 39. Polished section. Magn. 10x.

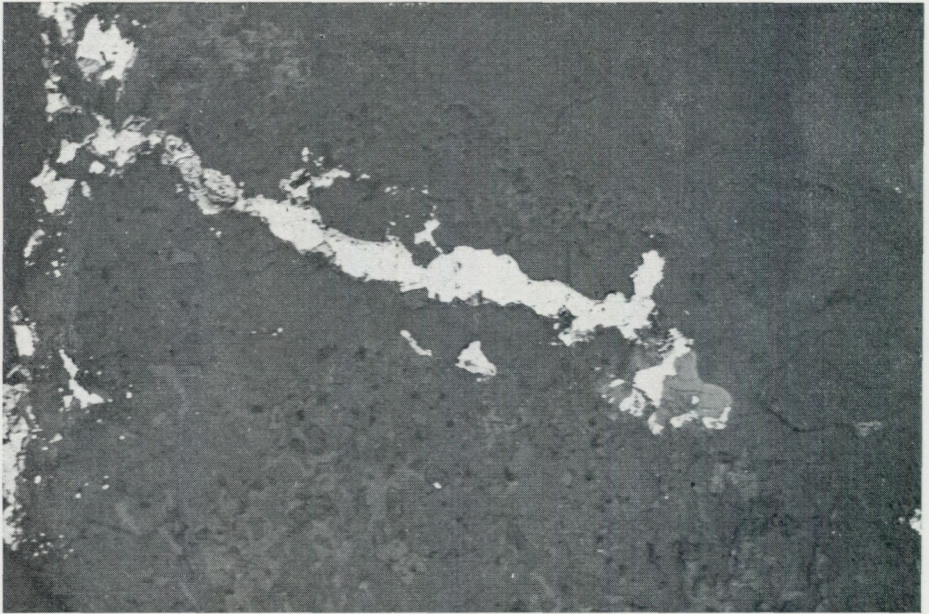


Fig. 10. Aitik; veinlet of chalcopyrite, some magnetite crystals. Pp 7380. Polished section. Magn. 10x.

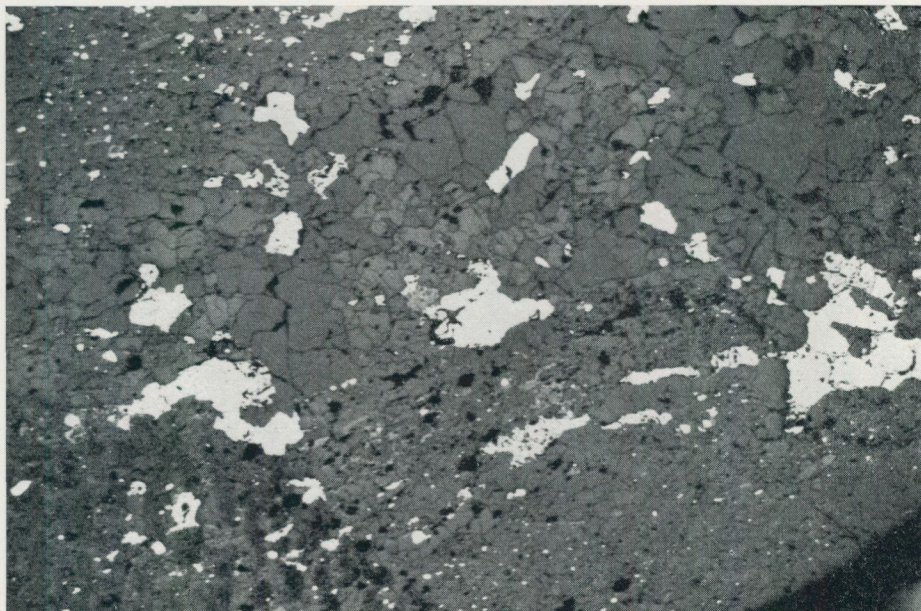


Fig. 11. Aitik; chalcopyrite partly disseminated, partly in small veinlets. Pp 5578, dh 160. Polished section. Magn. 10x.

Larger grains of chalcopyrite may contain inclusions of the other ore minerals, but the chalcopyrite also occurs as small grains or veinlets in the other minerals. Pyrite has been observed to be coated by chalcopyrite and magnetite, as well as chalcopyrite by magnetite.

Inclusions of chalcopyrite in pyrite are rather rare, but chalcopyrite sometimes brecciates the pyrite.

Quartz and barytes are the most frequent gangue minerals. Fluorite and calcite are occasionally met with. Black tourmaline, scapolite and apatite occur within the mineralization, but these minerals are common in the area of higher metamorphism in the western part of the Aitik—Nautanen zone and are not only characteristic for the ore. The tourmaline occurs partly disseminated, or as fels in the bedrock and partly in the pegmatites.

According to determinations of the refraction indices, the scapolite is generally a dipyr [$Ma_{70}Me_{30}$, $(n_{\omega} + n_{\epsilon})/2 = 1.550$].

Chabasite has been observed on joints.

The most important skarn mineral is a dark hornblende, which often occurs together with biotite. Epidote is partly connected to red aplitic gneisses rich in late microcline. The skarn minerals are often concentrated in schlieren and veinlets. In this form they are common in parts of the ore and in the footwall. A concentration of chalcopyrite and pyrite is common in these veinlets and

schlieren and we can thus observe a connection between ore and skarn minerals. However, the skarn minerals are not only typical for the ore and its immediate surrounding, but also for the entire western zone of higher metamorphism.

Sericite is clearly connected with the mineralization, especially with the type rich in pyrite which is common towards the hanging wall. The sericite seems to be mainly an alteration product of biotite.

BEDROCK

The mineralized bedrock consists of a series of metamorphic rocks, ranging from mica quartzites to mica schists, biotite gneisses, biotite-amphibole gneisses and gneisses with skarn schlieren. The biotite schists and gneisses may contain red garnet in certain parts of the mineralization. The main type is a biotite microgneiss, towards the hanging wall more sericitic.

The texture is generally lepidoblastic and the rocks are fine-grained.

TABLE 7

	Min.	Max.	Most frequent
Quartz and feldspar	0.05 mm	0.2 mm	0.1 mm
Mica	0.1	1.0	0.4
Garnet	0.1	10.0	1.0

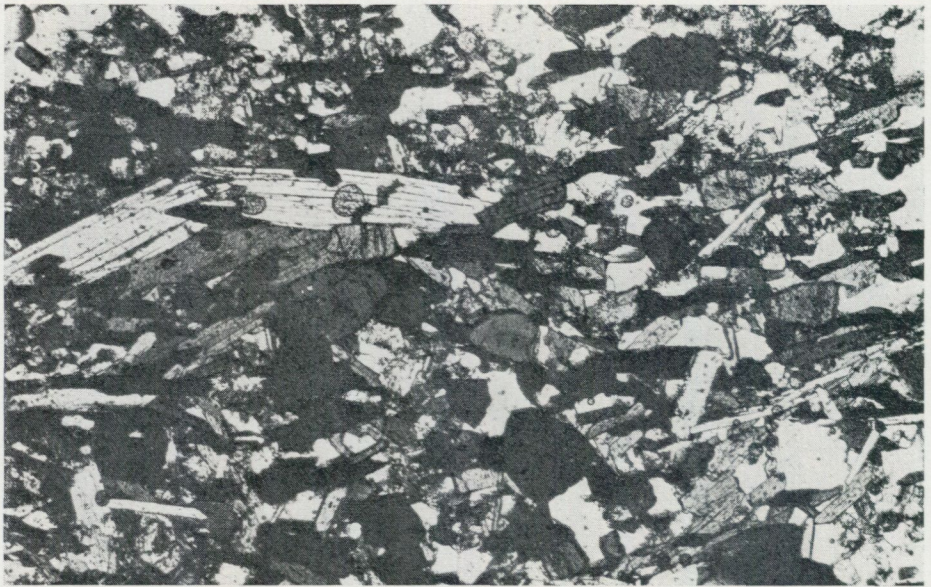


Fig. 12. Aitik bedrock; mica schist. The main minerals are quartz (white), biotite (grey-black flakes), muscovite (white flakes), tourmaline (triangular black-grey crystals). Muscovite cuts through biotite. Sp 10109. Nicols not crossed. Magn. 25x.



Fig. 13. Aitik bedrock; a sericite-biotite quartzite with microcline. Quartz, biotite, sericite, microcline, ore minerals. Sp 11319. Crossed nicols. Magn. 25x.



Fig. 14. Aitik bedrock; biotite gneiss with garnet. Quartz, oligoclase, biotite, sericite, garnet, tourmaline, ore minerals. Sp 11383. Crossed nicols. Magn. 25x.

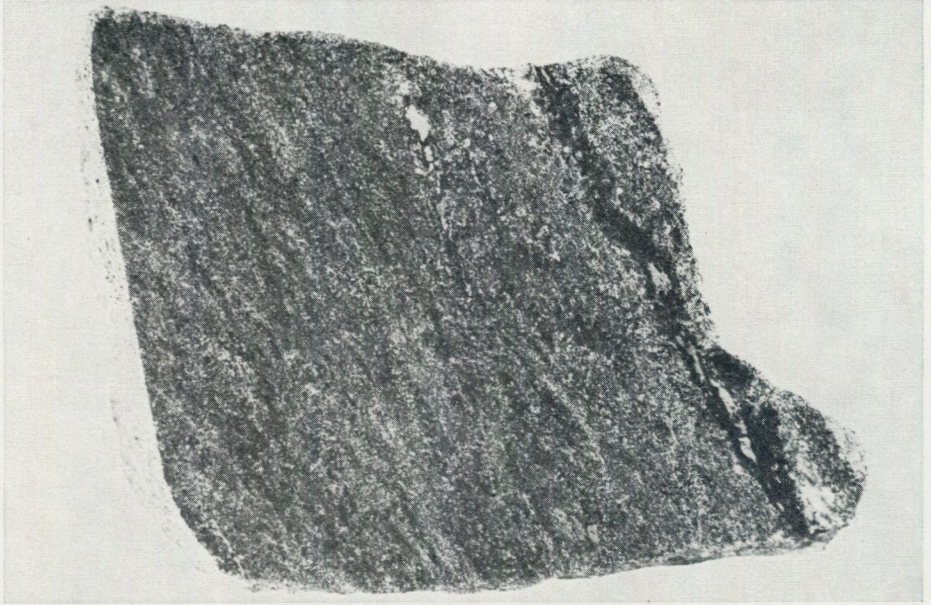


Fig. 15. Aitik bedrock; biotite gneiss with disseminated chalcopyrite. Beside a very fine-grained dissemination which is hardly visible, one can observe more coarse-grained chalcopyrite in connection with dark biotite bands. About natural size.

It has been difficult to relate different rock types from one drill hole to another, due to the fact that many small variations exist in composition and alteration, and that a characteristic horizon or bed is lacking, with the exception of the hanging wall. The hanging wall is formed by a layer of skarn-banded gneisses which is very typical and can easily be recognized in every drillhole.

The quartzites contain varying amounts of biotite and feldspar. They go over into mica schists with increasing amounts of biotite and sometimes muscovite, and into gneisses with an increasing content of feldspar. The feldspar is generally an oligoclase, often showing alteration into sericite. Microcline is subordinate but common throughout the mineralization and the whole west zone of higher metamorphism. The microcline is idiomorphic, does not show any alteration and has typically crystallized later than plagioclase and biotite.

The general sequence from the hanging wall to the footwall is the following:

Skarn-banded rocks. Hanging wall of the mineralized zone.

Sericite schists, quartzites and micro-gneisses. Disseminated pyrite and some chalcopyrite. The rocks contain mainly sericite, quartz, oligoclase and varying amounts of chlorite and biotite.

Biotite micro-gneisses, often with some garnet. Disseminated chalcopyrite and some pyrite. The rocks contain mainly biotite, quartz and oligoclase, with changing amounts of garnet, scapolite, tourmaline, microcline and chlorite.



Fig. 16. Aitik bedrock; biotite gneiss with disseminated chalcopyrite (the chalcopyrite cannot be seen in black and white photographs). Main type of bedrock.



Fig. 17. Aitik bedrock; sericite schist towards the hanging wall.

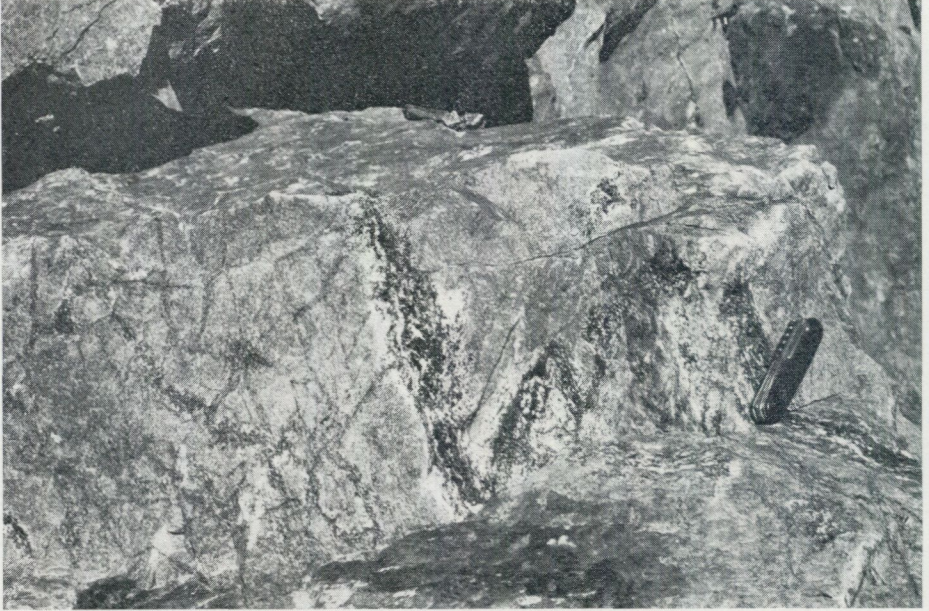


Fig. 18. Aitik bedrock; folded amphibolitic band with white leached zone on both sides. Chalcopyrite follows the amphibolitic band. Footwall of mineralization.



Fig. 19. Aitik bedrock; skarn veinlets. The rock shows also scapolitization.



Fig. 20. Aitik bedrock; skarn and quartz veinlets. The quartz infiltrates and cuts the skarn veinlets.



Fig. 21. Aitik bedrock; amphibole-epidote skarn band with white border zone of quartz and feldspar. Mobilization of mafic material. Chalcopyrite is concentrated in the skarn band.

Amphiboles become more frequent towards the footwall.

Gneisses with skarn veinlets and schlieren (hornblende, biotite, chlorite, epidote). Chalcopyrite and pyrite concentrations together with the skarn. Sometimes veinlets of baryte. These rocks form the footwall of the mineralized zone, and are generally outside the economic mineralization.

Coarse-grained gneisses occur on the footwall side of the mineralization.

Red aplitic gneisses occur in some parts of the ore zone, partly together with epidote. They are most common towards the footwall and especially in the deeper parts of the deposit, e. g. near and below the 600 m level in section 19N (dh Aitik 523). This rock type has been formed by infiltration of microcline and different degrees of microcline content can be observed, from very small contents to pure microcline rock. Generally these rocks show only a very poor or no mineralization at all. However, in the deeper parts of dh Aitik 523 the red aplitic gneiss contains considerable copper contents.

Most of the observed structures should be tectonic features and not primary sedimentary structures. An exception are the skarn bands in the hanging wall which probably represent primary sedimentary features. Otherwise one can generally only observe foliation, shear zones and cleavage.

The pegmatites follow generally the foliation, but can also cut right through the bedrock.

MINERALIZATION — MODE OF OCCURRENCE

The mineralized zone occurs on the western flank of an antiform structure and is, at the surface, almost 3 km long and 400 m wide. On the western side, towards the hanging wall, we have a sharp limit of the mineralized zone, marked by the skarn-banded gneisses. To the east the mineralization fades out gradually and there is no sharp geological limit.

The general dip of the mineralized zone is 45°W and the strike $\text{N}10^{\circ}\text{—}20^{\circ}\text{E}$. The dip of the footwall (grade limit) is generally somewhat steeper than the dip of the hanging wall. In the deeper parts the dip of the hanging wall flattens to about 35°W .

The plunge of the economic mineralization is $25^{\circ}\text{—}30^{\circ}\text{N } 20^{\circ}\text{E}$ in the northern part of the ore. In the southern part the plunge is probably around $20^{\circ}\text{S } 20^{\circ}\text{W}$ according to observations of fold axes. However, this has not been verified by drilling.

Within the above mentioned 3 km long mineralized zone, ore with an average of 0.4 % Cu occurs at the surface over a length of 2 km and a width of 200 m.

The known ore areas on the different levels are the following:

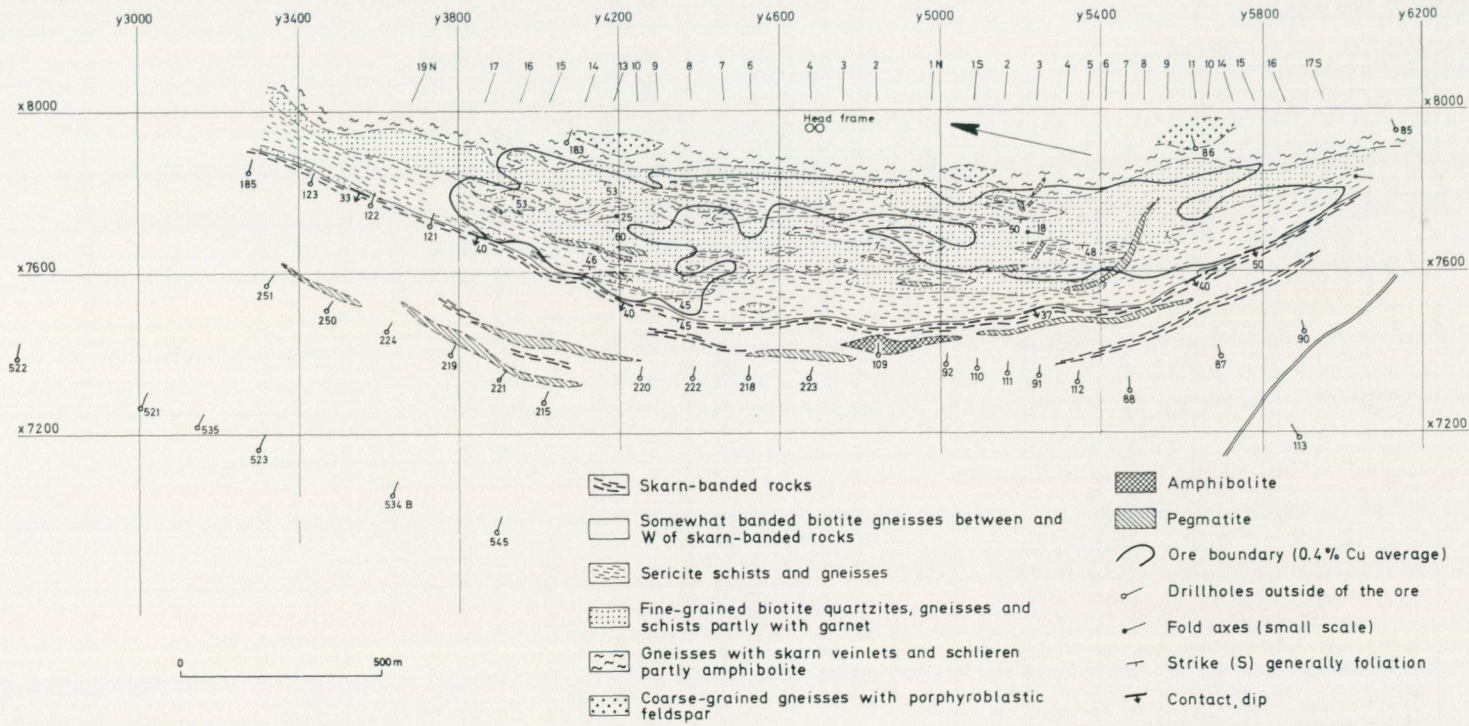


Fig. 22. Geological map of the Aitik copper deposit.

TABLE 8

	Average % Cu	Cut-off % Cu	Area m ²	Average % Cu	Cut-off % Cu	Area m ²	Average % Cu	Cut-off % Cu	Area m ²
Surface	0.68	0.5	100,000	0.5	0.32	220,000	0.4	0.22	380,000
300 m	0.65	0.5	92,000	0.54	0.40	205,000	0.42	0.22	480,000
600 m	0.70	0.5	14,000	0.52	0.40	97,000	0.38	0.22	270,000

The 300 and 600 m levels are at present only known in the northern part of the mineralization.

The mineralized zone is generally wider at deeper levels (see sections 13, 15 and 19 N). However, the ore sections within the mineralized zone are generally unchanged or less wide. At the deepest known levels the ore zone is partly interrupted by pegmatites and the ore sections can therefore be smaller than at the higher levels (see e.g. section 15 N).

Pegmatites occur also at the surface, but are there generally not more than 1 m wide and not very numerous. Their number and width increases with depth, especially below the 400 m level.

When we talk about ore sections at deeper levels, we mean sections with Cu contents that are considered as ore at those levels which can be mined in open pit. However, we must keep in mind that higher grades will be required for an underground operation. This means that from an economic point of view, the ore sections and areas will be considerably smaller (an average content of at least 0.7 % Cu will probably be necessary). From a geological point of view it is more appropriate to talk about areas and sections of the same content, disregarding whether they can be of economic value at one level and non-economic at another level.

Several types of mineralization can be distinguished within the Aitik ore:

1. Disseminations and stringers of chalcopyrite and some pyrite in fine-grained biotite gneisses, schists and quartzites. Garnet may occur in the biotite gneisses and schists. These rocks may partly show scapolitization and tourmalinization. The chalcopyrite occurs often together with concentrations of pyrite.
2. Disseminated pyrite and chalcopyrite in sericite schists and quartzites or partly sericitized biotite gneisses.
3. Chalcopyrite and pyrite in skarn schlieren and veinlets. Stringers of magnetite and barytes.
4. Chalcopyrite and pyrite in quartz veins and veinlets (partly with some bornite and chalcocite).
5. Chalcopyrite in red aplite-like microcline-infiltrated gneisses (only known in one drill hole at the 600 m level).



Fig. 23. Cu distribution. Aitik ore, northern part. First bench — based on results from production drilling.



Fig. 24. Cu distribution. Aitik ore, southern part. First bench — based on results from production drilling.

No. 1 is the most important type, forming the main part of the economic mineralization, followed by No. 2, the dissemination connected with sericitization. This type is mainly developed towards the hanging wall (see sections Figs. 26—27).

Pyrite often dominates in this type and the Cu content is partly of non-economic grade. The skarn schlieren type occurs generally near the footwall and is only locally (in the northern part of the open pit) of economic value.

Quartz veinlets with chalcopyrite are irregularly distributed throughout the mineralization, but larger veins are rare. However, they can locally be of economic importance because of high Cu contents, partly due to the occurrence of bornite and chalcocite.

Fig. 23 shows the distribution of the Cu contents in the northern part of the Aitik ore. We can recognize several centres of concentrations with average contents of more than 0.70 % Cu, within the general mineralization grading 0.15—0.70 % Cu. The main zone with higher Cu values occurs in the northern part between the centre of the mineralization and the hanging wall. This zone consists of several lens-shaped concentrations which occur "en echelon". Within the > 0.7 % Cu concentrations we even have parts grading more than 1 % Cu. A minor zone of concentrations is situated on the eastern side of the northern part of the open pit and this zone strikes with interruptions towards the southern part of the mineralization.

Fig. 24 shows the distribution of the Cu contents in the southern part of the ore. At present the results of the production drilling are only available for a part of the southern zone. The pattern of the Cu distribution is somewhat different from the northern part. In the north, the Cu concentrations follow the direction of the bedding and the schistosity, which means around N—S. In the south we can also observe features of the Cu concentrations following the same stratigraphic and tectonic directions, but there is also a strong tendency to follow E—W to N60°W directions.

On the geological map we can see that the pegmatites in this part of the ore zone strike N60°W to E—W, with a flat dip to the south. As there is no mineralization in the pegmatites, this direction of the Cu concentrations can partly be faked by the low Cu values where the drillholes have cut the pegmatites (the Cu values are never zero, because the 15 m long drillholes have cut through the pegmatites and into the bedrock with Cu disseminations). However, even where no pegmatites have been cut by the drillholes, we can observe this E—W directions. A possible explanation is, that pneumatolytic activity in connection with the pegmatites, has redistributed an earlier N—S dominated pattern.

There exists a zonal distribution between pyrite and chalcopyrite (see sections Figs. 26—27). The pyrite is more abundant towards the hanging wall. With the distance from the hanging wall, the amount of pyrite decreases and the amount of chalcopyrite increases. Section 19N suggests also that pyrite is concentrated at the top of the mineralization. Sericitization is partly related to higher pyrite

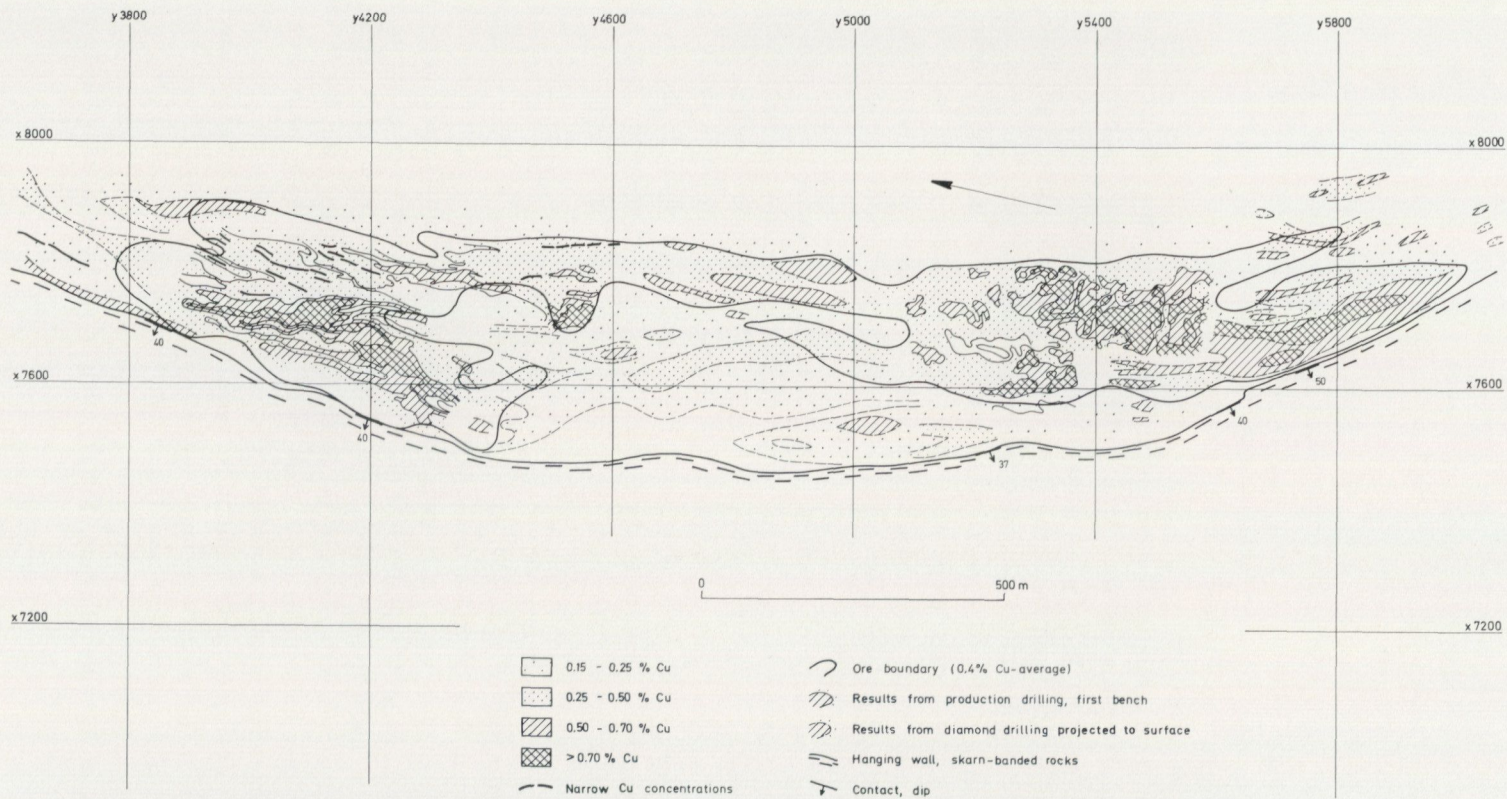


Fig. 25. Cu distribution i the Aitik ore zone.

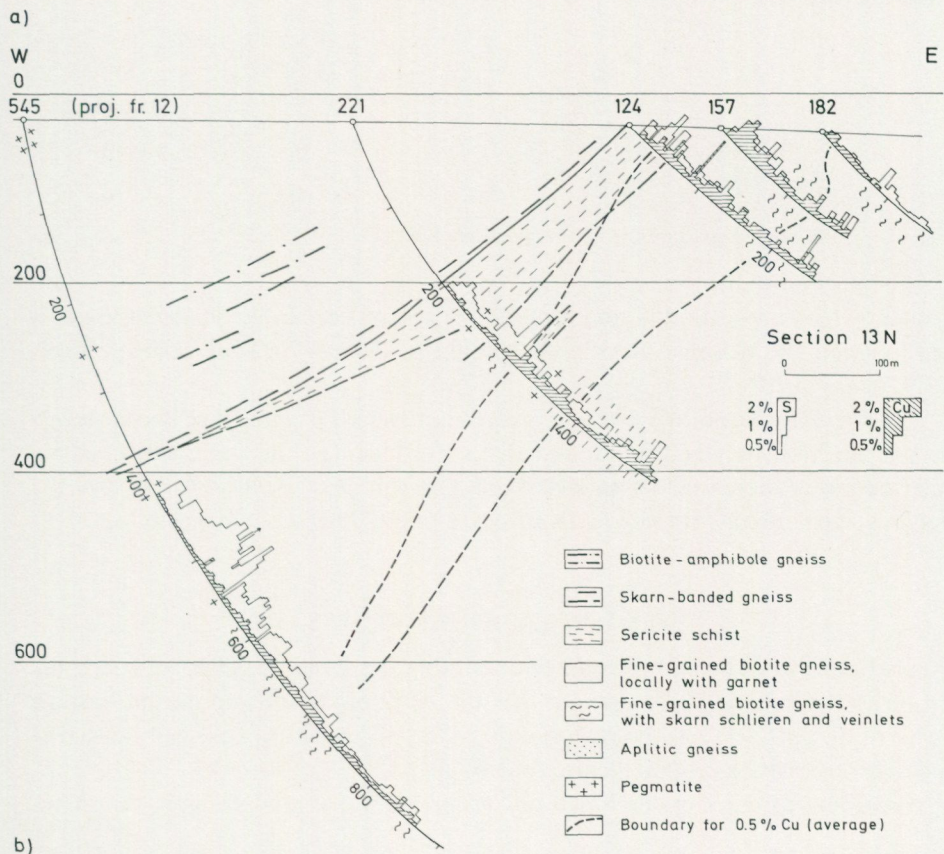
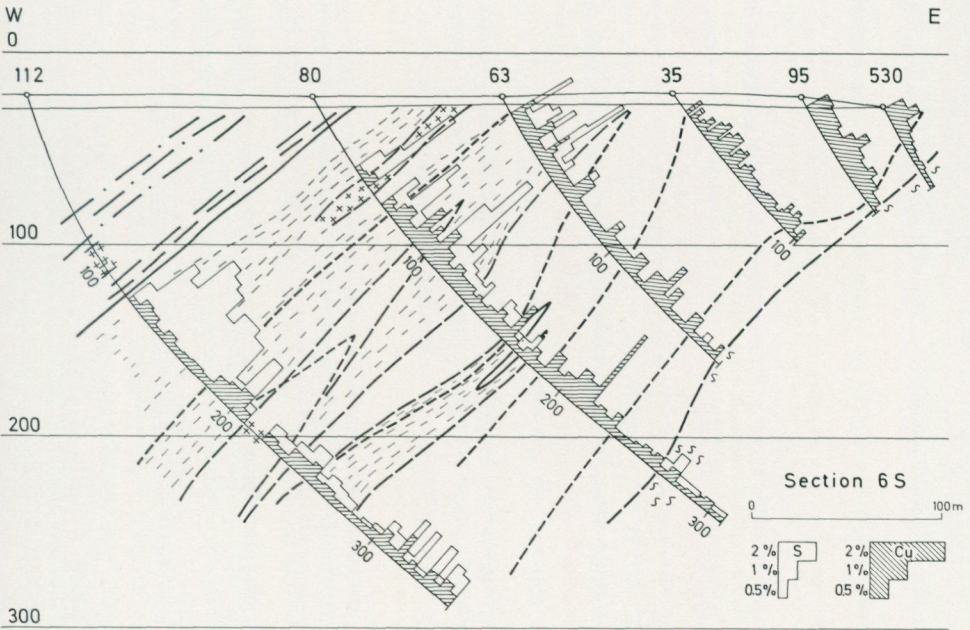


Fig. 26. Aitik ore, cross sections; a = section 6 S; b = section 13 N.

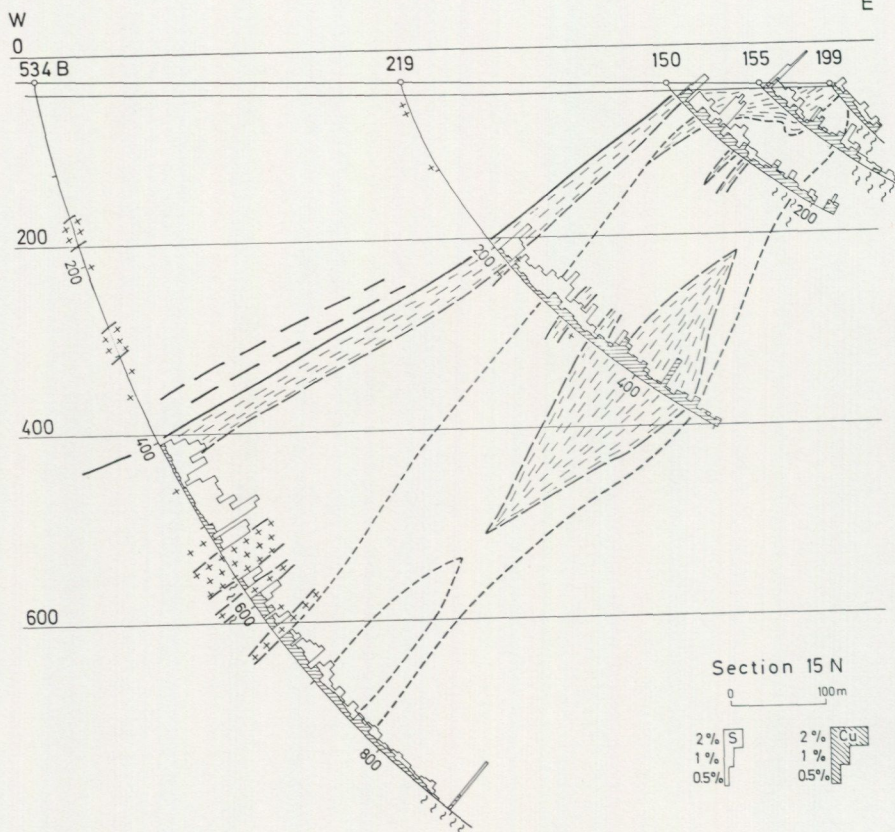


Fig. 27 a. Aitik ore, cross section. 15 N. (Legend see Fig. 26.).

contents. In some sections a minor pyrite concentration can be observed towards the footwall and in some sections the zoning is not so typical as in the sections 13N, 15N and 19N.

The southern part of the ore is at present not so well examined at deeper levels as the northern part and many S-analyses are lacking. The pyrite-chalcopyrite distribution is therefore not so well known in this part. Section 6 S shows the geology and Cu-S distribution in the southern part of the ore.

TECTONIC OBSERVATIONS

It has been discussed in the chapter on stratigraphic relationships and tectonic problems, that there are indications that the Aitik ore is situated on the western flank of an antiform and dome structure. We will therefore here only describe tectonic observations within the ore zone.

According to the sections based on results from diamond drilling, the mine-

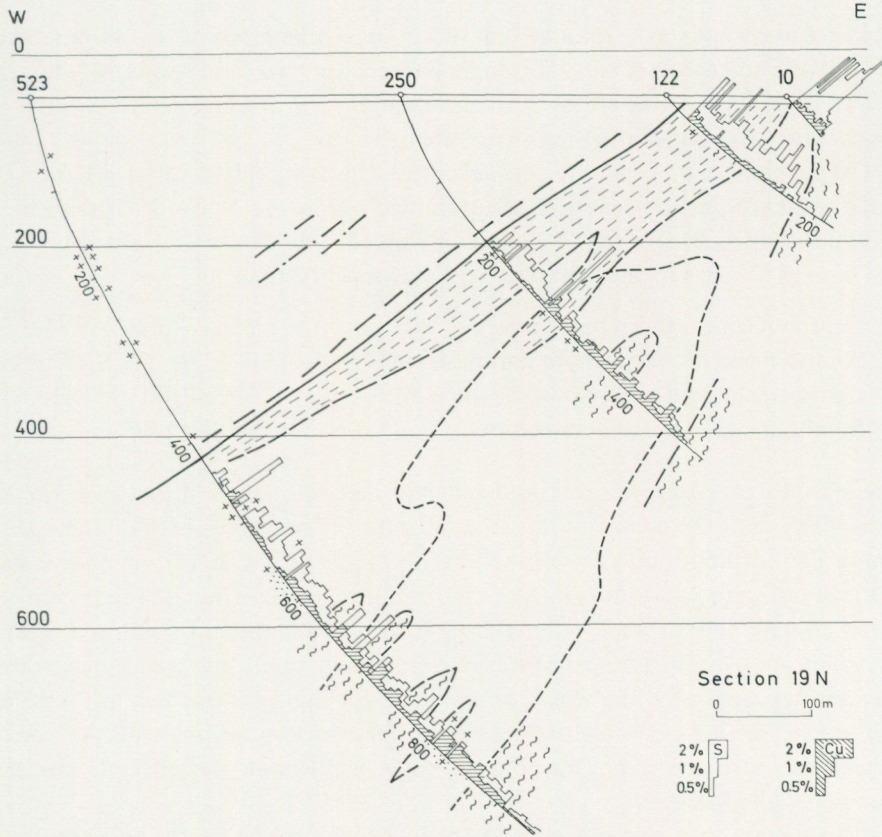


Fig. 27 b. Aitik ore, cross section 19 N. (Legend see Fig. 26.).

ralized zone dips uniformly and without complications about 45° W. Unfortunately the bedrock is very much jointed and cracked within the first benches which are worked at present. Structural observations can therefore only be made occasionally. However, it has been observed that the bedrock in some parts is intensively folded on a small scale (cm to dm). In the northern part of the open pit, there occur somewhat uncertain structures which indicate an anticline on the western side, followed by a thrust zone. It seems therefore that the picture is not so simple and uniform as expected from the drill holes and that both folding and thrusting have occurred within the mineralized zone. It is also probable that the mineralization is situated in a minor anticline on the western flank of the larger antiform structure.

The following main joint sets have been observed within the ore zone:

1. N50—80°E/80°N—80°S
2. N60—85°W/80°N—80°S
3. N10—20°W/70°E—85°W

The first two joint sets form a system of tension faults more or less symmetrical to the strike and the fold axes. The angle between the two joint sets is $50\text{--}60^\circ$.

The third joint set is not so well developed. It is approximately parallel to the general strike and consists of shear joints.

The pegmatites are generally parallel to the schistosity ($N10\text{--}20^\circ E$). However, in the southern part of the mineralization they follow the $N60\text{--}85^\circ$ joint set.

Some shear zones striking N—S and dipping $45\text{--}60^\circ W$ can be observed.

The axes of small scale folds have the following directions:

- | | |
|---|--|
| 1. Centre of the northern part of the open pit: | $25^\circ\text{--}30^\circ N 25^\circ W$ |
| 2. Southern end of the northern part of the open pit: | $0^\circ, 5^\circ N, 10^\circ S 30^\circ W$ |
| 3. Centre of the southern part of the open pit: | $18^\circ S 20^\circ W, 15^\circ S 10^\circ W$ |
| 4. Southern end of the mineralization: | $25^\circ S 20^\circ W$ |

These fold axes observations could indicate that the top of the culmination is somewhere near the centre of the mineralization. The plunge of the mineralization in the northern part is confirmed by drilling. The 0.4 % Cu ore shows also in the south part a flat plunge to the north and does thus not follow the dip of the small scale folding axes to the south. However, the mineralization as a whole, including the pyrite disseminations, seems to follow the folding axes also in this part and the plunge of the whole mineralized zone is probably flat to $20^\circ SSW$. The bottom of the 0.4 % Cu ore has been established by drilling with the exception of the northern end. The bottom of the whole mineralized zone has not been met with in any part.

If we have a look at the dip of the skarn-banded rocks in the hanging wall, we can see that the dip is flat in the northern part of the ore, where the ore zone is plunging north. In the southern part this dip becomes steeper, up to 50° . This indicates that the folding is getting more isoclinal to the south.

THE LIKAVAARA EAST DEPOSIT

MINERALOGY

As in Aitik chalcopyrite is the only mineral of economic importance. Regarding other minerals there exist some differences between the two deposits. In Liikavaara East pyrrhotite is more abundant than pyrite, magnetite on the other hand is not so common as in Aitik.

Galena and sphalerite are often observed, but the Pb and Zn content is generally below 1 % respectively. The average content in Pb and Zn is low, however.

The grain sizes of chalcopyrite, pyrrhotite and pyrite are about the same as in Aitik. However, pyrrhotite occurs also in larger grains.

Chalcopyrite may be observed as inclusions in the pyrrhotite, especially when the pyrrhotite occurs in larger aggregates. On the other hand, chalcopyrite con-



Fig. 28. Tourmaline-calcite veinlet from Liikavaara East. Calcite, tourmaline and ore minerals. Sp 7927. Crossed nicols. Magn. 25x.

tains often inclusions of pyrrhotite. Chalcopyrite veinlets cutting the pyrrhotite have also been observed. Magnetite has been observed occurring between pyrite and pyrrhotite, as a border around pyrite (see Fig. 30). Pyrrhotite shows often inclusions of marcasite, obviously exsolutions.

Galena and sphalerite occur occasionally on small fractures filled with calcite.

Scheelite occurs in several sections of the Liikavaara East mineralization and is especially connected with quartz veinlets and sometimes calcite veinlets. These quartz veinlets cut the Cu mineralization and occur even outside the ore zone, e.g. in granite 1 km north of Liikavaara East. The WO_3 content can locally be up to 0.28 %.

Quartz and calcite are the most common gangue minerals. Fluorite occurs in connection with calcite veinlets. Black tourmaline and apatite are common within the mineralized zone. Barytes and scapolite, two minerals that are typical for the Aitik zone, are almost absent here.

Sericite occurs only occasionally; biotite and hornblende are typical minerals in the bedrock, as well as chlorite.

BEDROCK

The main bedrock in Liikavaara East is a biotite schist. With an increasing plagioclase content (generally oligoclase) the schists can go over into biotite gneisses, with an increasing quartz content into biotite quartzites. The biotite is partly

altered into chlorite. In some parts amphiboles are quite abundant and the bedrock consists of biotite-amphibole schists or gneisses. West of the ore zone occur feldspar quartzites with conglomeratic layers (dh 65).

Calcite is found throughout the mineralized zone. The calcite is partly more or less uniformly distributed in the bedrock, but appears also in small veinlets and as aggregates. Small tourmaline-calcite veinlets have been observed, sometimes with some grains of scheelite. It has not been possible to determine if all the calcite is primary and the veinlets represent mobilized carbonate material, or if part of the calcite has infiltrated.

Zircon is abundant, forming pleochroic halos in the biotite.

Tourmaline can be observed disseminated in the bedrock and as tourmaline fels. Apatite is often observed.

Quartz veinlets occur frequently. They only occasionally contain Cu minerals but sometimes scheelite.

The relatively high MgO content indicates that the biotite partly may have been formed by Mg metasomatism. Even the Ca content is somewhat higher, but the difference from the arenite formation is not so strong that a carbonate infiltration must be concluded.

MINERALIZATION — MODE OF OCCURRENCE

The tectonic position of Liikavaara East is not very clear. It seems to occur on the eastern side of the Liikavaara syncline. As the ore is only known from drill-holes, it is not possible to make any detailed observations on joints, folds, fold axes etc.

The mineralization occurs in a N15°W striking zone of biotite schists and the dip is about 80°W (see Fig. 31). The length of the mineralized zone is about 1 km and the width 100 m. Within this mineralized zone it has been possible to determine the following ore areas:

TABLE 9

Level (below surface)	Area m ²	Average % Cu	Cut-off % Cu
40 m	20,600	0.55	0.3
120 m	16,700	0.52	0.3

The Cu content varies both on the cm and m scale. On the m scale the Cu values may generally change between 0.2 and 1 %, but there occur also sections which are 0.4—2 m wide with Cu contents between 2 and 5.3 %.

According to the section in Fig. 31, the mineralized zone has about the same width from the surface down to 240 m, but the sections with average grades over 0.5 % Cu diminish somewhat with depth. However, the mineralization at 240 m

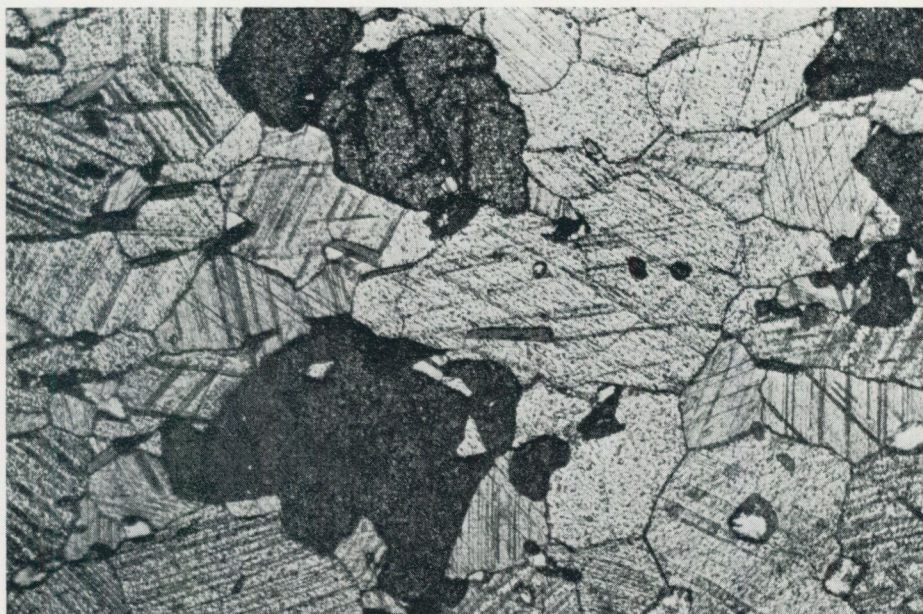


Fig. 29. Calcite veinlet with scheelite from Liikavaara East. Calcite and scheelite. Sp 7920. Nicols not crossed. Magn. 25x.

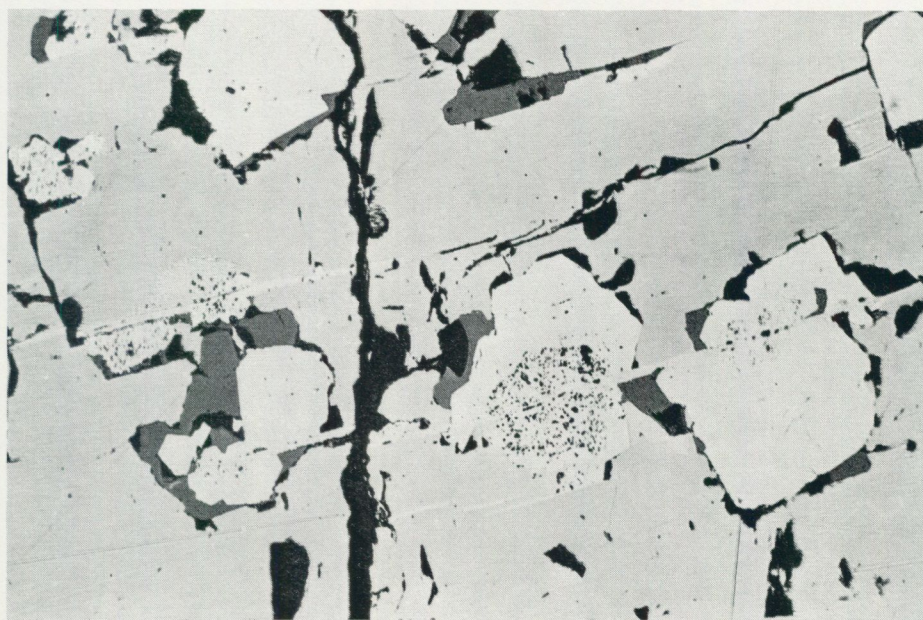


Fig. 30. Pyrite crystals within pyrrhotite. Magnetite between pyrite and pyrrhotite. Pp 4642. Polished section. Magn. 10x.

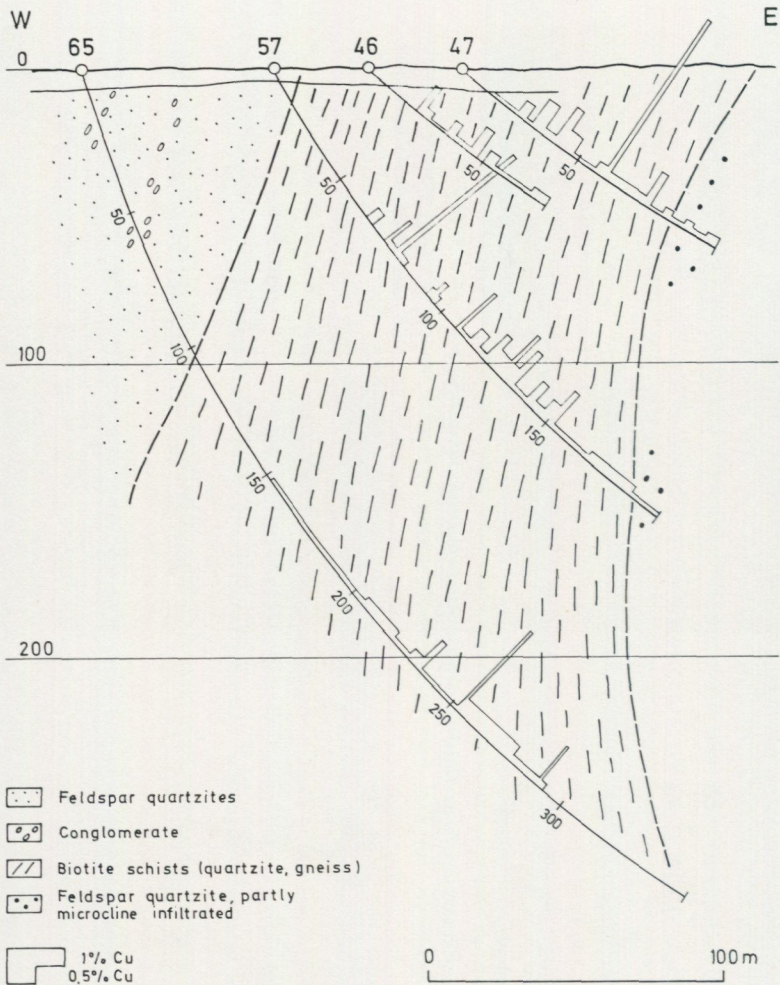


Fig. 31. Liikavaara East, vertical section.

is only known in one drillhole (dh 65) and it is therefore too early to draw any definite conclusions.

Scheelite occurs in minor contents quite generally. In certain sections, especially where many quartz veinlets occur, scheelite can be quite abundant. The following table shows the WO_3 content of the best sections.

TABLE 10

Dh	Section (m)	Width (m)	% Cu	% WO_3
14	33.90—48.23	14.33	1.11	0.17
49	107.94—115.39	7.45	0.13	0.28
57	169.47—178.81	9.34	0.47	0.08

However, the average content within the Cu zone is not more than 0.05 % WO_3 .

Scheelite does not only occur in the zone of Cu mineralization. Dh 22, situated 1 km N of Liikavaara East, shows e.g. 0.33 % WO_3 in granite over a width of 5 m. The scheelite also is connected here with quartz veinlets which also contain some chalcopyrite.

Galena and sphalerite occur occasionally in small fractures together with calcite. The Pb and Zn contents are below 1 % respectively in the best sections. The average Pb and Zn contents are far below an economic grade.

GEOCHEMICAL INVESTIGATIONS

GEOCHEMISTRY OF THE COUNTRY ROCKS

TABLE 11

Liikavaara group. Chemical composition of the arenites and amphibolitic rocks

		1	2	3	4	5	6	7	8
SiO_2	%	48.0	51.0	55.8	58.1	60.5	61.3	57.2	53.6
Al_2O_3		15.0	14.2	19.4	18.0	16.6	16.6	17.0	13.8
Fe _{tot}		8.6	7.4	6.2	3.4	3.8	3.6	5.0	5.4
FeII		4.7	4.5	2.7	2.0	2.8	2.5	3.0	2.3
MnO		0.25	0.19	0.09	0.14	0.19	0.10	0.1	0.37
MgO		5.1	4.4	1.3	2.3	2.7	3.3	3.0	7.8
CaO		6.5	7.5	3.1	5.1	4.2	4.2	5.0	6.6
Na_2O		2.9	3.3	5.5	4.4	4.4	5.1	4.7	5.5
K_2O		3.1	3.1	4.1	2.4	2.8	2.4	2.5	2.4
TiO_2		1.2	1.1	0.6	0.5	0.5	0.5	0.7	0.85
S		0.02	0.15	0.04	0.05	0.02	0.02	0.13	0.1
Ba		0.15	0.12	0.19	0.10	0.13	0.08	0.09	0.08
Zn	g/t	155	120	155	43	70	90	94	185
Pb		5	6	11	2	3	2	8	8
Cu		150	760	70	70	65	8	180	33
As		<2	6	18	12	<2	4	15	3
Sb		<5	<5	<5	<5	<5	<5		<5
Bi		<0.5	1	0.5	1	<0.5	<0.5	1	<0.5
Sn		<2	4	2	<2	<2	<2	2	<2
In		<0.5	0.5	0.5	<0.5	<0.5	<0.5		<0.5
Ga		20	18	25	12	22	24		18
Ag		<0.3	0.4	0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Ge		0.6	0.7	1.1	1.3	1.1	0.7		1.4
Mo				<20				<20	<2

1 Dh 53, 95 – 100 Reddish feldspar quartzite

2 Dh 53, 45 – 50 Grey feldspar quartzite

3 Dh 50, 45 – 50 Reddish conglomeratic feldspar quartzite

4 Dh 52, 55 – 60 Coarse-grained feldspar quartzite

5 Dh 51, 70 – 75 "

6 Dh 51, 45 – 50 "

7 Average arenites 25 samples from dh 50, 51, 52, 53, 25, 57 (10 – 40 m) 65 (10 – 115 m)

8 Amphibolitic rock

Some information on the chemical composition of the country rocks has already been given in the respective descriptions of the different rock types. We shall here first give some more details regarding the variations within a certain rock type, including the trace elements, and afterwards compare the chemical composition of the different country rocks. The chemical composition of the different rocks can be studied in Tables 11 and 12.

TABLE 12

Aitik group. Chemical composition of the biotite gneiss and skarn-banded rocks

		1	2	3	4	5	6	7
SiO ₂	%	50.9	52.9	55.5	56.4	58.8	55.2	56.8
Al ₂ O ₃		15.8	14.9	17.2	17.9	17.7	14.9	16.6
Fe _{tot}		9.4	9.1	5.8	5.8	5.5	5.7	6.2
FeII		2.1	2.8	1.4	2.1	2.2	0.9	1.9
MnO		0.23	0.32	0.30	0.20	0.30	0.36	
MgO		3.2	4.3	3.2	2.8	2.8	5.7	3.1
CaO		7.2	6.1	7.7	6.9	5.4	9.9	6.3
Na ₂ O		4.2	4.1	2.9	3.1	1.4	0.9	3.2
K ₂ O		2.5	2.3	3.0	2.3	3.6	2.6	2.8
TiO ₂		1.8	1.5	0.75	0.8	0.8	0.65	
S		0.06	0.06	0.04	0.05	0.06	0.04	
Ba		0.05	0.07	0.03	0.03	0.11	0.04	0.07
Zn	g/t	110	360	70	70	85	105	103
Pb		5	11	6	6	5	13	9
Cu		20	55	5	6	3	5	12
As		4	<2	<2	<2	<2	19	6
Sb		<5	<5	<5	<5	<5	5	
Bi		<0.5	0.5	<0.5	0.5	0.5	1.5	1
Sn		2	4	<2	2	<2	<2	3
In		<0.5	<0.5	0.5	<0.5	<0.5	1	0.3
Ga		22	25	22	24	23	20	
Ag		<0.3	0.5	<0.3	<0.3	<0.3	<0.3	<0.3
Ge		1.0	1.5	1.0	1.0	1.1	1.4	1.2
Mo		<20	<20	<20	<20	<29	280	20

1-6 Samples from dh Aitik 534

7 Average 22 samples from dh Aitik 534 and Liikavaara 219, hanging wall

CHEMICAL COMPOSITION OF THE AITIK ORE

Table 13 shows the chemical composition of the northern and the southern parts of the ore. The assays are based on 90 and 72 point samples respectively from drill cores. These samples have been taken within the 0.5 % Cu ore. Those of the ore zone, related in Table 15 and used in Figs. 32 and 33 as well as for the factor analyses, have been taken over the entire mineralization.

The assays show that most of the metallic elements except Cu occur in minor amounts only. This confirms the fact that other minerals than the main ore mine

erals have only been observed occasionally or in traces. Silver occurs probably mainly in the form of very small tetrahedrite inclusions in the chalcopyrite.

BaO is relatively high, as baryte is a common mineral within the mineralized zone. Fluorine occurs partly in fluorite and partly in apatite, chlorine in scapolite.

TiO₂ occurs partly in ilmenite, partly in titanite and amphiboles.

TABLE 13
Average chemical composition of the Aitik ore

	Aitik North (90 point samples from drill cores)	Aitik South (72 point samples from drill cores)
SiO ₂ %	58.6	61.8
TiO ₂ %	0.50	0.45
Al ₂ O ₃ %	18.1	17.1
Fe _{tot} %	5.2	5.3
FeII %	3.6	3.6
MnO %	0.40	0.40
MgO %	1.8	1.7
CaO %	2.6	2.5
Na ₂ O %	2.1	1.0
K ₂ O %	6.5	5.9
Au g/t	0.5	0.4
Ag g/t	4	6
Cu %	0.56	0.48
Co %	0.005	0.004
Ni %	0.0025	0.003
Zn %	<0.01	<0.01
Cd %	<0.001	<0.001
Hg %	0.0002	0.0004
Sn %	<0.001	<0.001
Pb %	0.002	<0.001
Bi %	<0.001	<0.001
Sb %	<0.001	<0.001
As %	<0.001	<0.001
Mo %	0.005	0.002
Te %	<0.001	<0.001
S %	<0.003	<0.003
Se %	1.4	1.5
SO ₄ (S %)	0.03	0.03
BaO %	1.04	0.90
WO ₃ %	0.001	~0.001
CO ₂ %	0.04	0.03
F %	0.033	0.036
Cl %	0.020	0.017
H ₂ O _{tot} %	1.26	1.16
P ₂ O ₅ % (different sample)		0.18
V ₂ O ₅ %	0.06	0.06

CHEMICAL COMPOSITION OF THE LIIKAVAARA EAST
MINERALIZATION

Table 14 gives the chemical composition of the Liikavaara East mineralization. The material for the assay has been taken from sections of four drillholes representing an average of the mineralization. We can note, that also here Cu is the main element of economic importance, but there exist some differences in the amount of minor elements compared with Aitik. The contents in Zn, Pb, As and Bi are several times higher than the respective contents in Aitik. Especially interesting are the higher contents of WO_3 , Mo and Sn, indicating that the pneumatolytic activity at Liikavaara East has been somewhat different from that in the Aitik area — possibly because of the nearer position in relation to the granite. Ba on the other hand occurs in higher contents in Aitik. The MgO content is considerably higher than in other rocks of the Aitik — Liikavaara zone (with the exception of amphibolite and skarn-banded rocks) and especially higher than in the surrounding arenite formation.

TABLE 14

Average chemical composition of the Liikavaara East ore
(from four representative drill cores)

SiO ₂ %	52.6	Ag g/t	8	As %	0.02
TiO ₂ %	0.80	Cu %	0.58	Mo %	0.02
Al ₂ O ₃ %	13.3	Co %	0.012	Te %	<0.005
Fe _{tot} %	8.2	Ni %	0.004	Se %	<0.003
FeII %	6.8	Zn %	0.09	S %	1.8
MnO %	0.13	Cd %	<0.001	BaO %	0.03
MgO %	4.6	Hg %	<0.001	WO ₃ %	0.04
CaO %	5.0	Sn %	0.003	CO ₂ %	1.9
Na ₂ O %	1.2	Pb %	0.08	F %	0.16
K ₂ O %	3.5	Bi %	<0.01	P ₂ O ₅ %	0.23
Au g/t	0.2	Sb %	<0.01		

COMPARISONS BETWEEN THE CHEMICAL COMPOSITION OF
THE DIFFERENT ROCK TYPES AND MINERALIZATIONS

If we study Table 15, giving various analyses of the different rocks and Table 16, where the average compositions and Niggli values respectively of the rock types and ores are related, we can draw the following conclusions:

1. The arenites show the highest Na₂O content compared with the K₂O content ($k = 0.26$) of all the rocks in the area. As the arenites are the rocks which have been least affected by metamorphism and alteration, we can conclude that the Na₂O dominance has been a primary feature of the rocks in the Aitik area, which has been changed in connection with metamorphism, the intrusion

of the Lina granite and the mineralization. The average *k* value is somewhat higher in the biotite gneisses and skarn-banded rocks. Within these rocks *k* varies considerably and the somewhat higher K_2O contents are due to microcline infiltration.

2. There is no principal chemical difference between the eastern part and the western part of the area, with the exception of the rocks of the Aitik bedrock. The biotite and biotite-amphibole gneisses are chemically very similar to the arenites. The *c* values is somewhat higher in the gneiss formation and indicates a slightly more calcareous composition. The typically skarn-banded rocks are those with the highest *fm*, *c* and *mg* values, as well as low *si* and *al* values.

3. All the rocks except the biotite gneisses and skarn-banded rocks show high Cu contents. This is partly due to the fact that the samples have been taken from boreholes which have been drilled to check geophysical anomalies. Even those holes which did not show any obvious mineralization, did in any case indicate shear or brecciated zones, where we can expect anomalous contents of trace elements. It is therefore difficult to tell what the primary average Cu content of the arenitic rocks could be. However, even if we exclude samples with high Cu contents, we still obtain average Cu values of about 40 g/t. We have also to consider that most of the samples have been taken in a profile between Aitik and Liikavaara East, probably an anomalous zone.

What has been said for Cu applies also to Ba.

4. The biotite gneisses show low contents of trace elements with the exception of Zn.

5. All the rocks belonging to what we have called the Aitik formation below the skarn-banded rocks show high Cu contents (other trace elements are relatively low). This again is partly due to the fact that the boreholes have been drilled selectively and partly because extensive parts of the Aitik formation have obviously anomalous Cu contents.

TABLE 15
Average chemical composition of rocks and ores

		Biotite gneisses	Typical skarn- banded rock	Aitik ore zone	Aitik ore (N)	E-border zone (Aitik)	E-part of anti- form	Arenites	Amphibo- lite	Liikavara E ore zone	Liikavara E ore
SiO ₂	%	56.9	55.2	57.0	58.6	51.9	53.6	57.2	53.6	52.4	52.6
Al ₂ O ₃		16.7	14.9	16.1	18.1	16.8	16.7	17.0	13.8	14.1	13.3
Fe _{tot}		6.6	5.7	6.4	5.2	8.7	8.9	5.0	8.5	7.9	8.2
FeII		1.7	0.9	3.8	3.6	4.2	3.3	3.0	2.3	5.7	6.8
MnO		0.2	0.4	0.3	0.4	0.2	0.2	0.1	0.4	0.2	0.1
MgO		3.1	5.7	1.9	1.8	3.7	3.5	3.0	7.8	5.7	4.6
CaO		6.2	9.9	3.1	2.6	5.3	5.0	5.0	6.6	5.9	5.0
Na ₂ O		3.1	0.9	2.4	2.1	3.6	3.7	4.7	2.0	2.3	1.2
K ₂ O		2.8	2.6	4.8	6.5	3.5	4.5	2.5	2.4	3.4	3.5
TiO ₂		0.8	0.7	0.6	0.5	0.9	0.9	0.7	0.9	0.9	0.8
S		0.05	0.04	1.4	1.4	0.4	0.9	0.13	0.1	1.1	1.8
Ba		0.07	0.04	0.23	1.0	0.18	0.12	0.09	0.08	0.06	0.03
Zn	g/t	103	105	85	100	56	62	94	185	389	900
Pb		9	13	8	20	5	7	8	8	247	800
Cu		12	5	3630	5600	890	848	180	33	2269	5800
As		6	19	4	10	5	4	15	<3	20	200
Bi		1	1.5	4	10	1	1	1	<0.5	19	100
Sn		3	<2	6	10	3	2	2	<2	19	30
Ag		<0.3	<0.3	4.4	4	<0.3	<0.3	<0.3	<0.3	2.0	8.0
Mo		<20	<29	81	50	14	6	<20	<2	65	200
WO ₃					10						400

TABLE 16
Average Niggli values of rocks and ores

	Biotite gneisses	Typical skarn- banded rock	Aitik ore zone	Aitik ore (N)	E-border zone (Aitik)	E-part of anti- form	Arenites	Amphibo- lite	Liikavara E ore zone	Liikavara E ore
<i>si</i>	171	149	202	209	142	146	181	134	144	163
<i>al</i>	30	24	34	38	27	27	32	20	23	24
<i>fm</i>	35	40	35	29	41	40	31	53	47	48
<i>c</i>	20	29	12	10	16	15	17	18	17	17
<i>alk</i>	14	7	19	22	16	18	19	9	12	11
<i>mg</i>	0.39	0.57	0.29	0.32	0.37	0.35	0.45	0.55	0.50	0.44
<i>k</i>	0.37	0.65 ¹	0.56	0.67	0.39	0.44	0.26	0.44	0.49	0.66
<i>ti</i>	1.8	1.4	1.6	1.3	1.9	1.8	1.7	1.7	1.9	1.9

¹ The high k value depends on microcline infiltration. The sample has been taken in the hanging wall of the Aitik mineralization

GEOCHEMICAL ANOMALIES RELATED TO THE CU MINERALIZATIONS

The Aitik ore zone is especially characterized by high K_2O content. Fig. 32 shows how k (Niggli value) increases over the mineralized zone. The Aitik ore zone has actually the highest k values of the whole area, otherwise dominated by high Na_2O contents. In Fig. 32 we can also see that k is already increasing in the hanging wall of the mineralization, where no sericitization can be observed (probably partly due to microcline infiltration).

Mg decreases in the ore zone, but increases again in the footwall (rocks with skarn schlieren).

Alk only increases slightly towards the hanging wall of the mineralization.

The CaO content (c) falls rapidly between the hanging wall (skarn-banded rocks) and the mineralization.

The combined Fe and Mg content (fm) increases east of the hanging wall, but is relatively constant throughout the mineralized zone.

The SiO_2 content slightly increases east of the hanging wall, but decreases afterwards towards the footwall (rocks with skarn schlieren at the eastern border zone of the Aitik ore).

The Ba anomaly seems to coincide with the Cu mineralization. However, the Ba content is already increasing west of the mineralization (hanging wall) and indicates a certain zoning.

The content of trace elements is generally low compared with the non-mineralized rocks of the area. Pb and Zn in the mineralized zone are for example lower than in parts of the country rocks. Even in the ore there is only a slight increase in Pb , As , Bi and Sn . The only trace elements which are obviously more abundant in the ore are Ag and Mo . The Ag occurs probably mostly in very small tetrahedrite crystals within the chalcopyrite. Molybdenite can be observed here and there in the pegmatites and also disseminated in the bedrock.

Liikavaara East shows also a certain increase of K_2O in comparison with the arenitic rocks. The highest k values occur towards the hanging wall and decrease afterwards within the mineralized zone. This is similar to Aitik, but the average k values are considerably lower at Liikavaara East. Mg increases slightly, especially around the centre of the mineralization. Fm increases considerably, alk and al are decreasing and c is almost unchanged throughout the mineralization.

Ba shows very low contents at Liikavaara East, actually lower than the non-mineralized country rocks.

Pb and Zn on the other hand are considerably higher than in the country rocks and in Aitik. We know also that galena and sphalerite can be observed macroscopically on joints and fractures within the ore zone. The contents of As , Bi and Sn in Liikavaara East are higher than in any other part of the area. Ag and Mo are higher than in the country rocks, but lower than in Aitik.

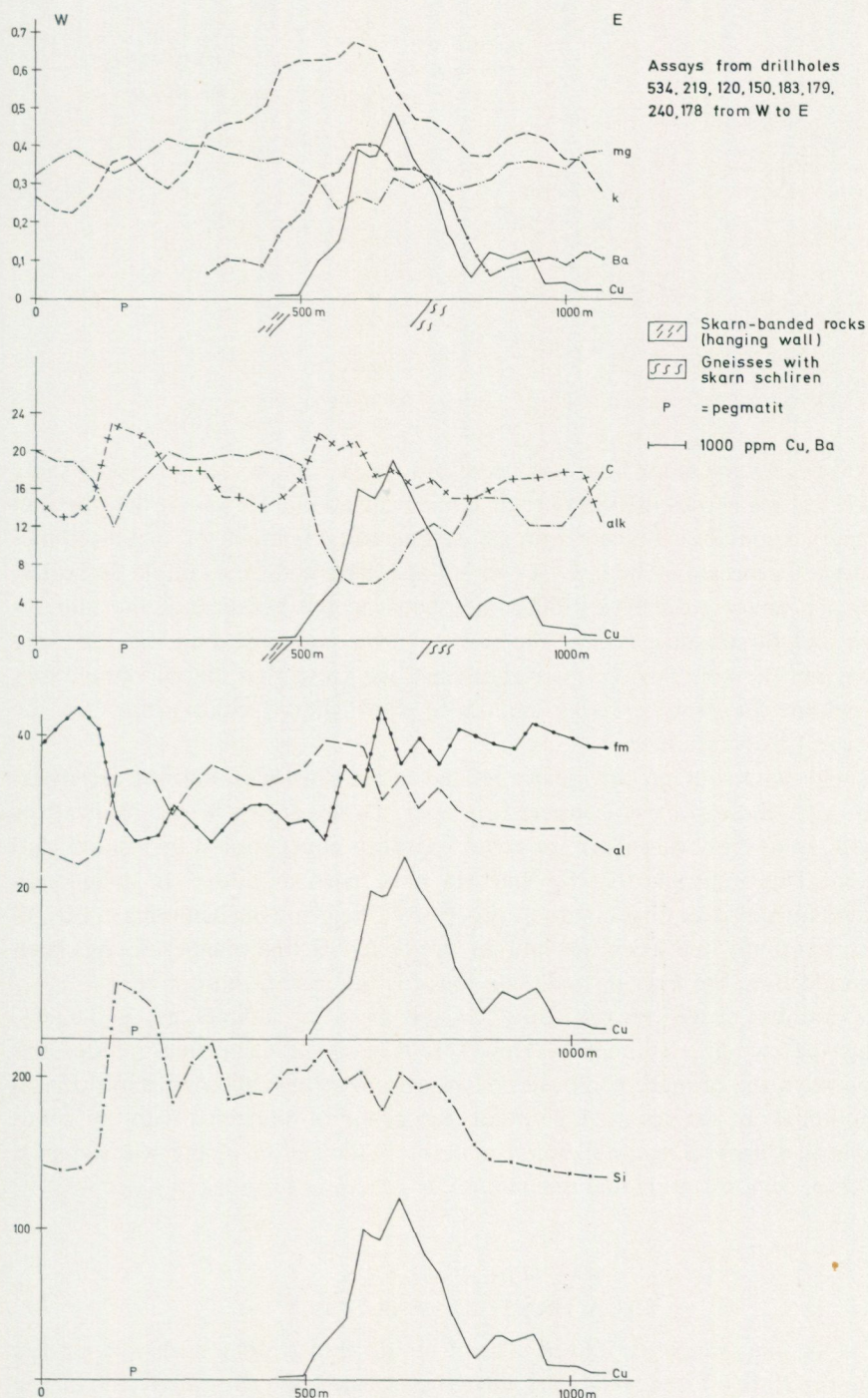


Fig. 32. Aitik ore zone — Niggli values — Running average.

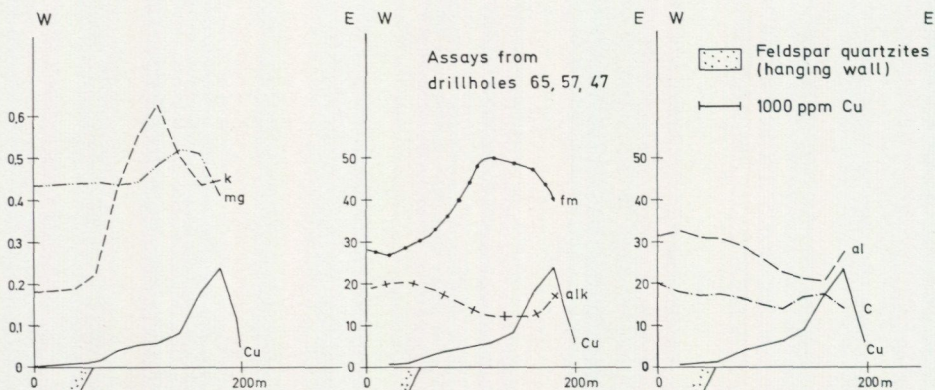


Fig. 33. Liikavaara East ore zone — Niggli values — Running average.

We can conclude from what has been said above, that certain elements show geochemical anomalies related to the Cu mineralizations. However, the question is, if these anomalies indicate primary sedimentary features or metamorphic-metasomatic processes. The low Ca content at Aitik could for example be explained by a primary sedimentary difference between the bedrock of the mineralization and the country rocks. The same can be said regarding the relatively high Mg and Fe contents of Liikavaara East; we know that amphibolitic zones occur within the arenitic rocks and these show similar compositions to the bedrock at Liikavaara East.

The high K_2O contents are clearly related to the ore zones, and the sericitization at Aitik indicates metasomatic processes. Observations in the footwall of the Aitik zone show that mafic material has been concentrated in veinlets and schlieren. This indicates that Fe and Mg have been mobilized in connection with metamorphism or pneumatolytic processes. The k and mg diagrams in Fig. 32 suggest that potassium has infiltrated the ore zone and that magnesium has been transported from the hanging wall side towards the eastern border zone.

It is doubtful if we can distinguish exactly between sedimentary and metamorphic-metasomatic anomalies. However, it is quite clear that besides the differences in the primary composition, we also have to reckon with infiltration and mobilization; besides the high potassium contents connected with ore zones we have also general scapolitization and tourmalinization in the western part of the area, demonstrating that pneumatolytic processes have taken place.

FACTOR ANALYSIS THE AITIK—LIIKAVAARA AREA

The 148 samples which have been taken from drillholes along an E—W profile through the Aitik—Liikavaara zone, have been treated by factor analysis. Among the 148 samples are 50 samples from the Aitik mineralization. The factor ana-

lysis has been made first for all samples and afterwards only for those of the Aitik mineralization. The samples have been taken over sections of 5 metres, with intervals of 20 metres.

We shall first have a look at the results of the analysis treating all the 148 samples (Tables 17 and 18). The log. transformed correlation matrix shows a close correlation between Cu, Bi, Sn and Ag and quite a good correlation between Cu, Sb, In, Ge and Ba. There exists of course also a good relationship between Cu, S and Fe. Regarding the correlation between Cu and the main elements, only a certain correlation to potassium seems to exist.

In the log. transformed Varimax matrix we have a concentration of Cu and many trace elements in factor 1. This indicates that these trace elements (Bi, Sn, In and Ag) are closely related to the Cu mineralization. Ba occurs in factor 1, but also in several other factors. In factor 8 Ba is connected with K_2O ; this may indicate the occurrence of Ba in the sericitized zone outside the main Cu mineralization. Zn and Pb are rather low in factor 1, their main occurrence is in factor 3 quite independently and without any stronger relationship to other elements (beside a certain connection to Sn). This can be interpreted that Pb and Zn are only partly related to the Cu mineralization.

K_2O occurs also in factor 1 to some extent and this confirms that part of the Cu mineralization is related to a higher K_2O content (sericitization, microcline infiltration).

Apart from K_2O and the above mentioned trace elements factor 1 does not show any major contributions of other elements, besides S and Fe_{II} , which obviously occur together with Cu (chalcopyrite).

As is not correlated to Cu in factor 1, but occurs independently in factor 4. This suggests that As is not directly connected with the Cu mineralization.

Ga is concentrated in factor 5, where it occurs quite independently, except for a slight relationship to SiO_2 . Also Ge occurs relatively alone in factor 9, together with some Sn.

Summarizing we can say that Cu, Bi, Sn and Ag occur mainly together in one factor, to some extent with Ba and K_2O . Other trace elements such as Pb, Zn, As, Ga and Ge occur entirely or partly independently of Cu. Of the main elements only potassium is to a certain extent related to Cu.

AITIK

50 samples from the Aitik mineralized zone have been treated separately. The correlation matrix table shows the same tendencies of relationships between Cu and the trace elements as the matrix for the whole area (Table 19), namely a close connection between Cu, Bi, Sn, In, Ag and Ba. The correlation with Zn is better, but the correlation with Pb is negative, as well as that with As and Ge. However, regarding the correlation between Cu and the main elements there is

a certain difference, as we can note a certain correlation to MgO and a better correlation to MnO and Fe_{tot} . This can be explained because in the first case the biotite gneisses and skarn-banded rocks have been included in the factor analysis. In these rocks Cu occurs only as traces and there exists no relation between Cu and the skarn-banded rocks. The relationship between Cu and the rocks with skarn schlieren in the footwall of Aitik did therefore not show up. In the second case the hanging wall rocks are not included and the relationship to the skarn rocks in the footwall becomes evident.

TiO_2 is closely related to MgO, MnO and Fe_{tot} , suggesting that most of the TiO_2 occurs in amphiboles where also Zn and Sn are concentrated. Thereby we also obtain a better correlation to Cu (amphiboles in the footwall rocks), which was negative for the whole area.

Pb has no correlation with Cu, but shows a certain correlation with SiO_2 and Na_2O , suggesting that Pb partly occurs in albite (pegmatites show relatively high Pb contents).

The log. transformed Varimax matrix shows part of the Cu in factor 1, together with MgO, CaO, MnO, TiO_2 , Fe_{tot} and Fe_{II} . This factor indicates the correlation between Cu and the skarn rocks in the footwall (E-border zone of the Aitik mineralization). Part of the Ba occurs also in this factor, but the trace elements are only represented to a minor amount, with the exception of Zn and to some extent Sn, which are obviously related to the amphiboles (Table 20).

The main Cu factor is No. 2, where also most of the trace elements, Ba and K_2O occur. Note that the relationship to Na_2O and SiO_2 in both factors is reverse. Factor 2 represents the main Cu mineralization connected with potassium, factor 1 the part which is connected with the skarn rocks. Bi, Sn and Ag are also concentrated in this factor, Zn both in factors 1 and 2.

We can also note that As occurs independently of Cu, but related to Sb in factor 3 (reverse relationship in factor 2) and that Ga again is concentrated in a special factor (No. 6).

Ba appears again partly together with K_2O in one factor (No 4), without any relationship to Cu. This shows that Cu and K_2O are only partly related, and that K_2O occurs quite independently.

Pb appears mainly in the factors 4 and 7, where also Na_2O occurs, suggesting again that Pb is concentrated in albite (not in microcline as one might suppose).

Zn is partly related to Cu in the factors 1 and 2 but shows up also independently in factor 12. This could be interpreted that Zn is partly connected to Cu in skarn rocks (amphiboles), partly to the main Cu mineralization, but that it also occurs without any connection to Cu.

Summarizing we conclude that the factor analysis of samples from the Aitik ore zone shows that the variance of Cu is accounted for by two factors, one representing the main type of mineralization, partly related to K_2O , and the other representing the Cu concentrated in skarn schlieren and veinlets. The

TABLE 17

Aitik — Liikavaara area. Correlation matrix of 148 samples

	Zn	Pb	Cu	As	Sb	Bi	Sn	In	Ga	Ag	Ge	Ba
Zn	1.000	.508	.283	.252	.138	.435	.507	.253	-0.082	.304	.027	.115
Pb	.508	1.000	.223	.113	-0.102	.390	.511	.300	-0.005	.239	.417	-0.292
Cu	.283	.223	1.000	.016	.301	.641	.638	.494	.059	.781	.355	.472
As	.252	.113	.016	1.000	.267	.056	.148	-0.042	-0.063	-0.094	.101	-0.071
Sb	.138	-0.102	.301	.267	1.000	.270	.217	.185	.116	.300	.157	.254
Bi	.435	.390	.641	.056	.270	1.000	.738	.597	.064	.640	.384	.214
Sn	.507	.511	.638	.148	.217	.738	1.000	.523	.121	.550	.521	.040
In	.253	.300	.494	-0.042	.185	.597	.523	1.000	.142	.576	.451	.077
Ga	-0.082	-0.005	.059	-0.063	.116	.064	.121	.142	1.000	.167	.199	.082
Ag	.304	.239	.781	-0.094	.300	.640	.550	.576	.167	1.000	.295	.413
Ge	.027	.417	.355	.101	.157	.384	.521	.451	.199	.295	1.000	-0.191
Ba	.115	-0.292	.472	-0.071	.254	.214	.040	.077	.082	.413	-0.191	1.000
S	.228	.221	.861	-0.108	.217	.627	.628	.459	.084	.723	.347	.420
SiO ₂	-0.361	.085	-0.105	-0.066	.060	.040	-0.092	-0.048	.257	-0.008	.220	-0.175
Al ₂ O ₃	-0.070	-0.279	-0.214	.023	.051	.195	-0.304	-0.243	.146	-0.194	-0.284	.160
MgO	.548	.092	-0.053	.211	-0.078	.002	.107	-0.053	-0.266	-0.226	-0.231	-0.014
CaO	.307	-0.025	-0.291	.135	-0.115	-0.223	-0.174	-0.147	-0.239	-0.369	-0.336	-0.167
Mno	.354	-0.215	.148	.110	.282	.173	.056	.037	-0.079	.152	-0.138	.426
TiO ₂	.475	-0.003	-0.051	.105	-0.032	-0.030	.049	-0.054	-0.172	-0.151	-0.304	.051
K ₂ O	-0.041	.054	.390	-0.106	.235	.320	.191	.191	.152	.391	.263	.485
Na ₂ O	-0.242	-0.152	-0.379	-0.046	-0.208	-0.453	-0.383	-0.296	.024	-0.443	-0.276	-0.255
Fe _{tot}	.480	-0.056	.167	.057	.004	.107	.115	.042	-0.157	.054	-0.186	.334
FeII	.565	.077	.467	.158	.115	.328	.376	.186	-0.109	.263	-0.024	.412

Table 17 continuation

	S	SiO ₂	Al ₂ O ₃	MgO	CaO	MnO	TiO ₂	K ₂ O	Na ₂ O	Fe _{tot}	FeII
Zn	.228	-0.361	-0.070	.548	.307	.354	.475	-0.041	-0.242	.480	.565
Pb	.221	.085	-0.279	.092	-0.025	-0.215	-0.003	.054	-0.152	-0.056	.077
Cu	.861	-0.105	-0.214	-0.053	-0.291	.148	-0.051	.390	-0.379	.167	.467
As	-0.108	-0.066	.023	.211	.135	.110	.105	-0.106	-0.046	.057	.158
Sb	.217	.060	.051	-0.078	-0.115	.282	-0.032	.235	-0.208	.004	.115
Bi	.627	-0.040	-0.195	.002	-0.223	.173	-0.030	.320	-0.453	.107	.328
Sn	.628	-0.092	-0.304	.107	-0.174	.056	.049	.191	-0.383	.115	.376
In	.459	-0.048	-0.243	-0.053	-0.147	.037	-0.054	.191	-0.296	.042	.186
Ga	.084	.257	.146	-0.266	-0.239	-0.079	-0.172	.152	.024	-0.157	-0.109
Ag	.723	-0.008	-0.194	-0.226	-0.369	.152	-0.151	.391	-0.443	.054	.263
Ge	.347	.220	-0.284	-0.231	-0.336	-0.138	-0.304	.263	-0.276	-0.186	-0.024
Ba	.420	-0.175	.160	-0.014	-0.167	.426	.051	.485	-0.255	.334	.412
S	1.000	-0.208	-0.208	-0.046	-0.310	.155	-0.009	.414	-0.420	.243	.430
SiO ₂	-0.208	1.000	.062	-0.668	-0.520	-0.456	-0.746	.131	.083	-0.794	-0.631
Al ₂ O ₃	-0.208	.062	1.000	-0.014	.027	.067	.032	.008	.208	-0.020	-0.099
MgO	-0.046	-0.668	-0.014	1.000	.830	.469	.838	-0.382	.017	.730	.638
CaO	-0.310	-0.520	.027	.830	1.000	.379	.757	-0.496	.181	.554	.359
MnO	.155	-0.456	.067	.469	.379	1.000	.483	-0.005	-0.365	.585	.495
TiO ₂	-0.009	-0.746	.032	.838	.757	.483	1.000	-0.241	.053	.828	.644
K ₂ O	.414	.131	.008	-0.382	-0.496	-0.005	-0.241	1.000	-0.274	.085	.143
Na ₂ O	-0.420	.083	.208	.017	.181	-0.365	.053	-0.274	1.000	-0.073	-0.151
Fetot	.243	-0.794	-0.020	.730	.554	.585	.828	.085	-0.073	1.000	.823
FeII	.430	-0.631	-0.099	.638	.359	.495	.644	.143	-0.151	.823	1.000

TABLE 18

Aitik — Liikavaara area. Factor analysis (148 samples). Varimax matrix accounting for 99.1 per cent of total problem variance

	Factor	1	2	3	4	5	6	7	8	9	10	11	12
Sum of squares		3.584	4.897	1.302	1.059	1.034	1.087	1.048	1.227	.998	1.052	1.049	.329
.995	Zn	.176	-0.470	-0.409	.140	-0.018	.109	.013	-0.049	.034	.083	-0.097	.010
.999	Pb	.153	.003	-0.925	.061	-0.008	.041	-0.122	.014	-0.164	-0.084	-0.095	.021
.951	Cu	.904	-0.037	-0.064	.039	-0.013	.079	-0.074	.097	-0.113	.114	-0.131	.053
1.000	As	-0.046	-0.094	-0.061	.977	-0.027	.020	.015	-0.047	-0.054	.139	.025	-0.001
.999	Sb	.171	.031	.069	.152	.050	.065	.036	.086	-0.048	.950	-0.057	.011
1.000	Bi	.517	-0.022	-0.196	.033	.010	.181	-0.050	.109	-0.104	.105	-0.267	.013
.997	Sn	.541	-0.095	-0.269	.101	.085	.135	-0.137	.021	-0.241	.077	-0.171	-0.004
1.000	In	.349	-0.004	-0.111	-0.033	.069	.088	-0.098	.033	-0.170	.066	-0.885	-0.009
1.000	Ga	.054	.154	.006	-0.027	.975	-0.024	.080	.048	-0.070	.046	-0.054	.023
.988	Ag	.752	.110	-0.090	-0.068	.090	.166	-0.072	.124	-0.002	.117	-0.258	-0.032
1.000	Ge	.228	.198	-0.189	.073	.097	.101	-0.133	.101	-0.871	.057	-0.177	.017
.998	Ba	.357	-0.120	.198	-0.036	.049	.096	.112	.284	.158	.097	.012	-0.011
.984	S	.916	-0.090	-0.060	-0.085	.037	.139	-0.063	.161	-0.103	.042	-0.085	-0.085
.996	SiO ₂	-0.113	.803	-0.087	-0.009	.122	-0.057	.033	.043	-0.063	.052	.034	.543
1.000	Al ₂ O ₃	-0.133	.012	.105	.016	.082	-0.079	.966	.024	.099	.034	.078	.007
.955	MgO	-0.080	-0.869	-0.094	.098	-0.109	.020	.008	-0.247	.028	-0.032	.025	.042
.985	CaO	-0.285	-0.749	-0.045	.040	-0.082	-0.072	-0.002	-0.284	.099	-0.006	.005	.089
.998	MnO	.072	-0.485	.137	.034	-0.012	.242	.049	-0.021	.027	.175	.001	-0.013
.989	TiO ₂	-0.067	-0.958	-0.037	.008	-0.017	-0.019	.031	-0.093	.112	.026	.017	.068
.996	K ₂ O	.254	.136	-0.018	-0.054	.054	.098	.026	.917	-0.089	.095	-0.036	.012
1.000	Na ₂ O	-0.260	-0.004	.051	-0.024	.029	-0.924	.091	-0.098	.088	-0.069	.083	.014
.963	Fe _{tot}	.129	-0.918	.068	-0.010	-0.027	-0.005	-0.017	.196	.015	-0.035	.002	-0.068
.992	Fe _{II}	.367	-0.764	-0.011	.095	-0.021	-0.004	-0.048	.125	-0.024	.024	-0.029	.039

TABLE 19
Aitik — mineralized zone. Correlation matrix of 50 samples

	Zn	Pb	Cu	As	Sb	Bi	Sn	In	Ga	Ag	Ge	Ba
Zn	1.000	-0.130	.571	.359	.385	.514	.718	.224	.057	.530	-0.160	.482
Pb	-0.130	1.000	-0.108	-0.133	-0.133	.052	-0.070	.035	.059	.185	.258	-0.366
Cu	.571	-0.108	1.000	-0.066	.249	.625	.712	.460	.247	.718	-0.123	.652
As	.359	-0.133	-0.066	1.000	.622	.086	.076	-0.218	.066	-0.073	.057	.202
Sb	.385	-0.133	.249	.622	1.000	.334	.404	.146	.034	.149	.140	.151
Bi	.514	.052	.625	.086	.334	1.000	.558	.589	.166	.635	-0.025	.439
Sn	.718	-0.070	.712	.076	.404	.558	1.000	.377	.290	.559	-0.048	.496
In	.224	.035	.460	-0.218	.146	.589	.377	1.000	.148	.503	.196	.230
Ga	.057	.059	.247	.066	.034	.166	.290	.148	1.000	.130	.112	.182
Ag	.530	.185	.718	-0.073	.149	.635	.559	.503	.130	1.000	-0.068	.356
Ge	-0.160	.258	-0.123	.057	.140	-0.025	-0.048	.196	.112	-0.068	1.000	-0.231
Ba	.482	-0.366	.652	.202	.151	.439	.496	.230	.182	.356	-0.231	1.000
S	.485	-0.162	.775	-0.310	.023	.408	.617	.324	.067	.571	-0.206	.522
SiO ₂	-0.474	.473	-0.249	.011	.026	-0.151	-0.384	-0.236	.085	-0.294	.324	-0.317
Al ₂ O ₃	.379	.035	-0.011	.164	.134	.130	.301	-0.140	.140	-0.083	-0.276	.186
MgO	.569	-0.233	.326	.155	.129	.154	.331	.040	-0.046	.087	-0.355	.325
CaO	.210	-0.090	.097	.076	.076	-0.039	.026	.007	.018	-0.010	-0.264	.015
MnO	.600	-0.399	.460	.279	.299	.419	.422	.152	-0.080	.248	-0.069	.586
TiO ₂	.543	-0.272	.319	.083	.114	.172	.413	.091	.060	.178	-0.435	.242
K ₂ O	.206	-0.003	.201	.177	.232	.299	.221	.058	.077	.250	.042	.403
Na ₂ O	-0.409	.339	-0.316	-0.234	-0.215	-0.168	-0.252	-0.165	.039	-0.290	-0.043	-0.490
Fe _{tot}	.615	-0.430	.479	.047	.041	.256	.426	.189	.040	.290	-0.307	.508
FeII	.641	-0.416	.579	.109	.161	.320	.464	.226	.077	.334	-0.251	.516

Table 19 continuation

	S	SiO ₂	Al ₂ O ₃	MgO	CaO	MnO	TiO ₂	K ₂ O	Na ₂ O	Fe _{tot}	Fe _{II}
Zn	.485	-0.474	.379	.569	.210	.600	.543	.206	-0.409	.615	.641
Pb	-0.162	.473	.035	-0.233	-0.090	-0.399	-0.272	-0.003	.339	-0.430	-0.416
Cu	.775	-0.249	-0.011	.326	.097	.460	.319	.201	-0.316	.479	.579
As	-0.310	.011	.164	.155	.076	.279	.083	.177	-0.234	.047	.109
Sb	.023	.026	.134	.129	.076	.299	.114	.232	-0.215	.041	.161
Bi	.408	-0.151	.130	.154	-0.039	.419	.172	.299	-0.168	.256	.320
Sn	.617	-0.384	.301	.331	.026	.422	.413	.221	-0.252	.426	.464
In	.324	-0.236	-0.140	.040	.007	.152	.091	.058	-0.165	.189	.226
Ga	.067	.085	.140	-0.046	.018	-0.080	.060	.077	.039	.040	.077
Ag	.571	-0.294	-0.083	.087	-0.010	.248	.178	.250	-0.290	.290	.334
Ge	-0.206	.324	-0.276	-0.355	-0.264	-0.069	-0.435	.042	-0.043	-0.307	-0.251
Ba	.522	-0.317	.186	.325	.015	.586	.242	.403	-0.490	.508	.516
S	1.000	-0.501	-0.049	.378	.104	.388	.424	.023	-0.180	.609	.573
SiO ₂	-0.501	1.000	-0.057	-0.625	-0.398	-0.460	-0.692	.247	.221	-0.776	-0.679
Al ₂ O ₃	-0.049	-0.057	1.000	.287	.158	.163	.339	.269	.124	.123	.102
MgO	.378	-0.625	.287	1.000	.772	.576	.858	-0.332	-0.099	.831	.781
CaO	.104	-0.398	.158	.772	1.000	.284	.700	-0.473	.133	.549	.489
MnO	.388	-0.460	.163	.576	.284	1.000	.407	.042	-0.458	.628	.605
TiO ₂	.424	-0.692	.339	.858	.700	.407	1.000	-0.251	-0.026	.833	.750
K ₂ O	.023	.247	.269	-0.332	-0.473	.042	-0.251	1.000	-0.506	-0.094	-0.064
Na ₂ O	-0.180	.221	.124	-0.099	.133	-0.458	-0.026	-0.506	1.000	-0.325	-0.319
Fe _{tot}	.609	-0.776	.123	.831	.549	.628	.833	-0.094	-0.325	1.000	.901
Fe _{II}	.573	-0.679	.102	.781	.489	.605	.750	-0.064	-0.319	.901	1.000

TABLE 20

Aitik – mineralized zone. Factor analysis (50 samples). Varimax matrix accounting for 98.9 per cent of total problem variance

	Factor	1	2	3	4	5	6	7	8	9	10	11	12
Sum of squares		5.116	3.547	1.863	1.692	1.357	1.077	1.220	1.179	1.017	.781	.571	.341
.984	Zn	.477	-0.507	-0.303	-0.253	-0.314	.031	.010	-0.034	-0.005	.127	-0.088	.428
.998	Pb	-0.239	-0.061	.074	.142	-0.056	-0.021	.930	-0.019	-0.114	-0.100	.075	.003
.978	Cu	.246	-0.838	-0.038	-0.107	.055	-0.135	-0.067	-0.179	.044	.109	.211	-0.001
.989	As	.087	.164	-0.858	-0.123	-0.041	-0.071	.003	.183	-0.025	.071	-0.067	.214
.994	Sb	.029	-0.187	-0.902	-0.083	-0.090	.025	-0.091	-0.122	-0.081	.054	.088	-0.148
.996	Bi	.073	-0.478	-0.163	-0.058	-0.093	-0.064	.057	-0.357	.028	.152	.010	.025
.991	Sn	.243	-0.660	-0.190	-0.095	-0.263	-0.168	-0.028	-0.134	-0.059	.056	-0.109	.042
.997	In	.067	-0.300	.039	-0.051	.073	-0.060	.012	-0.918	-0.128	.004	-0.047	.001
.999	Ga	-0.002	-0.117	-0.024	.017	-0.076	-0.983	.019	-0.051	-0.059	-0.043	.024	-0.003
.991	Ag	.067	-0.842	-0.019	-0.191	.067	-0.035	.206	-0.224	.063	.022	-0.227	-0.006
.996	Ge	-0.257	.066	-0.089	-0.030	.138	-0.071	.114	-0.120	-0.926	.037	.036	-0.001
.988	Ba	.212	-0.378	-0.077	-0.310	-0.116	-0.107	-0.200	-0.071	.114	.184	-0.016	.003
.993	S	.356	-0.746	.188	.002	.071	.011	-0.096	-0.055	.045	.052	-0.079	-0.011
.992	SiO ₂	-0.657	.181	-0.068	.023	-0.023	-0.083	.278	.136	-0.109	-0.067	.626	-0.040
.987	Al ₂ O ₃	.159	.042	-0.084	.024	-0.956	-0.081	.051	.063	.130	.043	.007	.023
.973	MgO	.914	-0.056	-0.084	.061	-0.106	.059	.021	.017	.113	.173	.012	.115
.989	CaO	.747	.076	-0.068	.202	-0.018	-0.028	.062	-0.012	.077	.033	.046	-0.037
.994	MnO	.441	-0.229	-0.184	-0.198	-0.082	.100	-0.199	-0.016	-0.075	.739	-0.040	.033
.983	TiO ₂	.903	-0.145	-0.058	.083	-0.172	-0.043	-0.072	-0.035	.195	-0.016	-0.058	-0.035
.982	K ₂ O	-0.298	-0.196	-0.141	-0.689	-0.359	-0.010	-0.008	.027	-0.021	-0.171	.104	-0.233
.986	Na ₂ O	-0.102	.141	.121	.905	-0.141	-0.027	.157	.072	.029	-0.189	.055	-0.117
.980	Fe _{tot}	.888	-0.243	.051	-0.159	.005	-0.023	-0.187	-0.035	.040	.120	-0.116	.015
.991	Fe _{II}	.839	-0.328	-0.058	-0.121	.018	-0.043	-0.209	-0.056	.006	.072	-0.004	.005

variance of most trace elements is also explained by the same factor. Most of the K_2O occurs in a special factor, quite independently of Cu and other metallic elements.

Possible genetic conclusions from the results of the factor analysis will be discussed in the chapter on the ore genesis.

REMARKS REGARDING THE PYRITE-PYRRHOTITE- CHALCOPYRITE-MAGNETITE ASSEMBLAGE

The pyrite, pyrrhotite, chalcopyrite and magnetite assemblage is very common in ore deposits. Schwartz (1949) lists 130 deposits where magnetite occurs in sulphide ores and districts. Apart from pyrite and pyrrhotite, chalcopyrite is the most common sulphide which occurs together with magnetite; according to Schwartz chalcopyrite has been reported in 122 of the 130 listed ore districts.

Magnetite is generally reported to have been formed earlier than the sulphides, but there occur also assemblages where the magnetite is later than the sulphides.

At Aitik pyrite and chalcopyrite occur mainly together with magnetite, at Liikavaara East the assemblage is generally pyrite-pyrrhotite-chalcopyrite. Barnes and Kullerud (1961) demonstrated that the assemblage pyrite-pyrrhotite-magnetite is at equilibrium at or below $250^\circ C$, if the ore solution is alkaline. At $250^\circ C$ the simultaneous deposition of pyrite, pyrrhotite and magnetite requires conditions of at least 0.8 pH unit above neutrality (if $\Sigma S > 10^{-3}$ m, where ΣS is the sum of activity of all sulphur containing ions or molecules in solution and in concentration in moles per 1000 g of solvent). Pyrite and magnetite are stable over a Po_2 range from reducing to slightly oxidizing conditions and may both occur where sulphates form the predominant aqueous solutions. The occurrence of pyrrhotite indicates reducing conditions (low Po_2). Po_2 and Ps_2 depend on the temperature, both increasing with temperature.

Both at Aitik and Liikavaara East pyrite-pyrrhotite and magnetite are co-existent, but the assemblage pyrite-magnetite prevails at Aitik and the assemblage pyrite-pyrrhotite at Liikavaara East. This could be interpreted that the conditions during the last crystallization were more reducing and the pH lower at Liikavaara East.

At Aitik one can observe that pyrite, chalcopyrite and magnetite generally seem to have crystallized contemporaneously. However, borders of magnetite around pyrite and chalcopyrite indicate that part of the magnetite has been formed later (see Fig. 8). This can be explained by changing chemical-physical conditions, e.g. by increasing O_2 pressure and (or) increasing pH. As the O_2 pressure depends on the temperature we can conclude that part of magnetite has been formed by metamorphic processes or (and) the influence of alkaline solutions.

At Liikavaara East we can observe that magnetite occurs between pyrite and pyrrhotite. Marcasite occurs in lamellae within the pyrrhotite, evidently formed by exsolution. The magnetite between the pyrite and the pyrrhotite may have been formed during primary deposition near equilibrium conditions. It seems rather probable though that pyrrhotite and pyrite originally have been formed under reducing conditions and that magnetite has been formed later under increasing O_2 pressure. However, the conditions have not changed as much as at Aitik, where magnetite is more abundant and borders of magnetite occur more frequently. This confirms the fact that metamorphism and pneumatolytic activity have been stronger in the Aitik zone, than in the Liikavaara East zone.

The interpretation of the geology is based to a large extent on the magnetic map. The difference between the Aitik formation and the Nautanen formation is first of all a difference of magnetic characteristics. However, these are influenced by the physical-chemical conditions during the deposition of the sediments and the ore minerals and during metamorphism. The two formations can therefore be the same from a geologic stratigraphic point of view, but there might have existed a higher O_2 pressure or pH during deposition of the sediments in the Nautanen zone or during later stages of metamorphism and alteration.

The author has also considered the possibility that what we call the Aitik formation could actually not be a geological formation but a metamorphic or physico-chemical "formation". In this case we should have had high S_2 pressure and low pH during metamorphism and alteration, so that most of the primary magnetite would have been transformed into pyrite. This would explain the lower magnetic amplitudes in the Aitik zone compared with the Nautanen zone. However, mineralogically we cannot observe alteration of magnetite into pyrite-pyrrhotite which could confirm such a theory. We generally observe the contrary, a late transformation of pyrite and chalcopyrite into magnetite. If a change from magnetite into pyrite-pyrrhotite has occurred, then all the mineralogical witnesses of this alteration have been extinguished.

SOME REMARKS REGARDING EXPLORATION METHODS

The first indications for possible copper mineralizations in the Aitik area were glacial boulders with disseminated chalcopyrite. However, these boulders did not form well defined boulder trains in the direction of the ice transport, but rather irregular concentrations at the northern and southern ends of the Aitik ore zone. Only 12 boulders are known near the northern end and 6 boulders near the southern end of the ore. The fact that no more boulders were found from this large ore body is partly due to the occurrence of extensive swamps east of the ore, followed by the lake Sakajärvi. Even near Liikavaara East only a few boulders are known from the ore. The ice transport in the area is quite compli-

cated, however, the most important transport has been towards $N60^{\circ}-75^{\circ}E$, but even $N80^{\circ}W$ transport has occurred.

Fortunately a small outcrop was found at the southern end of the Aitik mineralization during the first exploration period. This has to be regarded as an exception in these areas which are heavily covered by glacial overburden.

Later, almost every geophysical exploration method has been applied to investigate the Aitik area and mineralization. The results of these geophysical investigations are discussed in D. Malmqvist's and D. S. Parasnis's paper (1972), which includes also a case history of the Aitik ore. We shall therefore here only give a very short summary on the different exploration methods.

The following methods have been applied:

- Two-frame, high frequency
- Loop-frame, horizontal, medium frequency
- Resistivity
- IP (induced polarization)
- SP (self-potential)
- Ground magnetic
- Gravity
- Airborne magnetic
- Airborne EM (electromagnetic)
- INPUT (electromagnetic puls method)
- Geochemistry (moraine samples)

Of all these methods only a few have been of direct importance for the investigations of the Aitik and Liikavaara ores. Other methods were applied after the ore bodies had been outlined, mostly to test different methods on a low grade copper deposit.

The two-frame EM method (10 kHz) was the first geophysical method applied and it outlined roughly the extensions of the ore zones. The Liikavaara East ore shows stronger indications, due to the higher content of pyrrhotite (ratios 1.4 or more). The indications at Aitik were rather weak, with ratios between 1.00 and 1.20. Even if the extension of the Aitik mineralized zone is roughly outlined by the two-frame method, part of the Aitik North ore body with relatively high Cu contents but low pyrite contents was not indicated at all. Regarding the principals of the two-frame method we refer to Parasnis 1966.

The loop-frame method shows some distinct electromagnetic anomalies, the imaginary components being stronger than the real. The main zone indicated is the zone towards the hanging wall, where we have a concentration of pyrite (see remark on zoning p. 39). Concentrations of mainly pyrite are also indicated. Extensive parts of the low grade copper mineralization do not show loop-frame anomalies.

The resistivity survey shows an extensive low resistivity zone, lower than 1.0

kohm-m. The background resistivity values are of the order of 5—10 kohm-m. Between the hanging wall and the ore zone strong resistivity gradients between 10 kohm-m and 1 kohm-m show up. As a whole the resistivity survey outlines very well the contours of the low grade mineralization.

The SP-measurements show negative anomalies of 100—600 mV which coincide with the zones of low resistivity but they do not determine the ore zone as well as the resistivity survey.

Minor IP-measurements have shown strong anomalies, indicating the presence of the impregnation zone, however the picture is rather patchy (see Malmqvist and Parasnis 1972).

The magnetic ground survey has been of great help for the interpretation of the geology of the area. However, the ore bodies are not magnetic with the exception of some parts in the southern part of Aitik. The formations which are mineralized are poorly magnetic and the ores would not have been indicated by magnetic methods.

The airborne surveys included both magnetic and EM-measurements. The system used for EM-measurements was, during the 1957 survey, a modified rotary field method, and in 1962 a wing-tipped dipole system (see Malmqvist and Parasnis 1972). Both methods showed very poor anomalies on the Aitik ore, which hardly would have been regarded to be significant if the presence of the ore had not already been known. The Liikavaara East deposit on the other hand shows significant indications both for the real and the imaginary component. The magnetic airborne survey has been very important for the interpretation of the geology.

An INPUT airborne survey carried out by Barringer Research Ltd, Canada, showed indications both for Aitik and Liikavaara East (better indications for the latter which is a better conductor), which probably would have led to further explorations if the survey had been carried out in unknown areas.

The gravity survey does of course not show any anomalies connected with the ore. Gravity anomalies of the order of 1.5 mgal indicate the possibility of differences regarding the depth to the underlying granite.

A geochemical survey (moraine samples) was carried out both in the Aitik and the Liikavaara East area. The anomaly for Aitik is split up in three strips parallel to the N72°E direction of ice transport. It is not quite clear why the anomaly is split up, but this is probably due to conditions of the Quaternary geology, which up to now have not been studied closely. The Cu-anomalies show values of 100—200 ppm against a background of about 20 ppm.

The Liikavaara East deposit shows a very significant anomaly with Cu-values of 100—800 ppm against a background of 30 ppm.

Summarizing we can say that a deposit of the Aitik type is geophysically indicated best by resistivity methods, but that even EM-measurements give indications on parts of the ore. The geochemical survey shows significant indica-

tions, even if, in the Aitik case, they are somewhat difficult to interpret. We can conclude that it would be possible to localize a similar deposit by a combination of a geochemical survey and resistivity measurements, even if no direct geological indications, such as boulders or outcrops were known.

ORIGIN OF THE MINERALIZATIONS

Before we discuss the genesis of the Aitik ore and the Liikavaara East mineralization we can summarize briefly the most important geological information:

1. The bedrock and the country rock of the Aitik zone consist of metasediments. No rocks of definite volcanic origin have been observed south of the Lina river, maybe with the exception of possible agglomerates and porphyrites in the biotite gneiss formation. Porphyrite and quartz diorite have been reported from the area north of the Lina river (Snålkok).
2. The zone of metasediments is surrounded by the Lina granite, which intrudes into the metasediments. The granite occurs 1 km west of Aitik and 100—200 m east of Liikavaara East.
3. Pegmatites related to the Lina granite are frequent in the western part of the area. These pegmatites also occur in the Aitik ore zone and are younger than the mineralization.
4. The western part of the area shows in part intensive scapolitization, tourmalinization and mobilization of mafic material (skarn veinlets, skarn schlieren etc.). The recrystallization is more intense than in the eastern part.
5. The mineralizations consist mainly of chalcopyrite, pyrite, pyrrhotite and magnetite. Pyrrhotite is more frequent in Liikavaara East than in Aitik. In Aitik some bornite and chalcocite occur in quartz veins. Uraninite, scheelite, molybdenite, galena and sphalerite have been observed sporadically. In Liikavaara East galena and sphalerite are more frequent and scheelite occurs in connection with quartz and calcite veins and veinlets.
6. The bedrock in Aitik shows sericitization, especially towards the hanging wall. There exists a certain zoning between chalcopyrite and pyrite. The pyrite is more abundant on the hanging wall side and in the upper parts of the mineralization.
7. Towards the footwall the chalcopyrite is often connected to skarn veinlets and schlieren. These skarn veinlets show leached leucocratic zones on both sides and have obviously been formed by concentration of mafic material.
8. Both mineralizations show high K_2O contents, compared with the country rocks. In Aitik we can also observe a falling MgO content, rising again towards

the footwall. In Liikavaara East we have a high content of MgO and Fe compared with other parts of the area.

9. There exist good correlations between Cu, Ag, Bi, Sn, In and Ba. Zn is only weakly related to Cu; Pb, As and Ga not at all.

10. The Aitik mineralization occurs on the western flank of a dome structure, probably within a minor antiform which plunges 20—35° to the north. For Liikavaara East it has not been possible to determine a definite structural position. However, the mineralization seems to occur in the prolongation of the Aitik culmination. In any case the respective positions of Aitik and Liikavaara East opposite each other in a line perpendicular to the general strike should be of great interest. It seems also that the Cu contents between the two ores are probably higher than outside this zone.

Geijer (1917) discussed the genesis of the Nautanen mineralizations. He concluded that the ores were of pneumatolytic origin and related to the intrusion of the Lina granite. This interpretation was based especially on the connection of scapolite and tourmaline with Cu minerals in these mineralizations.

Scapolitization and tourmalinization can also be observed in Aitik. However, in Aitik the tourmalinization seems to be later than the mineralization. This conclusion is based on the following observations: The pegmatites which generally contain tourmaline cut the mineralization. They are not mineralized and are younger than the ore. We can observe that tourmaline infiltrates the bedrock on both sides of pegmatitic veins. This indicates that the tourmalinization is of the same age as the pegmatites and thereby later than the mineralization. We can also observe how crystals of pyrite and chalcopyrite increase in size towards the pegmatites.

Concerning the scapolitization, we have to remember that this is a regional feature in extensive parts of Norrbotten (see Sundius 1951, Geijer 1917 and 1930). Cu mineralizations on the other hand are only known at a few places (Svappavaara, Nautanen) within this large area of scapolitization and these Cu occurrences are only of minor size and importance.

We conclude therefore that neither tourmalinization nor scapolitization is directly related to the mineralizations of Aitik or Liikavaara East. This means that we have to consider a pre-pegmatitic-pneumatolytic origin of the ores.

On the other hand we can for example observe Cu concentrations in skarn schlieren, veinlets and scapolitized rocks. The skarn concentrations occur only within the zone of pneumatolytic alteration, indicating a connection between these rocks and the pneumatolysis.

This means that we might have an indirect relationship between the pneumatolytic alteration and a part of the Cu mineralization. The leached leucocratic zones suggest that mafic material has been mobilized and concentrated in skarn

veinlets and we can therefore conclude that the sulphides have also been mobilized.

The correlation between Cu and Sn (see factor analysis) could indicate a genetic relationship. As Sn is probably directly connected with pneumatolytic activity, one could suppose that this is also the case for Cu. This fact can on the other hand also be explained by the theory that Cu has been mobilized by the pneumatolytic activity which was adding Sn in traces to a pre-existing mineralization.

Regarding the primary origin of the Cu mineralizations we can choose between two alternative possibilities:

1. Originally sedimentary deposition.
2. Hydrothermal origin in connection with the Lina granite, but prepegmatitic.

In both cases we have to consider a later mobilization in connection with tourmalinization and scapolitization.

Concerning the Svappavaara Cu mineralizations there occur two types. One is related to scapolite rocks, by Geijer referred to as Svappavaara-Nautanen type. The other occurs in metasediments of the Svappavaara group (Frietsch 1966). The Svappavaara group consists of basic tuffs with subordinate graphite schists, biotite-rich quartzites, scapolitefels, amphibole schists and limestone.

The geographical positions of Aitik and Liikavaara East in relation to the granite could suggest that a hydrothermal origin of the mineralizations is more probable. On the other hand we have to remember that the Lina granite covers extensive areas in Norrbotten, that it is a very poorly differentiated migmatite-granite and that nowhere in other parts are any Cu mineralizations of importance known which could be related to the granite. The main mineralized zone from Aitik to Nautanen occurs along the general geological strike and in similar rocks. The whole area between Aitik—Liikavaara East and Nautanen consists of a type and facies of metasediments which is up to now unknown in other parts of Norrbotten. Also the Cu mineralizations are of a special type and are in any case geographically related to these metasediments.

It seems that the relationship between the Cu mineralizations and the metasediments which occur in this area is more significant than the relationship to the granite.

The high Cu content in most of the metasediments could also indicate a primary sedimentary concentration. However, the zone of metasediments between the eastern and the western granite in the Aitik—Liikavaara East section is only 5 km wide. That means that all the rocks are within the zone of influence of the granite and that the high Cu contents can be related to these intrusive rocks.

Summing up we can say that the problem of the origin of the mineralizations of the Aitik area is not definitely solved. The most probable hypothesis seems to be the following:

1. Sedimentary preconcentration of Cu in certain horizons and beds, especially in the rocks of what we have called the Aitik formation. The main concentrations were connected with the deposition of arenitic rocks (now occurring as mica quartzites or mica-feldspar quartzites) or arenitic rocks with some pelitic or dolomitic material (biotite to biotite-amphibole schists or gneisses). At Aitik, the skarn-banded rocks in the hanging wall (originally arenitic rocks alternating with dolomitic and pelitic beds) have been a definite primary limit for the primary concentrations of copper. The original environment at Liikavaara East (see analyses) was obviously more dolomitic than at Aitik. — If the tectonic-stratigraphic interpretation of the area, as interpreted in this paper is correct, the sedimentary preconcentrations of Aitik and Liikavaara East, have occurred in different stratigraphic formations.

The relatively high Cu contents in different rocks between Aitik and Liikavaara East could depend on repeated primary concentrations during sedimentation in this zone. Another similar zone could occur in the Nautanen—Liikavaara—Ferrum—Juoikama area.

The copper concentrations in an E—W-striking zone between Aitik and Liikavaara East could of course also be explained by structural control and the possible occurrence of near surface granite in this zone (culmination zone Aitik—Liikavaara East).

To reconstruct the primary sedimentary processes and their relationship to eventual sedimentary preconcentrations in detail is at the present stage of investigation not possible.

2. Folding and first stages of the intrusion of the granite. Regional metamorphism. Eventually, mobilization of chalcopyrite and other sulphides.

3. Sericitization and mobilization of sulphides in connection with early pneumatolytic-hydrothermal activity. In Aitik removal of MgO, Fe, CaO and Na₂O from the sericite zone to the east (footwall of mineralization). In Liikavaara East concentration of K₂O, MgO and Fe_{tot}, loss of Na₂O and Al₂O₃.

4. Tourmalinization and scapolitization in a first stage. Mobilization of mafic material and Cu, resulting in the formation of rocks with skarn schlieren and veinlets with sulphide minerals. Infiltration of Mo and Sn. The main pegmatitic intrusions are somewhat later.

5. Intrusion of quartz veins with local concentrations of Cu. The scheelite in Liikavaara East belongs to this stage of the mineralizing activities.

6. Regional metamorphism has probably also occurred later.

Concerning the distance of transport of mobilized material we have the direct observations of concentrated mafic material and chalcopyrite in the skarn schlieren. This distance is of cm to dm scale. The eventual transport of magnesium

for example could according to the diagrams in Fig. 32, be of the order of 100 m. If transport of mobilized sulphides over longer distances have occurred or not we do not know.

The picture of the copper distribution in the central to southern part of the ore (see Fig. 24) can indicate mobilization in connection with pneumatolytic activity. The pegmatites in this area cut the schistosity and follow a $N60^{\circ}-85^{\circ}W$ direction. The pegmatites are not mineralized, but as the assays are based on bulk samples of 15 m drillholes, they do not show up as zones with zero per cent Cu. Anyhow, the copper mineralization in this part shows a different pattern than in the northern parts of the ore, where the Cu distribution follows more or less the schistosity. This can be explained by redistribution during pneumatolytic activity, supposing that the direction of pneumatolytic alteration is more or less parallel to the direction of the pegmatites.

The Aitik copper ore has often in discussions been labelled as a porphyry copper deposit. From the descriptions given in this paper it should have been made clear that this is not the case. According to Bateman (1950) or Parsson (1939) some of the requirements of porphyry coppers are the following:

Low grade

Large-scale low-cost methods of mining

Association with stocklike intrusions of monzonitic porphyries

Disseminated replacement in porhyry or intruded schist

Blanket shaped, greater horizontal than vertical dimensions

Similar primary mineralogy

Intense sericitization and in places, silicification

Overlain by leached coppings

More or less supergene enrichment

Similar modes of origin.

Even if several of the above listed characteristics coincide with features of the Aitik ore, we can see that some of the important conditions are lacking, for example the association with stocklike intrusions of monzonitic porphyries and the blanket shaped horizontal dimension. The secondary enrichment will today not be regarded as a condition for a porphyry copper.

The proper place of the Aitik ore in a systematic classification would probably be among metamorphic ore deposits.

SUMMARY

The Aitik Copper Mine is situated about 15 km east of Gällivare, Norrbotten County, Sweden, at lat. $67^{\circ}07'N$ and long. $21^{\circ}E$. About 5 km east of Aitik occurs a similar but smaller mineralization, called Liikavaara East, and to the north the rock formations strike into the Nautanen area, where several small mineralizations of the same type are known.

The country rock of the area consists of Precambrian metasediments. The whole area is flat and covered with extensive swamps and moraine. Outcrops are rare with the exception of a section along the Lina river north of the mine. It has therefore been necessary to use the results of the geophysical surveys extensively for the reconstruction of the geological picture and the magnetic map especially has been of great help.

The first indications for a possible copper mineralization at Aitik were glacial boulders with disseminated chalcopyrite, found by personnel of the Boliden Co in 1930. As a result of geological investigations and an electromagnetic survey it was possible to localize the southern part of the mineralization in 1933. Prospecting work and diamond drilling has been going on during several periods since the first discovery. The last period of intensive investigations started in 1957 and especially the resistivity surveys, performed between 1960 and 1962 were of great help.

By 1963 so extensive an area had been outlined by diamond drilling that a feasibility study for an open pit mine was started, which showed that the project was economically reasonable. The development work started in 1965 and the first ore production in 1968.

The first project was to develop the mine for a 2 million ton/year open pit operation, with an average content of 0.5 % Cu and a cut-off grade of 0.37 % Cu. In project No. 2 the mine was being developed for a 5 million ton/year output with an average grade of 0.4 % Cu.

The mineralized zone of Aitik is about 3 km long and 400 m wide. Within this zone the ore has a length of about 2 km and a width of up to 200 m.

The surface area is 380 000 m² for an average of 0.4 % Cu and 0.22 % Cu cut-off. At the 300 m level the area is 480 000 m² with 0.42 % Cu average and 0.22 % Cu cut-off (for more details see p. 36).

The Likavaara East deposit (not in production) has an area of 20 600 m² at the 40 m level, calculated on an average of 0.55 % Cu and 0.3 % Cu cut-off.

The bedrock at Aitik consists of metamorphic rocks, ranging from sericite schists to biotite quartzites and gneisses, biotite-amphibole gneisses and gneisses with skarn schlieren. The main part consists of very fine-grained biotite schists and gneisses which partly contain garnet.

At Liikavaara East the bedrock is generally a biotite schist, partly chloritic.

The hanging wall of the Aitik mineralization (not the ore) is a layer of skarn-banded rocks.

At Aitik the feldspar of the bedrock is generally an oligoclase, often showing alteration into sericite. Microcline is subordinate but common throughout the mineralization. The microcline is idiomorphic, does not show any alteration and has obviously crystallized late.

The bedrock is sometimes red aplitic, often with some epidote. This type consists mainly of microcline and has been formed through microcline infiltration.

The sericite schists and quartzites occur mainly towards the hanging wall, the skarn

schlieren type of bedrock towards the footwall. The skarn schlieren and veinlets consist mainly of dark hornblende and biotite. Around these concentrations of dark minerals one can often observe a white leached zone, mainly consisting of plagioclase and quartz. This indicates, that the skarn schlieren and veinlets have been formed through concentration of hornblende and biotite from the bleached zones. The chalcopyrite and the pyrite follow the concentrations of the dark minerals.

The bedrock shows often scapolitization and disseminated black tourmaline. Even black tourmaline fels can be observed.

Pegmatites occur mainly on the western side of the Aitik ore towards the granite. Their frequency and thickness diminishes from west to east. On the upper levels of the Aitik ore there occur a number of pegmatites, generally not more than 1 m wide, but sometimes up to several metres. Their frequency and thickness increases with depth. Between 400 and 600 m depth they can be numerous and up to 40 m wide.

Most pegmatites follow more or less the direction of the schistosity, but they sometimes cut right through the bedrock, as for example in the southern part of the open pit.

Mineralogically they consist of quartz, microcline and albite and contain mostly black tourmaline. Black tourmaline infiltrates the bedrock from the pegmatites.

The only mineral of economic importance is chalcopyrite. Besides the chalcopyrite there occur pyrite, magnetite and pyrrhotite. Malachite occurs occasionally in the weathering zone. Chalcocite and bornite are rare and mainly concentrated in quartz veins. Chalcopyrite is partly coated by chalcocite in the upper parts of the ore. Quantitatively these minerals are of no importance, but they can locally raise the Cu content of the concentrates.

Sphalerite, galena and arsenopyrite have only been observed occasionally. The Ag content of the ore is connected to small inclusions of fahlerz in the chalcopyrite.

Ilmenite occurs sometimes together with magnetite, and hausmannite has been observed in some polished sections.

Uraninite, scheelite and molybdenite occur now and then as isolated grains in the pegmatites.

Quartz and barytes are the most frequent gangue minerals.

At Liikavaara East sphalerite and galena are more abundant and they occur generally in small veinlets. Magnetite is not so common as in Aitik, but pyrrhotite is abundant. Scheelite occurs in several sections of the Liikavaara East mineralization, mostly in connection with quartz — or calcite veinlets, partly together with tourmaline.

The following types of mineralization can be distinguished at Aitik:

1. Disseminations and stringers of chalcopyrite and some pyrite in fine-grained biotite gneisses, schists and quartzites.
2. Disseminated pyrite and chalcopyrite in sericite schists and quartzites.
3. Chalcopyrite and pyrite concentrated in skarn schlieren and veinlets.
4. Chalcopyrite and pyrite in quartz veins and veinlets.
5. Chalcopyrite in red aplite-like microcline-infiltrated gneisses.

The mineralized zone occurs on the western flank of an antiform structure. Towards the hanging wall there exists a sharp limit between the mineralized zone, marked by the skarn-banded gneisses. To the east the mineralization gradually fades out, and a sharp geological limit does not exist.

The ore dips about 45° W and the strike is N10— 20° E. The dip of the footwall (grade limit) is generally somewhat steeper than the dip of the hanging wall. With depth the hanging wall flattens out to about 35° W (in the northern part).

The ore is probably situated in a minor anticlinal structure on the western side of the larger antiform.

The plunge of the economic mineralization is 20—30°N 20°E in the northern part.

The rock units of the area consist of Precambrian metamorphosed sediments occurring in a zone, 40 km long, parallel to the general N20°W strike and with an average width of about 5 km. This zone of metasediments is surrounded by the younger Lina granite, migmatites and gabbro (see Fig. 32). The Lina granite has an age of 1540 ± 90 million years (Welin 1970). The stratigraphic position in relation to other formations in Norrbotten is not quite clear, but it seems probable that they are older than the Kiruna porphyry.

In the eastern part of the area occur meta-arenites within a syncline. The sedimentary clastic origin of these rocks is established by the occurrence of conglomerates as well as cross- and graded bedding. Metamorphism, recrystallization and alteration are of low grade. The rocks of the eastern part have been labelled as the Liikavaara group. Tectonically the eastern part is a syncline with a SSE dipping axis. The deposit Liikavaara East occurs on the eastern side of this syncline.

In the western part, metamorphism and recrystallization, as well as hydrothermal-pneumatolytic alteration are much more intense. Tourmalinization, scapolitization, skarn schlieren and veinlets are wide spread. Primary sedimentary features cannot be recognized.

Tectonically the western part is interpreted as a double folded antiform with the main structural high east of the Aitik mineralization.

The rocks of the western part have been labelled as the Aitik group.

The Aitik group consists of biotite to biotite-amphibole gneisses, partly somewhat skarn-banded, and the rocks of the Aitik formation, where the Aitik ore occurs.

The term Aitik formation has been applied to summarize different rock types which occur in the centre of the antiform structure and which show low magnetic anomalies. The magnetic anomalies of the overlying gneisses are considerably higher.

The main rock types of the Aitik formation are skarn-banded gneisses, fine-grained biotite gneisses, partly with garnet or amphiboles, sometimes going over into mica schists or quartzites, gneisses with skarn schlieren, amphibolites and coarse-grained biotite gneisses. Sericitization, scapolitization, tourmalinization and microcline infiltration have changed the original composition of the rocks.

The Aitik ore occurs in a layer of sericite schists and fine-grained biotite gneisses and quartzites (partly with garnet) in the upper parts of the Aitik formation, with skarn-banded gneisses in the hanging wall. Structurally it is situated on the western flank of the antiform.

The term Nautanen formation, as used in this paper, includes a formation of rocks of high magnetic anomalies, striking from the Lina river to Nautanen in the north. Petrographically this formation is very similar to the Aitik formation, but the magnetic characteristics are considerably different. Geologically the relationship between the two formations is not definitely settled, but most probably they constitute a single geological formation and the difference in magnetic intensity is due to changes in the primary sedimentary facies or differences in metamorphism.

Geochemically the Aitik ore zone is mainly characterized by a high K₂O content, the country rocks otherwise dominated by high Na₂O contents. *Mg* decreases in the ore zone, but increases again in the footwall. *Alk* only increases slightly towards the hanging wall. The Ba anomaly coincides with the Cu anomaly. Regarding the other elements we refer to Fig. 32 on p. 57.

The content of trace elements is generally low compared with the non-mineralized

rocks of the area. The only trace elements which are obviously more abundant are Ag and Mo.

The factor analysis shows that Cu occurs mainly in two factors; in factor 1 Cu occurs together with MgO, CuO, MnO, TiO₂, Fe indicating the correlation between Cu and skarn rocks, factor 2 represents the main copper mineralization connected with K₂O, Bi, Sn and Ag.

The origin of the mineralization is explained by primary sedimentary preconcentration and later mobilization in connection with metamorphism and pneumatolytic activity.

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