SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ca AVHANDLINGAR OCH UPPSATSER I A4 NR 62

DAVID RICKARD (Ed.)

THE SKELLEFTE FIELD

7th IAGOD SYMPOSIUM
AND NORDKALOTT PROJECT MEETING

EXCURSION GUIDE NO 4

UPPSALA 1986

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With contributions by L.-Å. Claesson, R. Jonsson, R. Larsson, D. Rickard, S.-Å. Svensson, P. Weihed and M. Willdén

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A. Trochlea ad cavernam, Reguninus nomine insignitam. Suedice Regerings Schaktz wind. B. Aquæ ductus, ubi collecta in cisternis aqua egeritur. Suedice Kust Stugu C. Trochlea quæ jumentis circumagitur, ad cavernam à Rege Carolo XII. dictam, altitudine LX. hexapedum seu ulnarum. D. Peritrochium, seu machina tractoria ad cavernam nomine Reginæ Udalricæ Eleonoræ appellatam, et LX. ulnas profundam. E. Fumus ex officinis molliendo metallo exstructis. Suedice Kallrostar. F. Vetus Curia metallicorum. G. Peritrochium ad cavernam, quæ columna candida dicitur, vulgo Blankstöten, XL. ulnarum profunditate. H. Caverna columnæ candidæ 35 ulnarum. I. Trochlea arcularum, Suedice Kistewinden, 51 uln. K. Curia nova conventui metallicorum [illegible] L. Trochlea ad cavernam lignariam 70 ulnarum. M. Caverna à Carolo XI dicta, per subterraneos meatus 127 ulnas depressa. N. Ligamentum magnum e columna candida [illegible] Anno 1687

Falu copper mine has been continuously mined for more than 900 years. Copper plate engraving from 1687 in Dahlberg's *Svecia Antiqua et Hodierna.*

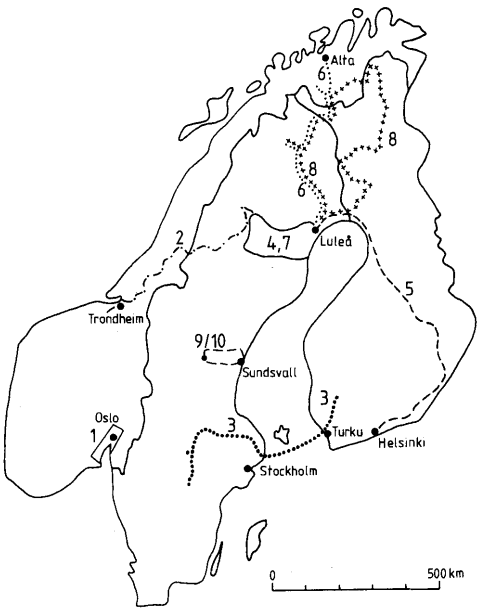
FOREWORD

Mining has ancient traditions in Scandinavia and Finland. In Bergslagen, Sweden, numerous mines produced Cu, Fe and Ag already during the medieval period. Some of them, e.g. Falun and Dannemora, are still active and are thus among the oldest operating mines in the world. Minerals like scheelite, gahnite and långbanite were first recognized in this region and the word skarn (originally having a pejorative connotation in Swedish meaning crap and whore) was used as a name for a certain mineral association for the first time by the old miners in Bergslagen. The most famous mining districts in Norway are Kongsberg, where silver was produced 1623–1957, and Røros, where copper was mined from 1644 until recently. The first mine in Finland was the Ojamo iron ore deposit, which was opened in 1540.

In addition to these ancient workings, ore bodies in several new mining districts have been exploited during the last century. Some of the most important of these occur in northern Sweden such as the Kiruna iron ores, the sulphide ores in the Skellefte district, the Laisvall Pb-mine and the Aitik Cu-Au mine. The sulphide ores in the Outokumpu district and in the Vihanti-Pyhäsalmi area are the most well-known Finnish deposits discovered during this century. In Norway, numerous deposits of pyrite and base metals were discovered round the turn of the century in the Sulitjelma and Grong districts and have been of major importance for the Norwegian mining industry. The discovery of extensive Mo-mineralization in the Oslo area, Norway and Pt-mineralization in the Kemi area, Finland have not led to any significant mining but have revealed new aspects of the metallogeny in the Nordic countries.

As a result of this long tradition in mining, the question of how ores are formed has been debated longer than any other geological problem in Scandinavia and Finland. It is therefore of special interest for the Nordic countries that the International Association on the Genesis of Ore Deposits (IAGOD) this year will arrange its 7th symposium in Scandinavia. The symposium, which is held in Luleå, Sweden, is arranged by the Geological Surveys of Sweden, Finland and Norway and the Luleå University of Technology. As an important part of the symposium programme, nine pre- and post-symposium excursions covering most of the important mining districts in Norway, Sweden and Finland are arranged (see overleaf). For these excursions, guide books have been written and are now available amongst the publications of the Geological Survey of Sweden (SGU Ca 59–67). The Swedish part of excursion no 6 was prepared in 1980 and was published by the Geological Survey of Finland. To all who have been involved in planning and organizing the excursions as well as writing the guide books I would like to express my sincere thanks.

Krister Sundblad, Geological Survey of Sweden
coordinator of the IAGOD-excursions 1986



1. Metallogeny associated with the Oslo Paleorift
Guide book: SGU Ca 59.
Excursion leader: S. Olerud.
Topic: Porphyry molybdenum mineralizations (Nordli, Hurdal and Bordvika, Drammen). Native silver-bearing veins at Kongsberg. Mineralizations associated with the Drammen granite; contact metasomatic Zn-Pb deposits (Konnerudkollen), intramagmatic Mo deposits.

2. Stratabound sulphide mineralizations in the central Scandinavian Caledonides
Guide book: SGU Ca 60.
Excursion leaders: M.B. Stephens and A. Reinsbakken.
Topic: Early Palaeozoic, massive Cu-Zn sulphide mineralizations in both volcanic (Gjersvik, Joma, Løkken and Stekenjokk) and sedimentary (Ankarvattnet) environments. The Laisvall sandstone-hosted, disseminated Pb-Zn deposit.

3. Mineral deposits of southwestern Finland and the Bergslagen province, Sweden
Guide book: SGU Ca 61.
Excursion leaders: H. Papunen and I. Lundström.
Topic: Proterozoic Zn-Cu-Pb deposits in volcanosedimentary environments including the mined-out Orijärvi and Aijala deposits in Finland, and the Garpenberg and Åmmeberg deposits in Sweden; the iron ore deposit of Dannemora in Sweden. Deposits associated with intrusive rocks include the Vammala Ni-Cu mine in Finland and the Wigström W deposit in Sweden.

4. Massive sulphide deposits in the Skellefte district
Guide book: SGU Ca 62.
Excursion leader: D. Rickard.
Topic: Proterozoic Cu-Zn-(Pb-As-Au) mineralizations in volcanosedimentary environments, including the Boliden, Långsele, Näsliden and Kristineberg deposits.

5. Proterozoic mineral deposits in central Finland
Guide book: SGU Ca 63.
Excursion leader: G. Gaál.
Topic: Early Proterozoic mineralizations including the Kemi Cr mine, PGE mineralization in the Penikat layered intrusion, Pyhäsalmi Cu-Zn deposit, Outukumpu Cu-Co-Zn mine and the Enonkoski Ni-Cu deposit.

6. Precambrian mineral deposits in northernmost Scandinavia
Guide books: SGU Ca 64 (Norwegian part)
Geol. Surv. Finland (1980), Guide 078 A+C, part 1 (Swedish part)
Excursion leaders: J.S. Sandstad and H. Lindroos.
Topic: Precambrian copper and iron ore deposits including visits to two of the largest mines in northern Europe: Kiirunavaara underground mine (Fe) and Aitik open pit operation (Cu, Au). In addition, the Raipas, Repparfjord, Bidjovagge and Viscaria Cu deposits and Au prospects in the Gällivare area will be shown.

7. Proterozoic mineralizations associated with granitoids
Guide book: SGU Ca 65.
Excursion leader: B. Öhlander.
Topic: Mineralizations associated with Proterozoic granitoid intrusions including the Pleutajokk, Rävaberget and Björklund U deposits, the Allebouda and Kåtaberget Mo deposits, the Storuman W mineralization and Tallberget Cu-Mo deposit.

8. Archaean and Proterozoic geology in northern Finland, Norway and Sweden
Guide book: SGU Ca 66
Excursion leaders: T. Sjöstrand, M. Often and V. Perttunen.
Topic: Archaean and Proterozoic geological environments in the ore-bearing Nordkalott area, including greenstone belts and granulites.

9/10. Enåsen Au deposit and Alnö alkaline complex
Guide book: SGU Ca 67.
Excursion leaders: T. Lundqvist, S. Sundberg and P. Kresten.
Topic: Geology at and around the Proterozoic Enåsen Au deposit and the Alnö alkaline complex.

IAGOD-excursions 1986

THE SKELLEFTE FIELD

CONTENTS

GEOLOGY AND METALLOGENY OF THE SKELLEFTE FIELD

D. Rickard

The Skellefte Field is a district of early Proterozoic marine supracrustals and intrusives which border the river Skellefteälven in northern Sweden (Fig. 1). The district forms an elongated belt about 200 km long and 50 km wide between migmatites to the south and continental supracrustals to the north. The Skellefte Field is a region of particular economic interest because of the occurrence of over 100 sulphide mineralizations. Nine mines are operating at present and a tenth is being prepared for mining. The mines are operated by the Boliden company, named after the famous Boliden deposit which closed in 1967. The Skellefte Field is a region of particular geologic interest because of its partially excellenty preserved Proterozoic supracrustals. Since the work of Rickard and Zweifel (1975), it has been the focus of international interest as an early Proterozoic analogue of a Phanerozoic volcanic arc.

HISTORICAL

The name 'Skellefte Field' was first coined by A.G. Högbom in 1899 describing several reconnaissance trips to the 4000 km^2 of supracrustals between Skellefteå on the coast and Arvidsjaur. Comprehensive geological descriptions of the area were presented by A. Högbom (1937) and S. Gavelin (1955). The more recent work of the Geological Survey of Sweden (SGU) was summarized by Lundberg (1980).

The area has been interesting from the mineral viewpoint for at least two hundred years. The earliest account of mineralization in the Skellefte district is of copper ore being mined in 1704. Friedric Wasserman, the State Prospector, described rocks from the Skellefte river in 1770. However, although several mineral occurrences were noted in the eighteenth century, the area was considered uneconomic by Hermelin (1804).

In the middle of the nineteenth century an attempt was made to work silver east of Skellefteå. Svenonius was able to write in 1893 that the area was "colossally rich in sulphides". In 1901 Petrus Burman showed that quartz veins found in 1855 were gold-rich. This gave rise to intermittent prospecting activity in the district until 1908, but no economic ore was found.

Metal prices were high during the First World War and the blockade caused a scarcity of pyrite and copper. Axel Gavelin, Director of the Geological Survey of Sweden, began a reconnaissance study of the potential of the Skellefte Field in 1916. In 1918 groups of geologists and mining engineers formed Bergbyrån Ltd., and the Centralgruppens Emissions Company to exploit Lundberg's and Nathorst's electrical prospecting methods. In 1918 the Kristineberg ore was discovered, although it was not mined until 1941. In 1920, the Geological Survey of Sweden began a systematic survey of the Skellefte district together with the Centralgruppens Emissions Company.

In summer 1921, one of the Centralgruppens Emission Company's geologists visited the Svanfors district in the east of the district. Some trenches had been dug a few years earlier and some massive sulphide boulders discovered. The new electrical prospecting methods were employed starting at the village of Boliden and following the glacial transport direction northwards. A particularly noteworthy group of electrical anomalies was found 2.5 km north of Boliden village. Even though there was no outcrop it was decided to drill, and the second hole intersected an auriferous arsenic-copper ore beneath 18 m of moraine on 10 December 1924. Grip and Wirstam (1970) claim that the farm name on the official topographic map was a cartographer's misprint; it was actually Bjurliden. But the name stuck and, after mining began in 1925, the Centralgruppens Emission Company became the Boliden Mining Company.

For many years the Boliden mine was the only operating mine in the Skellefte Field, although trial mining had begun at the auriferous arsenopyrite deposit of Holmtjärn in 1924. Rakkejaur was also found before Boliden, but is only now being prepared for mining. Rävliden, in the west of the field, was the next to be mined continuously, from 1936. Kristineberg was mined from 1941. Several mines were started between 1947 and 1970, all based on these early discoveries. Some details of discovery and mining data are listed in Table 3.

PROSPECTING METHODS

Prospecting methods in the Skellefte Field have been primarily determined by the poor outcrop in the district, which is characterized by lakes, bogs and forest. Conventionally, prospecting has been based on boulder mapping and geophysical methods. In recent years, as more geological information has become available, geological modelling has become more important. Geophysical methods include electromagnetic, magnetic and gravimetric techniques both on the ground and in the air. Recently an exploration programme has been initiated for deep prospecting in the Skellefte Field. This is partly financed by the Swedish Board for Technical Development and involves the extensive use of down-the-hole geophysical methods in deep boreholes. Geochemical methods have been employed and lithogeochemistry is at present being investigated, but both have been subordinate to the geophysical approach in the past.

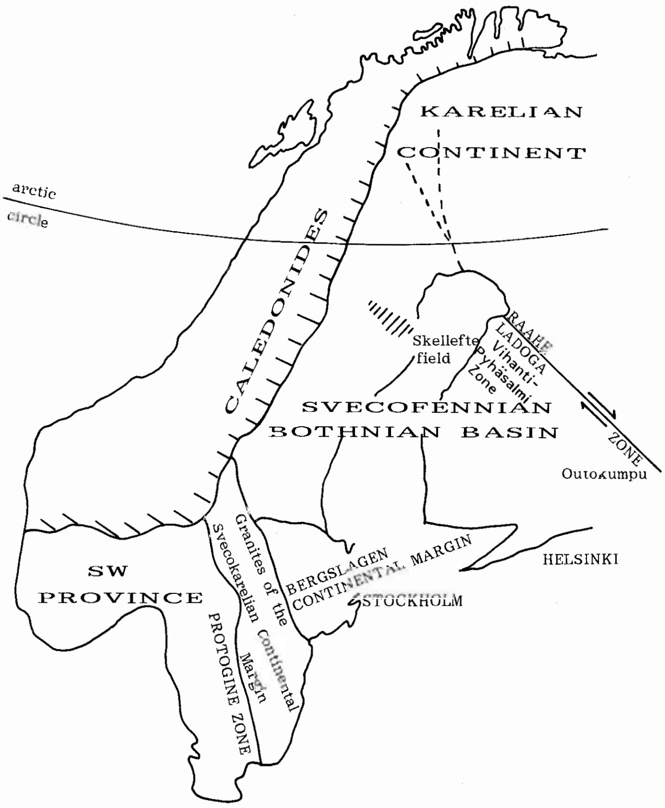


Fig. 1. Major geologic units of the Fennoscandian Shield.

GEOLOGY OF THE FENNOSCANDIAN SHIELD

The Fennoscandian Shield (Fig. 1) developed by accretion in SW–W direction (Rickard 1979). The oldest rocks are Archaean (>2.5 Ga) nuclei in the north and northeast of Finland and, possibly, in the Kola peninsula. Only three samples of Archaean age have been found in Sweden, mainly in the far north, and its extent is unknown.

The Archaean nuclei are mantled to the south and west by early Proterozoic rocks of the Svecokarelian orogen (c. 2.2–1.7 Ga). The Svecokarelian rocks consist of three main facies:

1. Karelian Facies, mainly continental supracrustals limited to the Karelian continent, particularly in the north and east of Finland.

2. Svecofennian Facies, mainly marine supracrustals, particularly concentrated in a belt of migmatites and greywackes across central Sweden and Finland.
3. Southwestern province, probably a piece of the Laurentian shield that was accreted into the Fennoscandian Shield during the middle Proterozoic. It is separated from the Fennoscandian Shield by the Protogine zone.

The Raahe-Ladoga zone is a line of dextral shears associated with a marked linear gravity anomaly that defines the SW margin of the Karelian facies in Finland. It is not easily traced into Sweden. It might appear to continue as the northern margin of the Skellefte Field. However, this is to a certain extent a feature of map projection. If the zone is "straight" on the earth's surface it will curve to the north of Skellefteå nearer the northern border. At present it seems it splays out in northernmost Sweden and may include faults through to the Kiruna and Aitik districts.

The Skellefte Field forms part of the marine Svecokarelian facies. In the south a second important sulphide ore district of Bergslagen stretches into southernmost Finland, and is separated from the Skellefte Field by the Bothnian Basin. The post-Svecokarelian margin of the Fennoscandian Shield is marked by a zone of middle Proterozoic I-type granitoids (cf. Nyström 1982) which can be traced from southeastern Sweden under the Caledonides to the far north. The Bergslagen sulphide province is considerably different to the Skellefte Field; Vivallo and Rickard (1985) suggested a continental margin environment rather than an island arc. Our latest investigations (Parr & Rickard, in prep) suggest significant non-marine component in the Bergslagen supracrustals.

Rickard (1985) proposed that the Svecokarelian rocks of the Fennoscandian Shield constitute part of the first global Wilson cycle. The various fragments preserved include a northern continent, the Outokumpu ophiolite (cf. Gaal *et al.* 1975), the Bergslagen continental margin, the Bothnian marine basin and the Skellefte Field — a Proterozoic equivalent of a Phanerozoic arc. In contrast, Witschard (1984) implied that vertical rather than lateral tectonics dominated crustal development in Fennoscandia at this time. Park (1985) suggested that the various fragments represent a tectonic melange of exotic terrains analogous to the Phanerozoic evolution of the northeast Pacific margin.

REGIONAL GEOLOGY

The volcanics, sediments and ores that characterize the Skellefte Field (Fig. 2) form a c. 200 km zone trending northwest from the coastal town of Skellefteå along the Skellefte river. This complex is folded on flat-lying axes trending in the same northwest direction. To the north terrestrial volcanics dominate. To the south, the Skellefte Field sediments thicken and become taken up in the migmatite and veined gneiss terrain of the Bothnian Basin.

Eklund (1923) recognized the transitional situation of the Skellefte Field between a stable craton to the north and an ultrametamorphosed sedimentary environment to the south. However, whereas no trace of Skellefte Field-type volcanics have been recognized in the north, small enclaves occur in the southern gneiss region. One of these enclaves, some 200 km south of the Skellefte Field proper, also hosts substantial massive sulphide mineralization of the Skellefte Field type.

Apart from these north-south variations across the Skellefte Field, significant lateral east-west variations occur. Conventionally, the Skellefte Field has been divided into three areas (cf. Fig. 7):

1, *the Eastern Area,* centered on the Boliden deposit
2, *the Central Area,* centered on the village of Norsjö
3, *the Western Area,* centered on Kristineberg

The division has been partly due to different areal responsibilities of the two main geological organisations in the district, the Geological Survey of Sweden, whose regional office was in Malå, and the Boliden Company, whose headquarters are at Boliden. However, it has become apparent that the geology of the Skellefte Field varies laterally from east to west. Generally, the Western Area is characterized by intense alteration of the rocks, the Central Area by excellently preserved sediments and volcanics and the Eastern Area by a higher metamorphic grade.

However, as discussed in more detail below, it is difficult to define the areal extent of the Skellefte Field with any certainty. Skellefte Field sediments and volcanics not only grade into the southern migmatites but also into the coastal gneisses to the northeast (cf. Lilljequist 1980). Even the northern margin is uncertain since it is beginning to appear that the terrestrial volcanics may overlie the Skellefte Field rocks in part. Probably the best definition includes the zone of sulphide deposits, which are mainly limited to the linear belt generally described as the Skellefte Field.

Stratigraphy

The major components of the Skellefte Field stratigraphy are well recognized. They were listed by Josef Eklund in 1925 (in Sundberg *et al.* 1925) and formalized by Gavelin (1955).

1. A lower volcanic complex, the *Skellefte Volcanics* of Gavelin (1955), with abundant sulphide mineralization.
2. An early orogenic granitoid group, the *Jörn Complex.*
3. An early sedimentary sequence, the Phyllite Series of Gavelin (1955) or the *Skellefte Sediments.*
4. A late series of conglomerates and volcanics, the *Vargfors Group.*
5. A late to post-orogenic granitoid group, the *Revsund Complex.*

However, detailed interrelationships between individual units have been and still are the subject of some debate. The discussion centres on the lateral chronological consistency of observed units in a highly active zone.

The approach of the Geological Survey of Sweden has

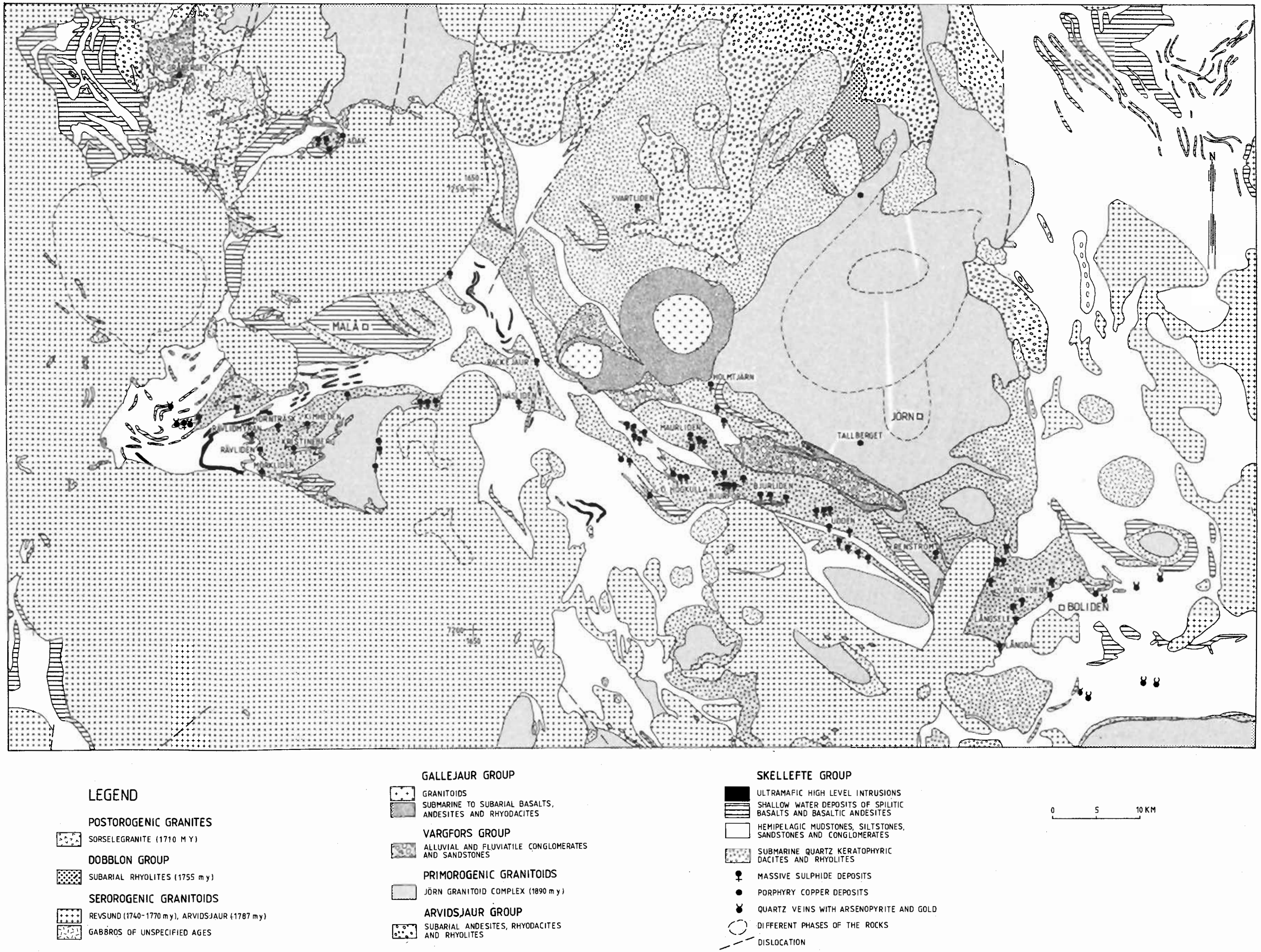


Fig. 2. Geology of the Skellefte Field (prepared by L.Å. Claesson from work done by the Geological Survey of Sweden and compiled by the Swedish Geological Company).

been to recognize the complexity of these volcano-sedimentary complexes and to attempt to erect a formalized stratigraphy which takes this into account (Kautsky 1957). Two stratigraphies, that of Gavelin (1955) and Lundberg (1980) are illustrated in Table 1. Gavelin's (1955) stratigraphy takes account of all previous work in the area, and Lundberg's (1980) stratigraphy, as modified by Claesson (1985), includes the results of later SGU investigations.

It has become important for exploration in the district to characterize local palaeoenvironmental conditions. This has led company geologists to adopt a less formalized and more dynamic approach to stratigraphic problems in the Skellefte field. Helfrich (1971) made a first attempt at such a representation (Fig. 3).

The Skellefte Group. The Skellefte Group includes the lower volcanic-dominated series and the overlying sediment-dominated series of the Skellefte Field supracrustals.

The Skellefte Volcanics. The lowermost rocks of the Skellefte district consist of predominantly felsic pyroclastics over 4 km in thickness. These are the products of violent explosive volcanism at a number of volcanic centres throughout the district. The felsic volcanics constitute the bulk of a series of highly variable local sequences which include acid lavas, intermediate and mafic pyroclastics and flows and interbedded greywackes and pelites.

TABLE 1. Stratigraphies of the Skellefte District from Gavelin (1955) and Lundberg (1980).

Gavelin (1955)	Lundberg (1980)
	Sorsele Granitoids Dobblon Group
	Unconformity
Adak granite series Sorsele granite series Vargfors series	Revsund granitoids Vargfors Group
Unconformity	Unconformity
Revsund granite series Gneisses Jörn granite series Arvidsjaur series Phyllite series Volcanic series.	Jörn complex Arvidsjaur group Skellefte group

In the Eastern Area (Vivallo, in prep.), two major units are observed. The lower unit consists of homogeneous felsic massive metavolcanics representing lava flows and domes, lapilli tuffs and agglomerates. A sulphide mineralization at Mångfallberget is located in the upper parts of this unit. The

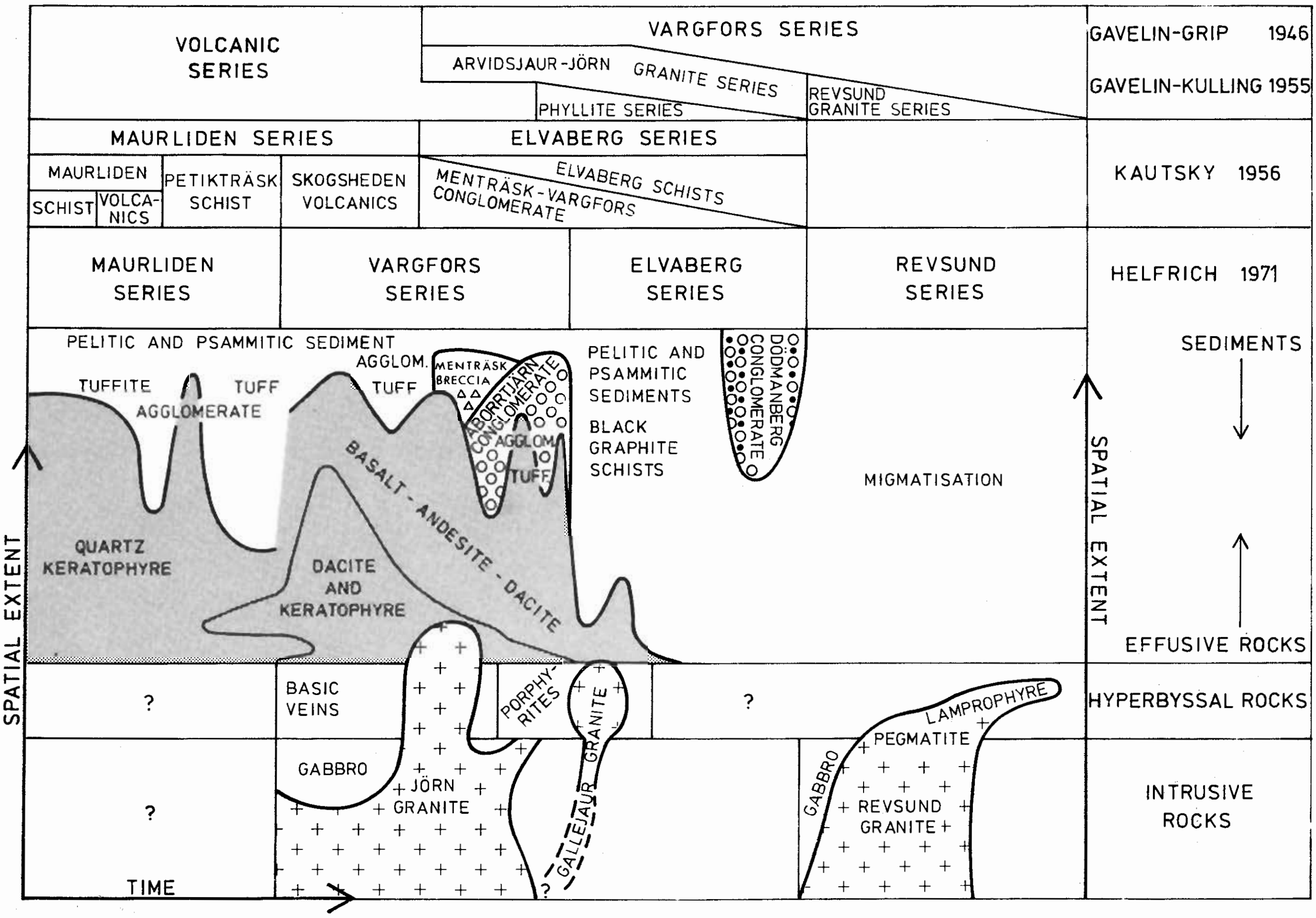


Fig. 3. Helfrich's (1971) dynamic stratigraphy of the Skellefte District (from Rickard & Zweifel, 1975, reproduced by permission of the Economic Geology Publishing Company).

upper unit shows considerable lateral facies variations with mafic to felsic tuffs and is characterized by cyclic repetition of volcanic units, each containing a mafic and felsic component. Metasediments become more frequent in the upper parts with well-preserved sedimentary structures such as slumping and graded bedding. Major sulphide ores, including Boliden and Långsele, are associated with calcareous and pelitic sediments in the upper parts of this unit.

In the Central Area, the Skellefte volcanics are represented by dominantly felsic pyroclastics with minor mafic intercalations. The pyroclastics include coarse fragmental rocks, crystal and lapilli tuffs and fine laminated tuffs. Massive lavas and domes are subordinate. The mafic component includes tholeiitic basalts and basaltic andesites as lavas, agglomerates and banded tuffs.

No simple stratigraphy is recognized in the Western Area where Willdén (p. 46–52 this volume) has developed a local model based on contemporaneous volcanism and sedimentation in a block-faulted basin. Reference to Fig. 34 illustrates the stratigraphic complexities of the district. A number of stratigraphic units are recognized but they are of variable lateral extent and often diachronous. Rhyolitic tuffs and a massive rhyolite form the bulk of the sequence, the massive rhyolite being interpreted as mainly intrusive domes. More mafic volcanics, including andesites and porphyries, are limited to a particular stratigraphic horizon. This consists of coarse felsic pyroclastics, basaltic and andesitic tuffs, dikes and flows, reworked volcanics and pelites. The Kristineberg sulphide ore is associated with pelites and carbonates at the top of the felsic and at the bottom of the mafic unit. The mafic phase possibly marks the end of a quiescent volcanic period where hydrothermal activity and sulphide deposition dominated. The sulphide mineralization at Rävliden to the north of the Kristineberg deposit occurs at the top of the volcanic complex, within redeposited tuffs and in the sedimentary sequence.

The major element compositions of the more abundant Skellefte Field metavolcanic types are listed in Table 2. The rhyolites show a generally consistent composition. The Eastern Area rhyolites show $K_2O > Na_2O$ and Vivallo (in prep.) notes that K enrichment appears predominantly above the ore zone. The Eastern Area andesites are SiO_2-rich, being more of dacitic composition. The lack of dacites in the west and central areas of the Skellefte Field has been noted. The general chemistry of the rocks tends to be more calc-alkaline in the Western Area and more tholeiitic in the Central and Eastern Areas (Vivallo in prep., Claesson 1985). However, the rocks show various degrees of alteration and more definite classification is difficult.

Subvolcanic intrusives are clearly recognized in several parts of the Skellefte Field. These include the homogeneous, massive rhyolitic domes, often brecciated, which occur throughout the area. In the Eastern Area these take the form of quartz porphyries and are closely related to the ore zones. In the Western Area the Viterliden porphyry is important in the Kristineberg mine area. It is a fine-grained feldspar porphyry with abundant mafic xenoliths and well-developed granophyric textures. It probably represents a high level stock related to the Jörn Granite. In the Eastern Area, Welin (in prep.) has obtained a zircon data for a quartz porphyry of 1882 Ma.

TABLE 2. Representative compositions of volcanic rocks from the Skellefte Field (data from Vivallo in prep. and Claesson 1985)

	RHYOLITE			ANDESITE			BASALT	
	West	Central	East	West	Central	East	West	East
SiO_2	73.66	73.66	75.29	57.77	53.92	62.68	51.08	49.84
TiO_2	0.33	0.29	0.16	0.52	8.90	0.65	0.71	0.88
Al_2O_3	13.11	13.57	11.74	15.52	18.23	15.83	15.37	18.01
FeO*	2.99	2.94	2.83	8.03	9.46	6.18	10.24	9.93
MnO	0.07	0.03	0.07	0.13	0.15	0.11	0.19	0.18
MgO	1.43	0.88	1.48	5.12	4.19	2.32	10.19	5.25
CaO	0.41	2.39	1.68	5.47	8.97	4.18	6.35	9.38
Na_2O	3.55	4.34	1.93	3.17	2.29	3.59	2.50	2.76
K_2O	2.34	1.57	2.74	1.36	3.03	2.03	1.15	<1.00
P_2O_5	0.12	0.14	–	0.05	0.24	–	0.39	–
	n=13	n=4	n=26	n=13	n=4	n=13	n=6	n=15

The Jörn Granitoid Complex. – The Jörn Granitoid Complex is essentially a series of granitoids which intrude their own volcano-sedimentary pile. For some years there was considerable debate concerning exactly what 'Jörn Granite' was. Granitoid outcrops around the Central Area village of Jörn display a variety of compositions and textures. 'Jörn Granite' also occurs in the Western Area at Kristineberg.

The importance of the Jörn complex was recognized originally by Joseph Eklund (op. cit. 1925) who stated that the granitoids caused extensive metasomatic alteration of the volcanics and sediments with the formation of sericite– and chlorite – quartzites, chlorite schists, Ca-Mg silicates and the sulphide ores. This theory was expanded and emphasized by Alvar Högbom (1937). However, Gavelin (1937) associated the ores of the Central Area with the late orogenic Revsund Complex and, later, Gavelin and Grip (1946) and Gavelin (1955) extended this to the whole area. Rickard and Zweifel (1975) demonstrated that the ores were early orogenic and coeval with their host volcanics and sediments, thereby returning, albeit indirectly, to Eklund's original thesis.

Claesson *et al.* (in press) have made a detailed geological, geophysical and isotopic investigation of the Jörn Complex. Their work shows that the Jörn Granitoid Complex includes three or four intrusions ranging from granite to granodiorite which formed around 1890 Ma, with a probable final crystallization age for the outer part of the complex at around 1880 Ma. These are essentially I-type granitoids (Chappell & White 1974, Wilson 1980) and include disseminated Cu-Mo porphyry mineralization in the outer rim (cf. p. 37–42).

Stratigraphically the Jörn Granitoid Complex intrudes the Skellefte Volcanics and overlying Skellefte Sediments. Grip (1935), Gavelin (1955) and Wilson *et al.* (in press) have shown on chemical grounds that the Complex is comagmatic with the Skellefte Volcanics. Balls of Jörn Granite form a characteristic constituent of conglomerates from the overlying Vargfors Group. The dating of the Jörn Complex is therefore central to the geochronology and stratigraphy of the Skellefte Field.

The Skellefte Sediments. – A major feature on Skellefte Field geologic maps is the contact between the Skellefte Volcanics and the overlying Skellefte Sediments. One reason for this is the ease with which pyrite and pyrrhotite-bearing graphitic shales register on electrical surveys. Gavelin's "Phyllite Series" nomenclature is a reflection of this feature. Some debate is now in progress about how much this contact is chronostratigraphic and how much it is lithostratigraphic. Grip (1973) referred consistently to a transition zone between the mainly volcanic lower rocks and mainly sedimentary overlying rocks.

Lundberg (1980) emphasized the important greywacke component of the sediments, partially of volcanogenic origin. They grade into pyroclastic tuffs and calcareous agglomerates with occasional thin limestones. The volcanogenic greywackes consist of slumped alternately pelitic and lapilli tuff beds with angular pelitic fragments and large volcanic blocks. The deposits show evidence of an unstable environment of simultaneous sedimentation and volcanicity. The volcanogenic sediments increase towards the northeast, whereas the sediments dominate towards the south and may reach several thousand metres in thickness. These include particularly, rhythmically layered greywackes. Interbedded with these sediments are mafic lavas and pyroclastics. These are especially abundant in the Central and Western Areas. Welin (in prep.) has obtained Sm-Nd ages for metapelites from the Eastern Area near Långsele of c. 1.9 Ga. In the Western Area, the metapelites around Rävliden also give Sm-Nd ages of c. 1.9 Ga.

The occurrence of ultramafic rocks in these sequences has led to some debate. Lundberg (1980) described 10–30 m thick ultrabasics occurring as lava flows. Claesson (1985) discussed these rocks in detail. He noted peridotitic high-level intrusions as stratiform layers in low-grade metasediments. The Skellefte peridotites contain c. 60 % serpentinized olivine and varying amphibole, biotite, chlorite and magnetite. The extrusive equivalents are described as pyroxene porphyritic or pyroxene and plagioclase porphyritic lavas and tuffs. The ultrabasic extrusives in the Skellefte Sediments display a highly primitive composition and are geochemically similar to komatiites. Vivallo (in prep.) describes komatiitic rocks from within the Skellefte Volcanics in the Eastern Area. However, his data show that the ultrabasics are unrelated petrogenetically to the other volcanics. Ultrabasics also host Ni-Cu mineralization in the high-grade terrain to the south of the Skellefte Field, and appear to have a similar composition (Nilsson 1985, Claesson 1985). In view of this there is some discussion as to whether these ultrabasic rocks actually represent synvolcanic intrusives and extrusives within the Skellefte Field – or reflect some much later and unrelated event.

The Vargfors Group. – The Vargfors Group includes a series of spectacular conglomerates which are well exposed along the river Skellefteälven. They were first described by Friedric Wasserman in 1770. They feature in all descriptions of Skellefte Field geology. They are classically typified by two main end member conglomerate types according to Kautsky (1957): the Abborrtjärn conglomerate and the Dömanberg conglomerate.

The *Abborrtjärn Conglomerate* consists of rounded fragments of grey felsic volcanics of the Skellefte Volcanic type and boulders from the Jörn granitoid. It is an important stratigraphic marker inasmuch as it places the Jörn granite firmly as a synvolcanic intrusive.

The *Dömanberg Conglomerate* is reddish and consists of well-rounded balls of different volcanic rocks, classically assumed to have been derived from the terrestrial volcanics to the north.

The Vargfors Group also includes volcanics, dominantly basalts within minor felsic tuffs. Lundberg (1980) associated these basalts with the thick basalts associated with the *Gallejaur Intrusive* – a nearly circular cauldron structure of c. 12 km diameter. Lundberg (1980) notes the intimate nature of the conglomerates and volcanics in this area.

The Vargfors Group are conventionally assumed to rest on a major unconformity, and thus represent a younger event than the underlying Skellefte Group series of Skellefte Sediments and Skellefte Volcanics. This would in turn presuppose a younger volcanic event associated with the deposition of these conglomerates.

The stratigraphic position of some parts of the Vargfors Group is debatable. By their very nature, these conglomerates will be deposited discordantly on underlying strata. However, at Nicknoret in the Central Area, conglomerates, apparently of the Abborrtjärn-type, grade down into fine-grained sedimentary strata which are very similar to the "turbidites" of the Skellefte Sediments. This would imply that the Vargfors Group was merely a local facies variation of the Skellefte sediments, and not a younger sequence. Skiöld (in prep.) reported a zircon age of +1.87 Ga for the terrestrial volcanics to the north (the Arvidsjaur volcanics), which is some 20 Ma younger than the Jörn Complex and the Skellefte Volcanics. If the Dömanberg conglomerate balls include fragments of these terrestrial volcanics, then the Vargfors-Gallejaur complex must represent a distinct younger event.

Lundberg (1980) showed that the Gallejaur intrusion consisted mainly of a large circular vent of basaltic agglomerates and fine tuffs. The Gallejaur granitoid is a thin circular body representing a small shallow intrusion emplaced late in the history of the structure. Interestingly, another granitoid body (of probably identical origin according to Lundberg) is situated around 12 km to the west at Grundträsk.

The Revsund Complex. – Rocks which have been described as "Revsund Granite" occupy perhaps 10 % of the Swedish shield area. The term includes a large number of late/post-orogenic intrusions which are mainly located within the Bothnian Basin to the south of the Skellefte Field. The typical Revsund rock is a coarse porphyritic, quartz- and potassium-rich, S-type granitoid. Associated diorites and gabbroids are very subordinate (Gavelin 1957). Some lithologic varieties have been given local names. Thus some small stocks north of the town of Skellefteå display a fine-grained type used as building stone and called "Skellefte Granite". Since this fine-grained variety also constitutes the marginal zone of coarser intrusions (Gavelin 1957, p. 37), there seems insufficient evidence at present to warrant separating it from the Revsund Complex, as has been suggested by Lundqvist (1979, p. 39).

The late-orogenic forms intruded apparently in metamorphic conformity with high-grade metagreywackes and the post-orogenic forms are associated with contact metamorphism. Within the Skellefte Field, the tongue of Revsund granite which extends northwards between Boliden and Renström is associated with conspicuous contact metamorphism of sulphide mineralizations. The granitoid in the Adak area to the northwest of the Skellefte Field is a more northerly member of the Revsund Complex (Welin *et al.* 1979).

The Rb-Sr data from a sample of Revsund granite from near Lycksele to the south of the Skellefte Field of c. 1750 Ma (Welin *et al.* 1971) is a key date in Swedish geological development. This date is generally accepted as marking the end of the Svecokarelian and the close of the Early Proterozoic in Fennoscandia. Wilson *et al.* (1985) examined the isotopic systematics of five Revsund-type granitoids within metagreywackes from the Bothnian Basin southwest of the Skellefte Field. These are all peraluminous, leucocratic, high SiO_2 granites and adamellites. Their zircon age is c. 1.77 Ga. Welin (1979) reported further Rb-Sr ages of c. 1.75 Ga for Revsund-type granitoids and Skiöld (in prep.) has found further zircon ages of around 1.75 Ga for granitoids from this Complex.

Within the Skellefte Field the Revsund Complex intrudes the Skellefte Volcanics and Skellefte Sediments and has been observed to intrude conglomerates from the Vargfors Group (Lundberg 1980).

The Revsund Complex is pegmatite-rich in part, in contrast to the early orogenic granitoids. This is in line with its origin through anatexis of sediments. Several well-known pegmatites are associated with late-orogenic granitoids in Sweden. One of these, the *Varuträsk pegmatite,* is situated within the Skellefte Field, some 15 km inland from Skellefteå.

The Varuträsk pegmatite (Fig. 4) has been described in detail by Quensel (1956). The pegmatite is lithium-rich and occurs as a roughly tabular body striking NNE–SSW. The dip varies from 30° WNW in the east to horizontal in the west. The pegmatite is zoned with a small quartz core, a quartz and muscovite border zone, and a muscovite (as thick books), quartz, beryl and tourmaline wall zone. On this zonation has been imprinted pneumatolytic replacement, according to Quensel, with abundant lepidolite, petalite, pollucite and spodumene. Quensel recognized lower temperature replacement units with dominant pure albite (cleavlandite), with lepidolite, rubellite, indolite and tantalite. Attempts have been made to mine the pegmatite, and all that is left now are abundant dumps. The pegmatite has been dated at 1750 Ma by the Rb-Sr method.

Tectonics

The Skellefte Volcanics and Skellefte Sediments are folded along flat-lying axes trending in the characteristic Svecokarelian NW–SE direction. Dips are moderately steep, commonly between 40–80°, but overturned strata are unknown to this author. A second, later stage of folding also on flat-lying to moderately inclined fold axes in a NE–SW direction produced the interference structures that typify the area. Indeed, Grip (1973) was able to classify the ores in the Skellefte Field in terms of the antiformal culminations or domes and synformal depressions that have been formed by the two folding stages. Towards the south, deformation becomes more intense as the gneissose terrain to the Bothnian Basin is approached. Tectonic patterns are complicated locally by late Revsund intrusions. It is also becoming more apparent that local synvolcanic deformation patterns around the sulphide ores were often quite complex. The full extent of synvolcanic and synsedimentary deformation in Skellefte Field is not appreciated as yet. Reflecting this complex history, local structural analyses appear to reveal multideformational histories.

A vertical axial plane schistosity is often well-developed in the area. Massive sulphide ores, with possibly considerably different rock mechanical properties than their hosts, tend to appear in fold hinges. This was a major factor in the development of the epigenetic Revsund-granite theory of ore deposition. As Grip and Wirstam (1970) wrote in their history of the Boliden deposit, this hypothesis was used with some success in the mine geology for around 30 years.

The Vargfors Group are relatively undeformed although a well-developed schistosity is observed in the Central Area, striking NW–SE and with a steep dip. However, the sediments themselves appear relatively flat lying in shallow NW–SE elongate basins.

Metamorphism

The metamorphic grade in the Skellefte Field is generally in the greenschist facies. However, it is variable and complicated by intensive hydrothermal alteration. No modern regional study of metamorphism has been made and most modern representations refer back to Gavelin (1955 and thus 1939). Gavelin separated areas dominated by biotite and areas characterized by sericite + chlorite in acid volcanics. This boundary appeared to follow the general line of the late orogenic Revsund intrusions. The higher biotite-grade rocks were towards the southern gneisses. The problem here is in the interpretation of these mineral isograds. Certainly, the area must have suffered at least two regional metamorphic events: (1) a primary burial metamorphism in connection with the development of the original volcano-sedimentary pile, (2) regional metamorphism associated with the culmination of orogeny and the development of extensive anatectic granitoids to the south. In addition, hydrothermal alteration associated with ore deposition caused extensive metasomatism, and individual granitoids display variably

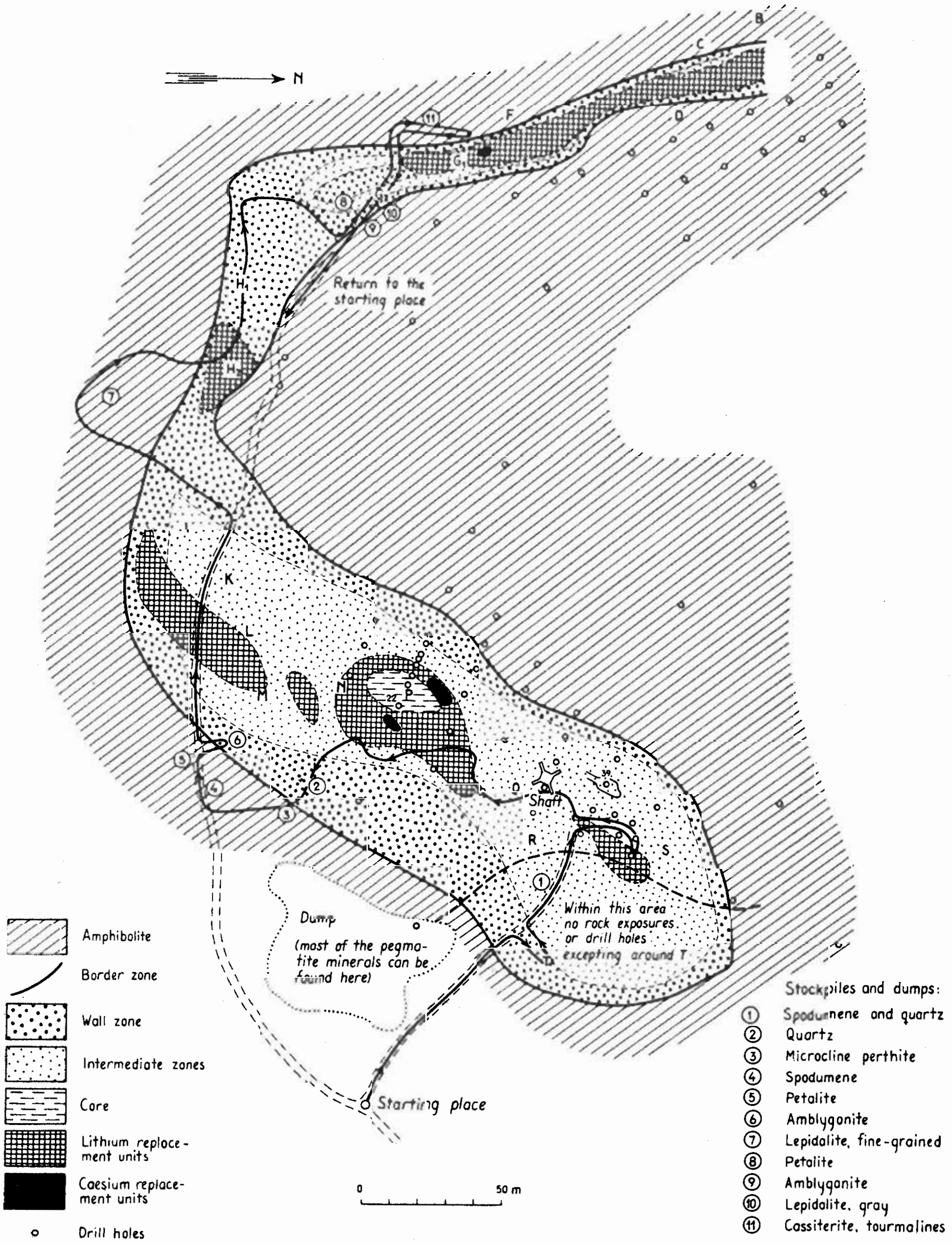


Fig. 4. Surface geology of the Varuträsk pegmatite, from Quensel (1960), reproduced by permission.

marked contact haloes, with the development of hornfels and porphyroblastic rocks.

The lowest grade of metamorphism is observed in the Central Area, especially to the north where rocks of the lowest greenschist facies are preserved. The Eastern Area is characterized by lower amphibolite facies and the Western Area by greenschist facies overprinting by regional sericitization resulting from intense hydrothermal alteration. Andalusite, cordierite, gahnite, and staurolite are found, usually as part of the intense alteration zones surrounding these ores. High pressure facies have not been recognized, although recent reports of kyanite have been noted for the Western and Eastern Areas.

THE SULPHIDE ORES

The ore deposits of the Skellefte Field are complex massive pyrite bodies of volcanogenic origin. A number of other types of mineralization occur including porphyry Cu-Mo and orogenic Au-quartz veins. However, these have not proven economic to date.

Form of deposits

The ores occur as lens- or slab-shaped bodies more-or-less elongated in the direction of the strike. They can be broadly classified as stratiform, although they include many cross-cutting features and discordant structures. An individual deposit will often consist of a number of different bodies and lenses. The total surface area of the deposits is c. 150 000 m^2 of which one deposit, Rakkejaur, contributes about one sixth. Tonnages are listed in Table 3 and deposit descriptions are presented below. The largest known deposit is Rakkejaur which is 550 m long and 65 m broad and at least 320 m deep. Seventeen million metric tons of ore have been proved to 320 m. Other deposits are much smaller and the gold-rich zone of Holmtjärn, as mined between 1924 and 1926 had a surface area of only a few square metres.

The deposits can be classified into two main types, massive pyrite bodies and stringer ores. The massive pyrite deposits represent proximal sulphide mounds and sheet slide deposits. The stringer ores are stockworks and generally occur in the stratigraphic foot wall of the marine deposits. Examples of the massive deposits include Kristineberg and Renström. A particular fine stockwork is observed at Näsliden.

The form of the deposits is partly a function of their primary shape and partly due to their subsequent tectonic history. The Udden deposit, for example, shows evidence of primary slumping and associated autobrecciation in the massive pyrite body resulting in deformation patterns of far greater complexity than that observed in the less competent wall rocks. The Boliden deposit itself was tightly isoclinally folded on an axis dipping 50° E. An intense E–W axial plane schistosity gave the appearance of a shear zone. The Näsliden ore, too, has been tightly folded but around fold axes dipping 80° S. In Kristineberg the ore follows zones parallelling an E–W axial plane schistosity and isoclinal folding on moderately W dipping axes. Transposition of bedding may occur in deposits such as Renström, which now takes the form of a steeply dipping rod-shaped body parallelling intense schistosity. Agglomerate pebbles in the shaft display relative elongation of around 6:1.

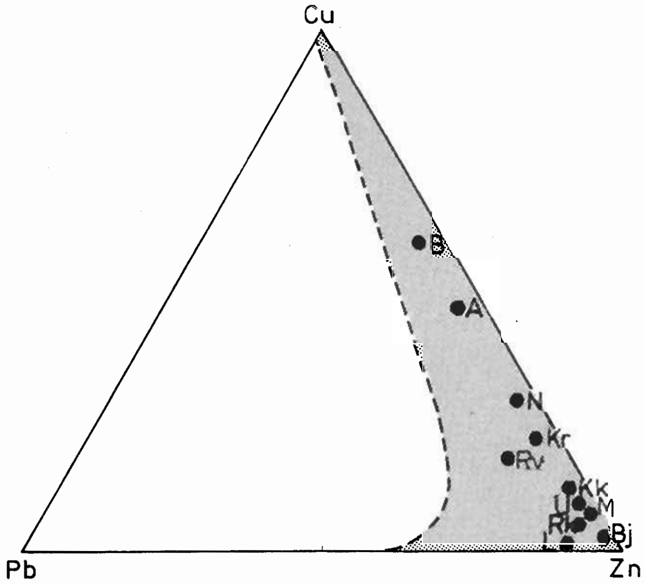


Fig. 5. Average compositions of Skellefte District ores in terms of % Cu, Zn and Pb: B=Boliden, Å=Åkulla, N=Näsliden, Kr=Kristineberg, Rv=Rävliden, Kk=Kankberg, U=Udden, M=Maurliden, Rk=Rakkejaur, Bj=Bjurliden, L=Långsele (from Rickard & Zweifel, 1975, reproduced by permission of the Economic Geology Publishing Company).

Composition of the ores

Pyrite is the dominant sulphide in the ores and other minerals are present in variable proportions. The major ore minerals are chalcopyrite and sphalerite. Arsenopyrite is common and locally abundant. Minor sulphides include galena and pyrrhotite. Sulfosalts are common accessories. Gold appears as native metal or electrum.

Pb-Zn-Cu ratios of the ores are shown in Fig. 5. The ores are particularly poor in lead, and most cluster around the Zn-rich corner. Average ore compositions are listed in Table 3.

The average values of Fe and S in the Skellefte Field deposits is 31 wt % and 30 wt % respectively. Pyrrhotite is locally abundant, particularly near to postorogenic Revsund granite intrusions, but iron-oxide minerals are rare. Arsenic is locally very abundant. At Boliden the average grade was 6.9 wt %, but only 25 % of the Skellefte Field deposits have concentrations more than 0.5 %. Näsliden South has 1.0 wt % and Rakkejaur 1.3 wt %, and they constitute the next richest As ores (Grip 1973).

Nickel and cobalt are insignificant in Skellefte Field deposits, less than 300 ppm Co and 400 ppm Ni, although the arsenopyrite ore at Boliden showed up to 0.7 % Co. Selenium was also enriched in Boliden (0.07 % Se), but is low in the rest of the Field.

Gold is a major product from the Skellefte mines. Boliden was in fact the richest gold ore in Europe with an average of 15.2 $g.t^{-1}$ over 8.34 million metric tons of ore through 43 years of production. In particular areas of the deposit, bonanza-type concentrations were encountered: over 600 $g.t^{-1}$ over 1 m in the "Gold Rise Ore" and over 200 $g.t^{-1}$ over 2 m in the root zone to the Eastern Ore. Gold was mined from a 40 m section of a continuous vein, up to 7 m thick, containing quartz, tourmaline and sulfosalts.

Gold in the Skellefte Field mines as a whole averages about 1.5 $g.t^{-1}$. Gold has been important for Kristineberg and will be an important by-product for Rakkejaur. However, no Boliden-style concentrations have otherwise been found, except in the small deposit of Holmtjärn in the west of the Central Area.

Silver is of less importance economically although still significant in the ores. It occurs in part with the gold in electrum, and significant Ag concentrations were found in the bonanza areas of the Boliden deposit. The silver mainly occurs as sulfosalts throughout the Skellefte Field ores. The

TABLE 3. Skellefte Field: Mines and concentrators

THE BOLIDEN DISTRICT
Långdal
In operation: 1967, discovered in the middle of the 1930s. Ore: Complex ore with copper, lead, zinc and precious metals. Annual production: 140 000 tons.

Långsele
In operation: 1956, discovered in the middle of the 1920s. Ore: Complex ore with copper, zinc, precious metals and sulphur.
Annual production: 360 000 tons.

Udden
In operation: 1971, discovered in the middle of the 1950s. Ore: Complex ore with copper, zinc, sulphur and precious metals.
Annual production: 360 000 tons.

Renström
In operation: 1952, discovered in the middle of the 1920s. Ore: Complex ore with copper, lead, zinc and precious metals. Annual production: 210 000 tons.

Central concentrator at Boliden. 1.14 million tons will be milled this year. Production of 22 800 tons of copper concentrate, 80 000 tons of zinc concentrate and 280 000 tons of pyrite concentrate. Metal contents in the concentrates: 4 800 tons of copper, 3 700 tons of lead, 44 000 tons of zinc, 47 200 kilogrammes of silver and 571 kilogrammes of gold.

THE KRISTINEBERG DISTRICT
Kristineberg
In operation: 1940, discovered at the end of the 1910s.
Ore: Complex ore with copper, zinc, sulphur and precious metals.
Annual production: 425 000 tons.

Näsliden
In operation: 1969, discovered at the beginning of the 1920s.
Ore: Complex ore with copper, zinc and precious metals. Annual production: 200 000 tons.

The Rävliden Field (Hornträsk, Rävliden and Rävlidmyran)
In operation: Rävliden, 1936, the operations discontinued 1951–1968. Discovered in the middle of the 1930s. Rävlidmyran 1950, discovered at the end of the 1930s. Hornträsk 1981, discovered in the 1930s.
Ore: Complex ore with copper, lead, zinc, sulphur and precious metals.
Annual production: 340 000 tons.

Central concentrator at Kristineberg.
970 000 tons will be milled this year. Annual production of 38 000 tons of copper concentrate, 3 600 tons of lead concentrate, 61 600 tons of zinc concentrate and 109 000 tons of pyrite concentrate. Metal contents in the concentrates: 8 500 tons of copper, 1 200 tons of lead, 34 700 tons of zinc, 32 800 kilogrammes of silver and 590 kilogrammes of gold.

average concentration for the ores as a whole is around 40 $g.t^{-1}$.

Mercury occurs in the Skellefte Field ores, commonly associated with sphalerite. The unusual mercury-rich metallic grey sphalerite from Kristineberg is well-known. Grip (1949) and Grip and Wirstam (1970) proposed that the Hg:Zn ratio in the ores was constant. Widenfalk (1979), however, found that the mercury in the ores was apparently proportional to their stratigraphic level.

Accessory minerals in the ores include apatite, which was locally abundant, especially in the arsenopyrite-rich parts of the Boliden deposit, and barite, which constitutes an important mineral in the Åsen deposits, with grades of 6–10 wt % $BaSO_4$.

Metal zonation

There is a general tendency for copper to be segregated from the Zn-rich ores in the Skellefte Field. The situation in the Skellefte Field is, however, far from simple because of the complex deformation of the deposits, the presence of arsenopyrite-rich ore (especially Boliden, but also Rakkejaur, Mensträsk, Näsliden) and the occurrence of quartz-tourmaline veins in several deposits.

Several deposits show a concentration of sphalerite towards the hanging wall, for example, the Kristineberg A-lens. In Långsele, Rävliden and Rävlidmyran, sphalerite is concentrated in the hanging wall lenses, whereas chalcopyrite is more abundant in the foot wall. At Udden, chalcopyrite concentrations occur towards the foot wall of the sphalerite ores.

Regional metal zonations have not been clearly recognized. Zinc is perhaps concentrated more in the northern deposits and Cu in the southern, according to Rickard and Zweifel (1975), but such a variation is uncertain.

Wall rock alteration

Alteration zones are commonly associated with Skellefte Field ores. The main alteration types are sericitization and chloritization. Almandine, biotite, cordierite, andalusite, staurolite and cummingtonite may be produced from altered felsic volcanics whereas skarn associations of actinolite-hornblende, andradite, diopside and epidote result from carbonates.

The rocks commonly associated with the sulphide ores include, especially, the sericite schists and chlorite schists. The sericite schists consist mainly of quartz and sericite with minor chlorite and biotite. Tourmaline, hornblende, albite, apatite, pyrite and iron oxides may be accessories. The chlorite schists consist of more-or-less equal quantities of chlorite and quartz with some remnant biotite. Hornblende, albite and pyrite may be accessory minerals.

Nilsson (1968) described wall rock alteration around the Boliden deposit. He identified an inner sericite zone and an outer chlorite zone. Both zones showed a loss of Ca and Na. The inner sericite zone also displayed an overall loss of Fe and Mg, but an addition of Al, K, Ti, Si, S and H_2O.

Generally, the alteration zones are limited to the Skellefte Volcanics and are not recognized in the Skellefte Sediments. The sulphide ores are not generally located at the center of the alteration zones, as at Boliden, Långsele and Långdal, because of original asymmetry and subsequent deformation. In addition, regional hydrothermal alteration is imprinted on the original local alteration zones, particularly in the Western Area, but also in the Eastern Area (Vivallo, in

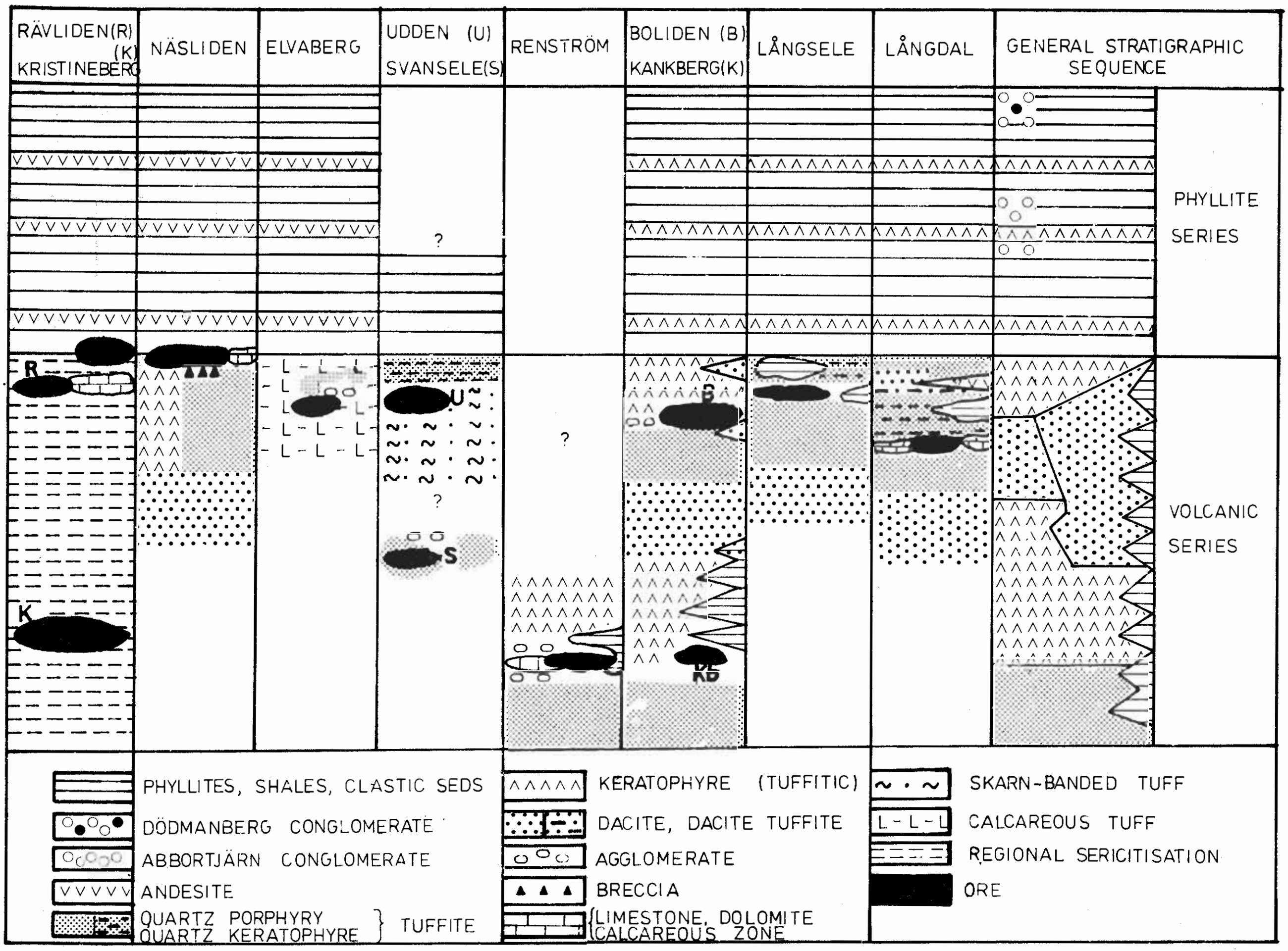


Fig. 6. Stratigraphic position of the Skellefte Field ores (from Rickard & Zweifel, 1975, reproduced by permission of the Economic Geology Publishing Company).

prep.). These regional changes particularly affect the feldspars in the volcanics producing for example spilitization of mafic and intermediate volcanics. In the Kristineberg area, for example, the rocks are enriched in Na and depleted in Mg, Cu, K, Rb, Ba and the ore metals, a classical pattern of submarine hydrothermal systems.

Stratigraphic position of the ores

The ores are mainly situated at the top of the Skellefte Volcanics in the transition zone to the Skellefte Sediments (Fig. 6). This represents an anticipated position for this ore type, that is, during periods of intense hydrothermal activity at the cessation of major pyroclastic deposition. In fact all the massive ores are intimately associated with sedimentary lenses, including graphitic schists, limestones and reworked tuffs, as pointed out by Zweifel (1982). This underlines yet again the uncertainty of the time-stratigraphic significance of the volcanic-sediment transition in general, and the first occurrence of the graphitic schists or phyllites in particular.

Ores also occur within the Skellefte Volcanics themselves. For example, the Kristineberg deposit occurs at the waning stage of a volcanic event, prior to the onset of a further eruption. In the Eastern Area, too, volcanic cycles have been recognized with individual deposits formed various levels in the stratigraphy. Even within the lower parts of the volcanics, the ores are commonly associated with calcareous lenses or black schists. The degree of apparent correlation between different deposits implied in Fig. 6 is therefore extremely uncertain and may be spurious.

DISCUSSION

Although the Skellefte Field is defined, according to A. Högbom (1937), as the sulphide-bearing supracrustal zone bordering the river Skellefteälven, its northern and southern boundaries are very diffuse.

Towards the south, there is a gradual transition to more a sedimentary environment, and the supracrustal succession becomes dominated by the greywacke sequences of the Bothnian Basin. At the same time, the metamorphic grade increases and migmatites and veined gneisses dominate. The post-orogenic Revsund granitoids are mainly limited to this area and Gavelin (1955) first determined their anatectic origin through their field relationships. Gavelin (1955) also noted that these granitoids were closely associated with the sediments. It may have been the volatile content of the sediments that catalyzed partial melting in these areas. Gavelin's interpretation has been confirmed by isotopic evidence which indicates ε_{Nd} values of 0 to −1 and heavy $\delta^{18}O$ values of +8 to +12 (Wilson *et al.* 1985), and typical S-type characteristics (Wilson 1980).

There is no obvious E–W faulting or thrusting at the southern margin of the Skellefte Field. Although the increased metamorphic grade would suggest substantial relative block movements, no major lineaments are apparent either geologically or geophysically. The gradational nature of the transition is further emphasized by the occurrence of enclaves of Skellefte Volcanics some 200 km south of the Skellefte Field. A substantial complex massive sulphide ore deposit has been found in one of these.

The original definition of the Skellefte Field by A.G. Högbom (1895) included the more terrestrial Arvidsjaur Volcanics to the north. Indeed, Gavelin and Grip (1946) and Lundberg (1980), considered the two areas together. The Arvidsjaur Field limits the Skellefte Field to the north. It consists of a series of comparatively flat-lying series of subaerial rhyolites to andesites, including abundant porphyries and ignimbrites. Folding is on north-east trending axes, and deformation is moderate. In several areas these terrestrial volcanics overlie Skellefte Sediments. However, the transition according to Lundberg (1980) is always conformable. No direct boundary is observed between the Arvidsjaur and Skellefte Fields. The Arvidsjaur Group is younger than the Skellefte Group, and has a zircon age of 1.87 Ma (Skiöld, in prep.).

As with the Skellefte Group, the basement of the Arvidsjaur Group is unknown. Although conventionally assumed to be the Karelian Continent (eg. Lundberg 1980) there is no evidence for this. Indeed, Wilson *et al.* (1985) were able to demonstrate isotopically that early orogenic granitoids in this region contained no Archaean component. Furthermore, where visible, the basement of the Arvidsjaur Group is constituted by the Skellefte Sediments.

To the northeast, Skellefte Sediments extend in a wide coastal belt, according to Ödman (1957) and, as implied in Fig. 2, based on recent SGU mapping. As in the south, the sediments become high-grade, migmatized and gneissose. There appears to be an important N–S lineament forming a boundary between the Arvidsjaur Field to the west and this coastal zone of Skellefte Sediments (Lilljequist 1980). In such a case, this zone may represent an uplifted block. However, this coastal belt is very poorly exposed and not well understood.

It is possible therefore that the submarine felsic volcanics and sediments of the Skellefte Group extend farther northwards than appears on the map, but are covered by the extensive terrestrial volcanics of the Arvidsjaur Group. There is no evidence for the extension of the Archaean rocks of the Karelian continent in this part of Sweden. Indeed, the westward prolongation of the Raahe-Ladoga line is unknown on the Swedish side of major N–S fault zones off the coast of the Gulf of Bothnia, and the Skellefte Field itself is limited by one such fault zone some 20 km off the Swedish coast. The terrestrial rocks of the Arvidsjaur Group therefore appear to have been deposited on the "Arvidsjaur Continent" of Wilson (1982); that is, a land-mass formed by uplift of the Skellefte volcanic arc.

Palaeoenvironment of the Skellefte Field

The Skellefte Field displays a general tendency toward a more deep water environment to the south and a more shallow water system to the north. This is particularly apparent in the Central Area where the Skellefte Sediments include turbidites which grade into fluviatile sediments, including conglomerates similar to the overlying Vargfors Group. However, it appears that this variation may be diachronous, at least in part, since the northern terrestrial volcanics are younger than the sediments. Furthermore, Skellefte Sediments appear to extend northward up the Bothnian coast.

The environment appears to have been marine. The regional alteration patterns, including Na enrichment, suggest the presence of seawater. Furthermore, at Åsen, abundant sulphate minerals are preserved. Zweifel (1982) suggested a relatively deep marine environment, at least in part. He noted the limited distribution of coarse fragmental rocks and no obvious abundance of vesicles in the volcanics. Both may relate to deep marine systems. Sedimentologically, the presence of pelites indicates frequent low energy conditions, consistent with deep water environments. Broman (in prep.) has found primary fluid inclusions in sphalerite from well-preserved ores in the Central Area. These inclusions do not show any evidence for boiling, and indicate a deep water origin for ore formation.

No areas have been found where a metasedimentary sequence introduces the succession to be followed by felsic pyroclastics and the general succession in Skellefte Volcanics to Skellefte Sediments must stand. However, it is simpler to regard the succession as one in which sedimentation is continuous but where felsic pyroclastics dilute the sediments in the early part of the succession. Translated into palaeoenvironmental terms this means that, prior to the volcanic activity, the area was not one where considerable sedimentation was on-going. This means that the original environment was either an offshore area or subaerial continental crust, or had only recently been formed.

Zweifel (1982) suggested that the Skellefte Field environment consisted of zones of great depth situated along trenches between volcanic islands. The lack of obvious abundant continentally derived sediments in most of the Skellefte Group is marked. Such sediments as occur, pelites and limestones and reworked volcanics, are all derived from the volcanics themselves or are consistent with an off-shore marine environment.

Towards the top of the succession, coarse conglomerates, turbidites and coarse sandy sediments in the Central Area are very reminiscent of the overlying Vargfors Group. This suggests a coarsening-upward regression sequence, possibly prograding beach and alluvial fan deposits (Dumas 1985).

Nature of the volcanic environment

Rickard and Zweifel (1975) originally suggested that the Skellefte Field was an early Proterozoic equivalent of a Phanerozoic volcanic arc. Pharaoh and Pearce (1984), Claesson (1985) and Vivallo (in prep.) corroborated this suggestion using geochemical discriminant diagrams. A feature of the Skellefte arc, however, is the relative absence of andesites, which dominate modern evolved arc suites (Jakes & White 1971).

Claesson (1985) and Vivallo (in prep.) have shown that the volcanism in the Skellefte Field is strongly bimodal, between tholeiitic and calc-alkaline in character. This type of bimodal volcanism is typical of extensional environments and suggests a rift setting. Such settings are now well-recognized as characteristic of volcanic arcs of the Mariana-type (cf. Uyeda & Nishuwaki 1980). Mariana-type extensional arcs, contrast the Chilean-type compressional arcs in having deeper trenches, steeper Benioff seismic zones, fissure eruptions from numerous monogenetic cones rather than repeated eruptions from single vents, and bimodal (basalt-rhyolite) volcanism (Uyeda & Nishuwaki 1980). Much of the earlier confusion about calc-alkaline volcanism in arc settings was caused by lack of appreciation of the effects of submarine hydrothermal alteration on host volcanics. Similar bimodal suites associated with complex massive sulphide ore deposition has been widely recognized in ancient systems, for example Rio Tinto (Munha 1979), Noranda (Mackechan & MacLean 1980), and Captains Flat, Woodlawn, Rosebery and Mt. Lyell (Scheiber and Marksham 1970).

The Kuroko deposits of Japan are also closely associated with bimodal volcanism (Ohmoto 1983, Cathles *et al.* 1983). Andesitic volcanism is not related to ore formation and is restricted to underlying and overlying, genetically unrelated, formations. The origin of this bimodal volcanism in the Green Tuff belt of Japan is still unclear in detail, although most modern writers accept an extensional system in a volcanic arc. Hodgson and Lydon (1977) and Ohmoto and Takahashi (1983) suggested that the Kuroko deposits were intimately associated with caldera formation. Explosive felsic volcanism created the calderas and the ores were deposited in depressions within the calderas. The sequence of events envisaged included major subsidence with fissure eruptions of basalts and minor felsic volcanics, major eruption of felsic volcanics and caldera formation, minor bimodal volcanism and deposition of mudstones and tuffs. The length of time involved for these events was about 12 Ma. Ohmoto and Takahashi (1983) suggested that the caldera distribution was controlled by basement fractures or rifts. Cathles *et al.* (1983) argued, in contrast, that the calderas are only indirectly correlated with the Kuroko mineralization and that both are connected with failed rifting of the primitive arc.

Many of the features discussed in the Kuroko deposits are recognized in the Skellefte Field, albeit through a metamorphic veil. Significant in this context is the identification of volcanic centers in the Eastern and Western areas (Grip 1973) and the elongated, rift-like basins in the Western Area by Willdén (p. 46–52 this volume). The fluid inclusion and related data suggest a deep marine environment during ore formation, but this was followed by a coarsening upward sequence in the Central Area, suggesting subsequent uplift. These rapid changes in elevation are characteristic of rift/caldera environments. Particularly interesting is Claesson's (1985) and Vivallo's (in prep.) observation that the mafic and felsic components of the bimodal volcanism are petrogenetically unrelated. In the Kuroko district, Cathles *et al.* (1983) relate this phenomenon to intrusion of the rift by basaltic magmas from the asthenosphere. Ohmoto and Takahashi (1983) connect it with resurgent activity of calderas, but this apparently would tap the same magma chamber. Claesson (1985) also recognizes mafic and ultramafic igneous components in the overlying Skellefte Sediments which are very primitive in nature. If they are in fact volcanics, his suggestion of transition to a back-arc situation is very much in line with the thinking of Cathles *et al.* (1983). However, in the case of the Skellefte Field the rifting would have been at least partly successful.

Formation of the ore deposits

Seafloor deposition of the massive sulphide ores is suggested by the common occurrence of massive pyrite with little sediment contamination. The ores are almost all closely associated with sedimentary horizons or lenses, however. This also suggests seafloor deposition rather than formation within the volcano-sedimentary pile where no such correlation would be necessarily observed. During ore-formation, explosive volcanism had temporarily ceased, allowing hydrothermal processes to dominate. It may well be that the commonly associated carbonate horizons reflect this process rather than normal sedimentation.

It is significant that there is an almost complete lack of iron oxide deposits associated with the ores, or in the Skellefte Field as a whole. By analogy with modern seafloor sulphide deposits, oxidation is to be expected. The lack of oxidation may reflect rapid burial or restricted water circulation in deep riftogenic basins. This latter seems a more probable explanation in view of the abundance of iron oxides in contemporaneous shallower water environments from other parts of the Fennoscandian Shield. At Åsen, in the Central Area, Rickard *et al.* (1979) were able to demonstrate Rayleigh distillation kinetics for sulphur isotopes of barite-pyrite pairs. The data suggests that sulphate-reduction occurred in a series of small basins with restricted sulphate circulation.

As mentioned above, a number of factors imply a deep marine environment for Skellefte Field ore deposition. These include fluid inclusion data, lack of shelf or near-shore sediments and the chemistry of alteration. Because of deformation few asymmetric alteration zones have been recognized. However, the common general association of an inner silicic zone, an enveloping sericite zone and an outer chlorite zone, especially beneath the ores, indicates ore formation through forced recharge-discharge systems. Significantly, the Skellefte Field ores are lead-poor, which is consistent with the development of lead from uranium and thorium in the crust through time. The source of the metals is therefore the penecontemporaneous volcanics themselves, as suggested by Gavelin (1955).

The majority of deposits in the Skellefte Field are proximal, being formed close to volcanic vents. The detailed model for the Långsele and Långdal deposits in the Eastern Area (Jonsson, p. 22 this volume) displays all the elements of proximal volcanogenic sulphide deposits, including a quartz porphyry stock and coarse fragmental volcanics. Near to the Renström deposit a coarse phreatic explosion breccia outcrops, similar to the mill-rock of the Canadian geologists. The Udden deposit displays slumping and autobrecciation of the original sulphide mound and the Näsliden ore is associated with a stockwork. Distal ores are less common. A possible exception is Rävliden where a finely bedded sphalerite and galena ore occurs in phyllites of the Skellefte Sediments. However, stockworks are not always recognized associated with the Skellefte ores. This may in part be a function of the intense formation associated with many of the deposits.

CONCLUSIONS: GEOLOGIC HISTORY OF THE SKELLEFTE FIELD

The events forming the Skellefte Field were initiated by massive explosive felsic volcanic activity in an offshore environment. There is no evidence for rapid subsidence, and the Skellefte Group appears to represent a coarsening upward regressive sequence. The sediments of the Skellefte Group appear to be transitional to the thick greywackes of the Bothnian Basin. They show little evidence of any relationships to the northern Karelian continent. The fact that the thickest sedimentary sequences are situated south of the Skellefte Field may suggest that derivation of sediments from more southerly sources (SW, SE) than from the northern Karelian Continent.

According to Welin (in prep.) the oldest sediments of the Bothnian Basin are older than 1930 Ma, which is significantly older than the Skellefte Volcanics (1880 Ma). This suggests that sedimentation was proceeding to the south prior to the initiation of the Skellefte Field volcanicity. In 1972, the Svecofennian was defined as Svecokarelian supracrustals without a known basement (Rankama & Welin 1972), and the problem of the basement of the Skellefte Field still exists. Gravity measurements in the Bothnian Basin (Eriksson & Henkel 1980) suggest that the mafic rocks, such as ocean floor materials, may underlie the metasediments. However, no such data are available from the Skellefte Field.

Vivallo (in prep.) argues that the fact that the earliest volcanics were overwhelmingly felsic in nature suggests generation from melted continental crust, and the Skellefte Field was ensialic. Welin (in prep.) also suggests initiation by rapid subsidence of Archaean basement southwest of the Raahe-Ladogan lineament, which was active at 1950 Ma.

In contrast, Sm-Nd isotopic studies of the Jörn Complex, which is comagmatic with the Skellefte Volcanics, does not support these suggestions of an underlying Archaean basement to the Skellefte Field. (Wilson *et al.* 1985; Claesson *et al.*, in press). ε_{Nd} values of +2.15 and +2.42 have been measured, which indicates that some material was derived from a LREE depleted mantle with a minimum contribution of older crustal material. This conclusion is supported by oxygen isotope data and the general I-type nature of the granitoids and volcanics (Wilson 1982). Modelling of the Sm-Nd data suggests a limited crustal residence time for the Jörn Complex.

It appears that the Skellefte Group was deposited directly on oceanic crust, as has been implied for the Bothnian Basin sediments. Rickard and Svensson (1984) found that ore lead isotopic data from the Skellefte Field suggested a primitive island arc environment and this is consistent with other geochemical data (Pharaoh & Pearce 1984; Claesson 1985). Petrologic data for the Skellefte Field, as discussed above, is more comparable with the Marianas-type arc than a Chilean type. Claesson (1985) has speculated that remnants of the original oceanic crust might be found in the ultrabasics that occur in both the Bothnian Basin and Skellefte Field.

The source of the sediments remains a problem. Apparently sedimentation was proceeding in the Bothnian Basin before the Skellefte Field was formed. This thick sedimentary pile is situated in a position consistent with derivation from a northern Archaean continent which, according to the discussion above, is limited to several hundred kilometres north of the Skellefte Field. However, the extensive belt of coastal gneisses to the northeast of the Skellefte Field appears to be similar marine sediments as the Skellefte Sediments. In which case, the sediments of the Skellefte Group (and Bothnian Basin) extend north of the Skellefte Field more towards the northern continent. Welin (in press) has examined Sm-Nd systematics of metapelites from the Skellefte Field. His data show that the sediments (from Långsele in the east and Rävliden in the west) have a T_{DM} of around 2.1 Ga; rather older than the Jörn complex, and thus the Skellefte Volcanics. This implies a greater Archaean component in these sediments. Interestingly this T_{DM} value increases slightly southward to central Finland and central Sweden suggesting an even greater Archaean component to the south. However, the low T_{DM} values emphasize, as pointed out by Huhma (in prep.) that newly mantle-derived material was the dominant component in the generation of Svecokarelian crust.

The idea of the Raahe-Ladoga lineament constituting a major lineament of Svecokarelian times was originally suggested by Hietanen (1975) and Rickard (1978), and has been a feature of plate tectonic models since. Conventionally, it makes a junction between an Archaean continent to the north-east and an oceanic environment to the southwest. In Sweden, the lineament is not clearly marked and appears to splay out in the far north. At present it appears to have been a zone of major dextral shears. Although this does not preclude vertical movement along this lineament in Svecokarelian times, it is remarkably similar to modern major transform faults as an integral part of the dynamics of plate movement.

Conventionally, the Skellefte Field has been assumed to have resulted from northerly subduction of a subduction zone situated to the south (Hietanen 1975). However, southward from the Skellefte Field there is a wide expanse of several kilometres thick, terrigenous turbidites, characteristic of modern mature marginal basins. Further south still is the Bergslagen Province, a zone interpreted as a Svecokarelian continental margin by Vivallo and Rickard (1983). Lundegårdh (1973) described the integral relationship between the Bergslagen Province and the Bothnian Basin (or Norrland Geosyncline as he called it). He proposed that the thick Bothnian Basin sediments were derived through erosion of the rapidly uplifted Bergslagen margin. This is consistent with Sm-Nd isotope data described above.

It is concluded, therefore, that whilst there is no overriding reason to connect the Skellefte Field with the northern continent, there is considerable evidence to suggest that the Skellefte Field, Bothnian Basin and Bergslagen Province were integrally related during Svecokarelian times. This in turn would suggest that the subduction zone associated with these events was situated to the north of the Skellefte Field and dipped southwards. The Skellefte Field represents an island arc, separated from a southern continent by the Bothnian Marginal Basin. All traces of the subduction zone appear to have been destroyed during late Svecokarelian ocean closure and continental collision which brought the arc-basin-continent complex of the Svecofennian in contact with the Karelian continent.

In this hypothesis, the subduction zone moved steadily northeastward during the period around 1900 Ma. Initially, the zone produced the active Bergslagen margin. As it moved away to the northeast this margin became uplifted and rifted with the formation of shallow and subaerial sediments and volcanics. The Skellefte Volcanic arc was developing at some distance off-shore in response to rifting and spreading along the continental margin, and the formation of the Bothnian Marginal Basin.

The spreading in the Bothnian Basin caused the Skellefte Island Arc plate and its associated trench to move northeastward. However, the arc plate increased in size, and resistance to movement of both plate and trench caused the arc to break and open new marginal seas. Karig (1972, 1974) noted that Pacific Island arcs commonly have several marginal seas of increasing age behind them, separated by small arc remnants. In the case of the Skellefte Field, some of these remnants are preserved as Skellefte Volcanic enclaves within the Bothnian Basin.

The present situation of the Skellefte Field relative to Bergslagen is thus a function of the rate of migration of the trench. At this stage the arc plate was too large to keep contact with the migrating trench.

An interesting problem in the Skellefte Field is why the ores are mainly situated along a narrow east–west belt situated south of the Jörn Complex. Obviously ore formation can occur in more northerly districts, as is shown by the location of the Adak and Laver ores. However, most of the ores are situated in groups and lines in this narrow zone. A common feature of the deposits is their situation at the end of a felsic volcanic event. This is related usually to hydrothermal activity, but is also presages the onset of more mafic volcanic activity, either with little sediment as in Kristineberg, or with the introduction of the Skellefte Sediments, as in many of the deposits. This in turn means that ore formation is also closely related to typical riftogenic bimodal volcanism. The distribution of ore deposits laterally along the Skellefte Field may therefore be related to longitudinal rifting of the Skellefte arc, in response to movement of the trench away to the north-east. The primitive mafic and ultramafic volcanics of the overlying Skellefte Sediments represent the formation of a new marginal basin, as has been tentatively suggested for the Central Area by Claesson (1985). The major ore forming event in the Skellefte Field then marks the initiation of this event.

The arc development continued with uplift and erosion as the subduction zone retreated. In the Skellefte Field, this is evidenced by the formation of the terrestrial Arvidsjaur volcanics and molasse sediments, and the Vargfors Group sediments.

The final Svecokarelian event affecting the Skellefte Field was ocean closure and collision between the northern continent and the Skellefte arc-Bothnian Basin-Bergslagen margin complex. The collision was accompanied by high heat flows and melting of the volatile-rich sediments of the Bothnian Marginal Basin. The intrusion of volatile-rich S-type granitoids and their pegmatites closed the Svecokarelian orogeny. The result was the formation of a new slab of continental crust, the Fennoscandian Shield.

TABLE 4. Summary of present geochronologic data on the Skellefte field succession. Age data from text.

Group	Age (Ga)
Sorsele Granitoids	1.71
Revsund Complex (inc. Adak Granitoids)	1.75
Dobblon Group	1.76
Arvidsjaur Granitoids Vargfors Group	1.79
Arvidsjaur Group	1.86
Jörn Complex	1.89
Skellefte Group	1.89

Some idea of the timescale for this process is available from geochronology of various fragments of this event (Table 4). Thus the oldest sediments are dated at 1930 Ma indicating that the Bergslagen Continental Margin was developing at this time. The Jörn Complex intruded its own volcanic pile around 1890 Ma suggesting that the Skellefte Arc developed at this time. Final cooling of the Jörn Complex may have been as late as 1876 Ma. Ores associated with Skellefte volcanics have been dated in this interval. The Arvidsjaur Group formed around 1860 Ma, suggesting that the arc was mature and uplifted by this time. The date for collision is not well-marked. Granitoids associated with this event appeared between 1800 and 1750 Ma, with the younger dates being postorogenic. Rb-Sr ages for these, and younger early orogenic granitoids, also indicate closure of the isotopic systems (at less than 400°C) at this date.

EXCURSION PROGRAMME

During the excursion, representative outcrops and mines in the entire Skellefte Field will be shown. Thus, the eastern part of the Skellefte Field will be visited on days 1 and 3, the central part on days 2, 4 and 5 and the western part on days 6 and 7 (see Fig. 7). In addition, the Jörn Granitoid Complex and related mineralization will be demonstrated during day 5.

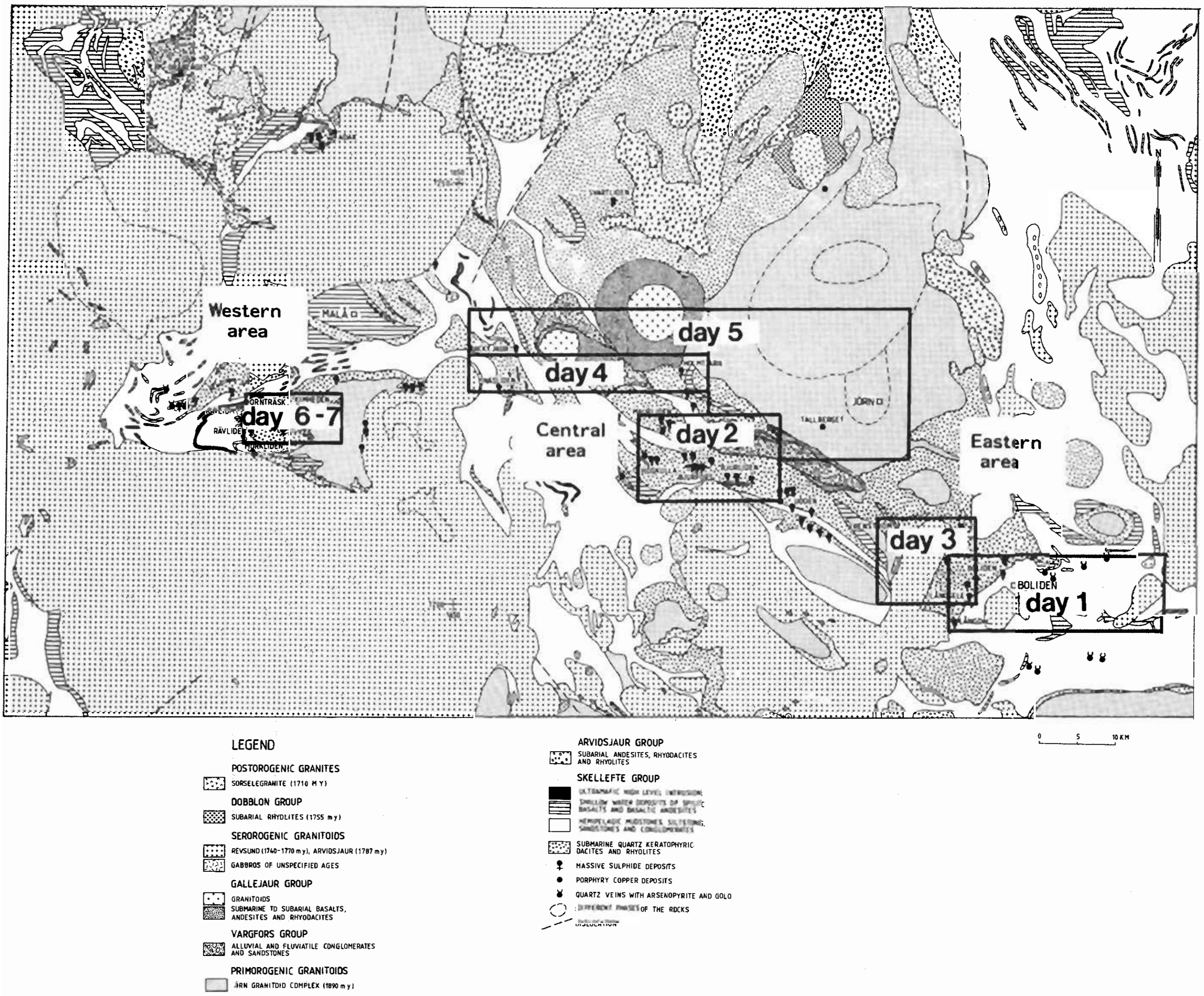


Fig. 7. The Skellefte Field excursion. Map prepared by L. Å. Claesson.

DAY 1. GEOLOGY OF THE EASTERN PART OF THE SKELLEFTE FIELD

R. Jonsson

INTRODUCTION

The Boliden area (Fig. 8) is situated at the eastern end of the Skellefte District. About twenty sulphide deposits have been discovered in this area and eleven of them have been mined. The area includes the most famous ore, the Boliden deposit, where mining ceased in 1968.

Most of the deposits are stratabound massive sulphides settled in volcano-sedimentary environments. The ores were deposited at two different stratigraphic levels. The lower one is situated on top of a lower rhyolitic unit, and underneath a mafic unit. The upper one is located at the top of an upper rhyolitic unit. The younger deposits were deposited at the bottom of the thick volcano-sedimentary sequence which today covers the areas to the south and east. A common feature of the stratigraphy in the ore zones is the occurrence of stocks and/or domes of quartz porphyry, which either intruded slightly before or after the ore deposition.

The area has been folded several times and especially three of the deformation stages gave the structural features of the rocks. An early deformation stage with gently dipping fold planes has been superimposed by two later phases with steeply dipping fold planes, one striking in NW and another in NE, producing a complex interference pattern in the rocks.

The metamorphic grade in the Boliden area is of greenschist facies to sub-amphibolite facies. Locally, high-grade minerals like garnet, kyanite, cordierite and andalusite are found.

THE LÅNGSELE-LÅNGDAL AREA

For this excursion, the Långsele-Långdal area has been selected in order to demonstrate the geology of the eastern part of the Skellefte Field. The Långsele-Långdal is situated about 5 km southwest of Boliden (Fig. 7). A simplified geological map of the area is shown in Fig. 9. Most of the bedrock is covered by sediments or moraine.

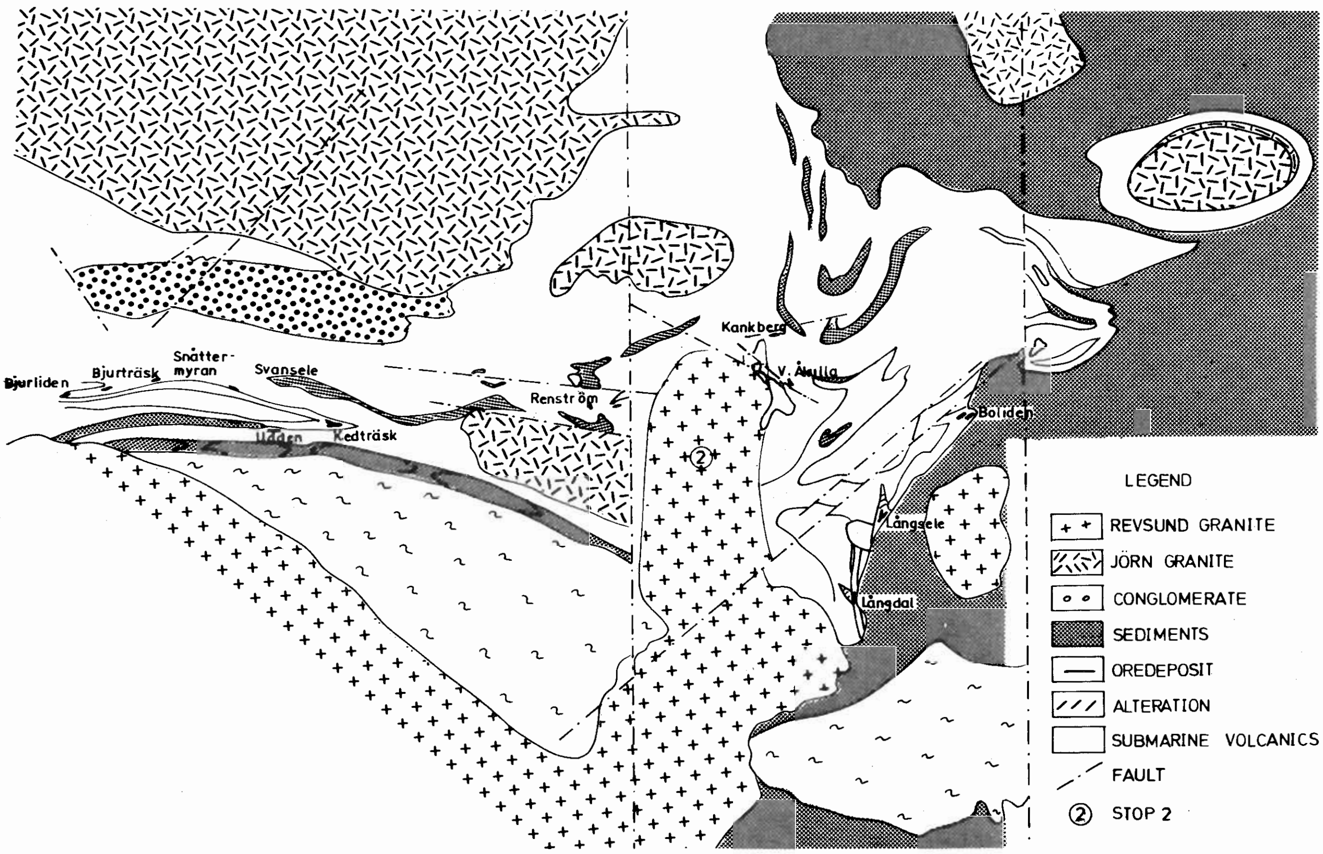


Fig. 8. Geology of the Boliden District.

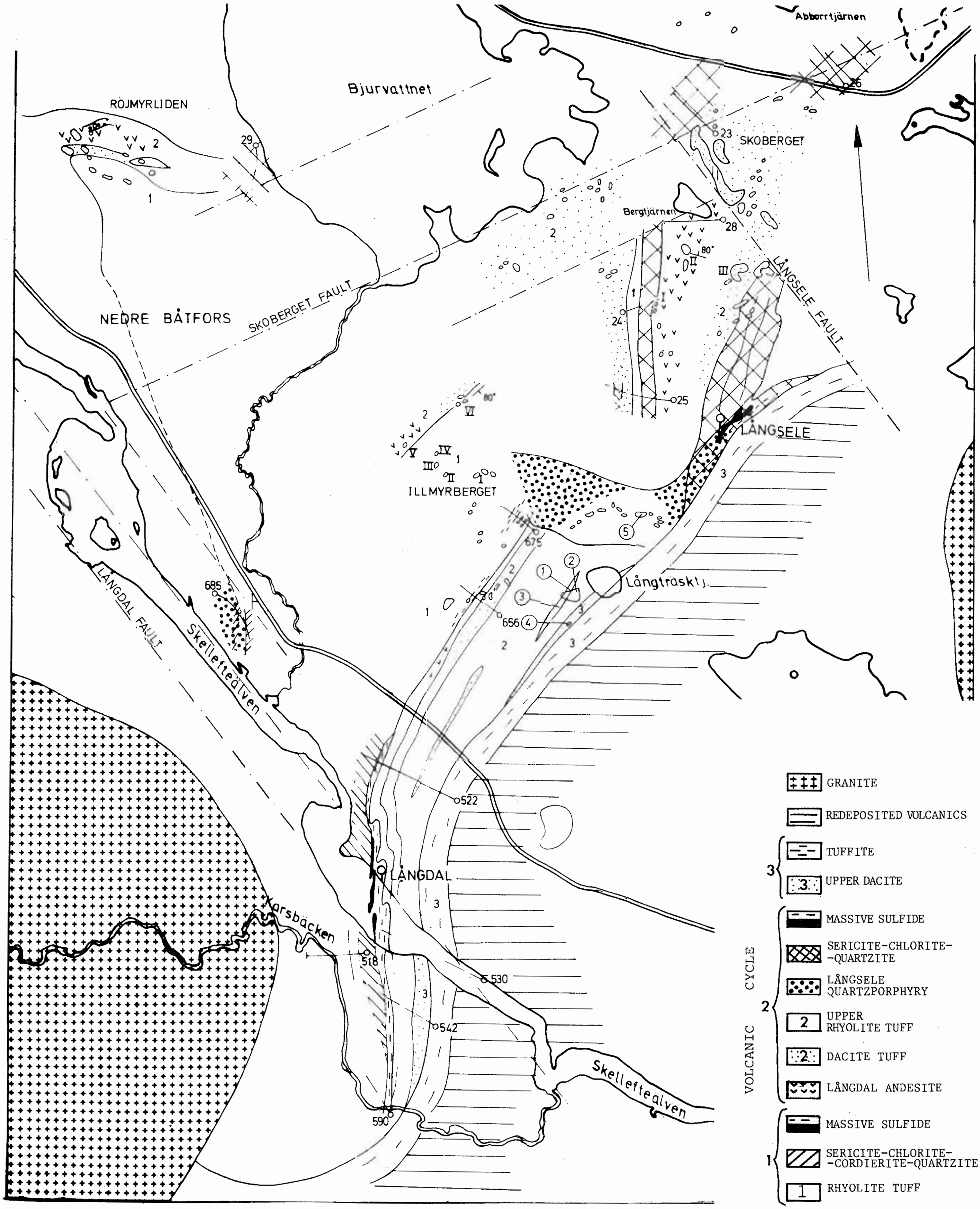


Fig. 9. Geology of the Långsele-Långdal area, showing surface tour stops.

The volcanic structures are rather well preserved in this area and coarse pyroclastic structures, for example, partly do not give the impression of strong deformation. In the central part of the area, to the northeast of Illmyrberget, a volcanic centre was probably located.

Several fault zones cross the terrain in different directions. The most common zones are oriented in N30–35° W (Långsele fault and Långdal fault) and N70° E (Skoberget fault).

STOP DESCRIPTIONS

The purpose of this excursion day is to demonstrate outcrops describing the stratigraphy near the Långsele deposit.

The volcanics are mainly pyroclastic and of acid to intermediate composition. The two stratabound massive sulphide deposits found there are associated with two different volcanic cycles and shown in Fig. 9.

Stop 1. – Acid agglomerates with elongated and folded fragments (size of fragments 5–10 cm).

Stop 2. – Bedded intermediate and acid tuff units with fragments.

Stop 3. – Volcanic breccia (debris flow or "mill stone") partly with 3–4 dm large fragments.

Stop 4. – Intermediate lapilli tuffs with acid fragments and calcareous tuff layers. Elongation of acid fragments with a steep plunge to the north.

Stop 5. – Homogeneous quartz porphyry with small, angular and round quartz grains.

DAY 2. GEOLOGY OF THE CENTRAL PART OF THE SKELLEFTE FIELD

L.-Å. Claesson

GENERAL GEOLOGY

The central part of the Skellefte district is situated between two ore producing provinces, the Kristineberg area in the west and the Boliden area in the east. The geology (Fig. 10) of this central part has been interpreted as showing the transition between a marine environment in the south and a continental towards the north with the belt of massive sulphide deposits in a very narrow zone striking approximately NW–SE.

An interpreted basement of granodioritic-tonalitic gneisses underlay felsic and mafic metavolcanites, the so-called "Skellefte volcanites" (Gavelin 1955). This volcanic sequence contains a bimodal formation (Claesson 1982, 1985) dominated by calc-alkaline felsic products probably extruded below sealevel. The mafic part of this sequence consists of spilitized basalts and basaltic andesites of a mildly tholeiitic affinity which have extruded as lavas and tuffs. The massive sulphide deposits in the area are mostly associated with the calc-alkalic felsic volcanites but occur at several stratigraphic levels (Rickard & Zweifel 1975).

On top of this volcanic formation sediments of the "Phyllite series" (Gavelin 1955) occur. The sediments change in facies and environmental types from south to north. In the southern part there are muddy and sandy rocks of a hemipelagic type rather than a pelagic depositional type (Dumas 1985). Along the Skellefte river towards the north the muddy and sandy sediments show a very similar petrography but the clasts can be much bigger and are far more rounded probably attributed to rolling on a shore. There are also structures in this area, such as slumping, cross-bedding and turbulent streams, indicating a far more unstable environment of deposition, probably a continental shelf not far from the shore (Dumas 1985). In these sedimentary rocks of the Skellefte Group, basaltic to ultramafic volcanism and high level intrusion occur. The volcanic part of this formation shows a komatiitic affinity (Claesson 1982, 1985).

Probably cogenetic with the felsic Skellefte volcanites are high level intrusions of felsic porphyries and the oldest facies of the Jörn granitoids (Wilson *et al.* in press.). Several low-grade copper mineralizations of porphyry copper type are found in the oldest Jörn granodiorite phase (Weihed, p. 37 this volume).

In the areas along Skellefteälven, sediments of the Skellefte Group are partly overlain by coarse sedimentary deposits of the Vargfors Group (the Abborrtjärn formation), which indicate a sharp terrestrial relief resulting from uplift of a continental margin. At the same time as these continental sedimentary deposits, volcanics of the Gallejaur Group extruded in part of the Central area forming a sequence of basaltic to dacitic lavas and pyroclastics. These are partly subaerial and partly volcanoclastic submarine sediments. The volcanoclastic rocks start with the Dömanberg

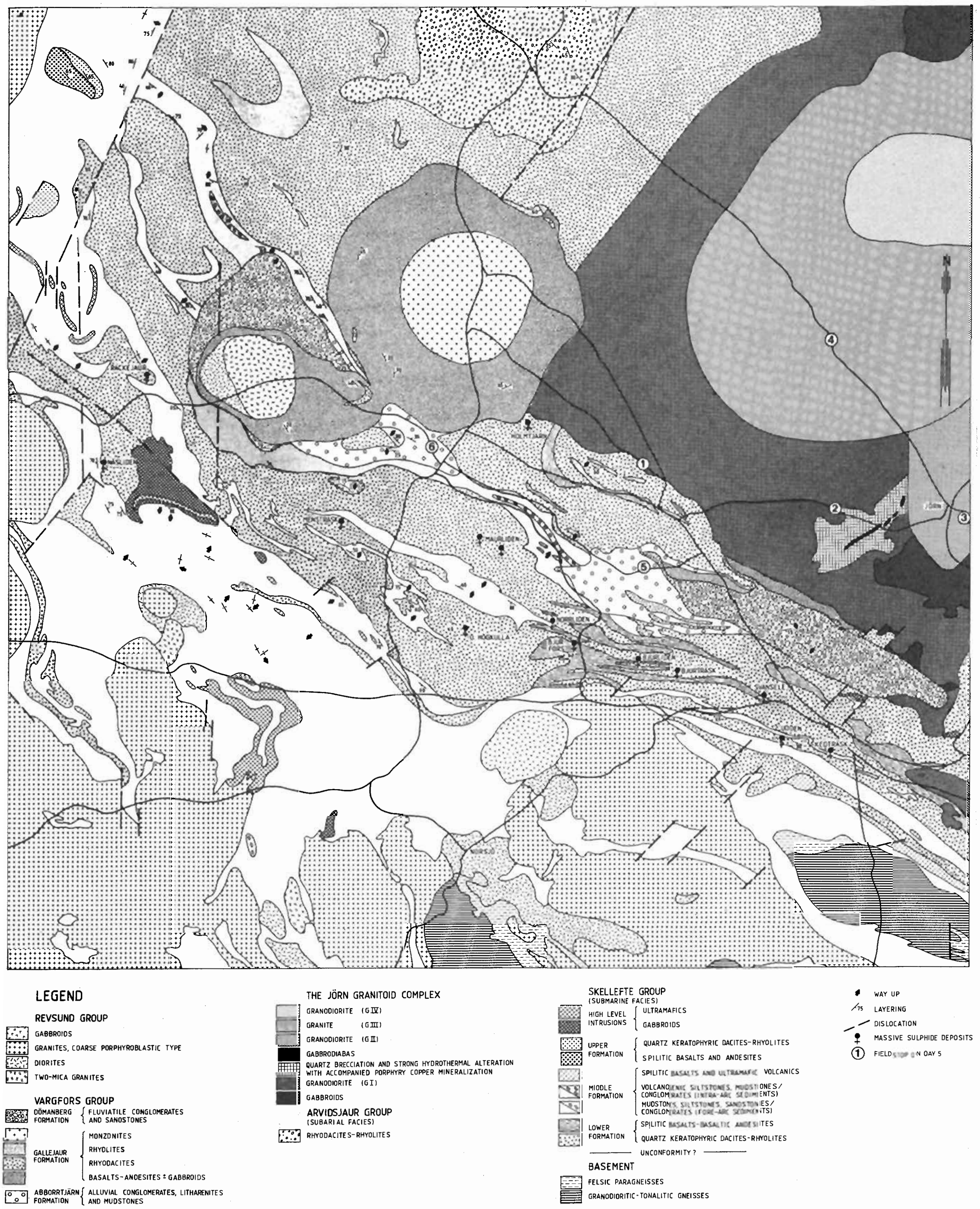


Fig. 10. Geology of the Central area.

formation where conglomerates dominate and probably result from the presence of a proximal braided system (Dumas 1985).

In areas north of Skellefteälven the volcanism shows a transition from the submarine deposited Skellefte Group to the subaerial deposited Arvidsjaur Group (Adamek & Wilson 1979).

Younger than all the above named rocks are the Revsund Group of granitoids and gabbroid rocks which often intrude as big multiple intrusions or penetrate the older supracrustal rocks, forming migmatites and two-mica granites in the southern parts of the Skellefte district.

Revsund group — 1760 Ma

Granitoids and gabbroids

Vargfors group

Dömanberg formation
Conglomerates and sandstones

Gallejaur formation
Gabbroids and Monzonites
Basaltic to rhyodacitic
volcanics and volcanoclastics

Abborrtjärn formation
Conglomerates, litharenite
and mudstone

——— unconformity ———

Jörn group — 1890 $\pm^{8}_{7}$ Ma

Granitoids and gabbroids

Arvidsjaur group

Andesitic-rhyolitic volcanics

Skellefte group

Upper formation
Basaltic to rhyodacitic volcanics

Middle formation
Mudstones, siltstones, sandstone,
basaltic and ultramafic volcanics

Lower formation
Rhyolitic and basaltic volcanics

Fig. 11. Stratigraphy of the Central area.

GEOCHEMISTRY OF VOLCANIC ROCKS BELONGING TO THE SKELLEFTE GROUP

Three different stratigraphic units of the Skellefte Group (Fig. 11) have been studied (Claesson 1982, 1985): the lower felsic, the lower mafic and the middle mafic-ultramafic units. All these have been affected by a regional alteration and are now found as quartz keratophyres, spilites and potassium-rich rocks. On the basis of their TiO_2 *versus* Zr/P_2O_5, the mafic rocks appear to be subalkaline. The lower mafic rocks are mildly tholeiitic while the lower felsic rocks shows a calc-alkaline trend when using SiO_2 and FeO* *versus* FeO*/MgO.

Basalt of the middle mafic-ultramafic rocks in the sedimentary environments are usually high in MgO and low in TiO_2 and Al_2O_3 contents. This compares them with komatiitic basalts and partly with boninites.

Discriminant diagrams designed to distinguish basaltic rocks of different palaeotectonic environments suggests that the bimodal lower formation of felsic and mafic volcanic rocks of different palaeotectonic environments suggest that setting. The setting in which the overlying mafic-ultramafic volcanics were deposited is less certain. These rocks do show a transition between volcanic arc and mid-ocean ridge basalt affinity, which may indicate an inter- or back-arc rift situation.

STOP DESCRIPTIONS

Seven stops will be visited during this day. Their locations have been indicated in Fig. 12.

Stop 1. – The Gradins mountain. Well bedded felsic tuff of the Skellefte Group.

Outcropping rock consists of small fragments of felsic type in a matrix of quartz, plagioclase, biotite, sericite, calcite and ore minerals. There are phenocrysts of oligoclase which show good zonation, but they have been partly altered to sericite and calcite. Quartz phenocrysts have been corroded and recrystallized and show undulatory extinction. This exposure is part of the country rocks of the Udden deposit.

Stop 2. – The Bjurliden road. Quartz porphyries of the Skellefte Group.

The quartz porphyries are, as in this outcrop, normally homogeneous in their texture and do not differ much in their composition. There has been speculation as to whether the porphyries are intrusives or extrusives. However, their textures are identical with that of effusive rocks and the porphyries are alternating with fine-laminated greenstone tuffs. Similar volcanics form the country rock of the Bjurliden deposit.

The quartz phenocrysts occupy 8–14 % of the porphyry and have usually been corroded in the contact to the matrix. A characteristic blue opalescence is present in the rocks rich in biotite or chlorite. The plagioclase phenocrysts are not as regularly distributed as the quartz phenocrysts. Twinning is common and normally the composition is albite. Potash feldspar has rarely been observed. The matrix usually consists of quartz, plagioclase and chlorite. In a few cases spherulites have been recognized.

Stop 3. – The Bjurliden deposit. A massive sulphide deposit within the Skellefte Group. The country rocks are quartz porphyritic volcanics with small inliers of effusive greenstones.

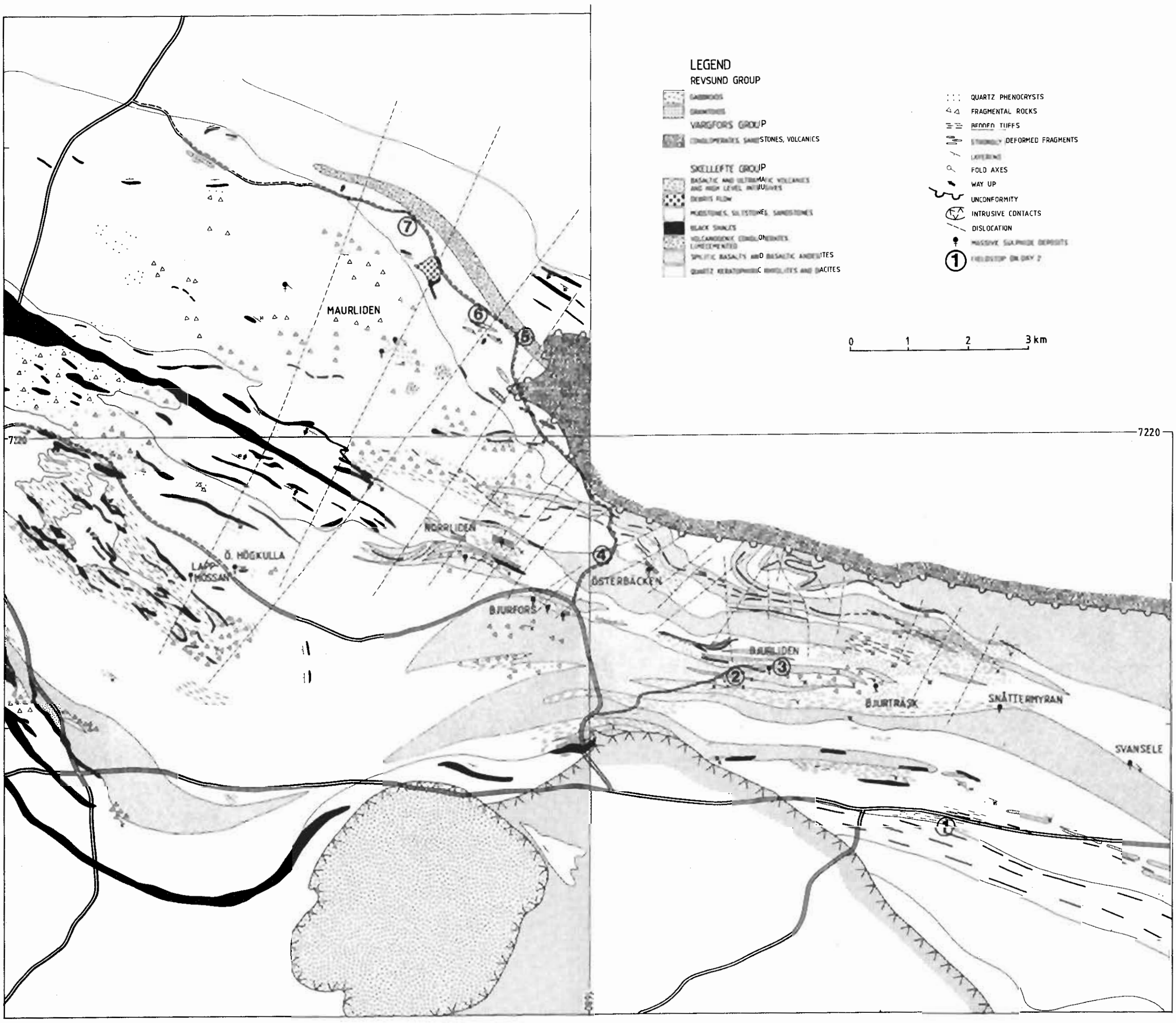


Fig. 12. Tour stops in the Central area.

The Bjurliden massive sulphide deposits contain several types of ore. In the pyrite-rich type, layering of sphalerite and pyrite are found. Another type is pure pyrrhotite ore with an insignificant content of other sulphides. This type grades continuously over to a sphalerite-rich ore with pyrrhotite fairly uniformly distributed throughout the ore. Arsenopyrite may sometimes be found in the massive ore types, generally in the form of idiomorphic crystals uniformaly distributed in the sulphide mass. Galena and antimony minerals are further megascopically visible in schlieren in the solid ore. Chalcopyrite has been observed in the solid pyrrhotite ore associated with hornblende-chlorite-rocks. The contacts of the ore are generally fairly sharp normal to the strike, whereas it successively grade into sulphide disseminated country rocks parallel to the strike.

The metal contents in the deposit vary quite considerably. The pyrite-rich type may contain up to 40 % S, and the zinc content may reach as high as 17 % Zn over a two or three metres wide section. The lead content are in a few sections 2–3 % Pb but on the average it is much lower. The silver content follows the lead and has given as maximum 250 ppm Ag. Gold is fairly low and does not reach 1 ppm. An estimation of the tonnage and metal content for this deposit, to approximately 80 metres depth, is 670 000 metric tons of ore with 0.11 % Cu, 3.5 % Zn, 0.36 % Pb, 17 % S, 0.3 ppm Au and 46 ppm Ag.

The country rocks (Fig. 13) of the Bjurliden deposits are quartz porphyric volcanites, banded felsic and mafic tuffs and coarse-grained amphibolitic greenstone. These rock types intercalate with each other repetitively. They show a regional alteration, "spilitization", and are altered to sericite and chlorite schistose rocks. Close to the ore (Fig. 14),

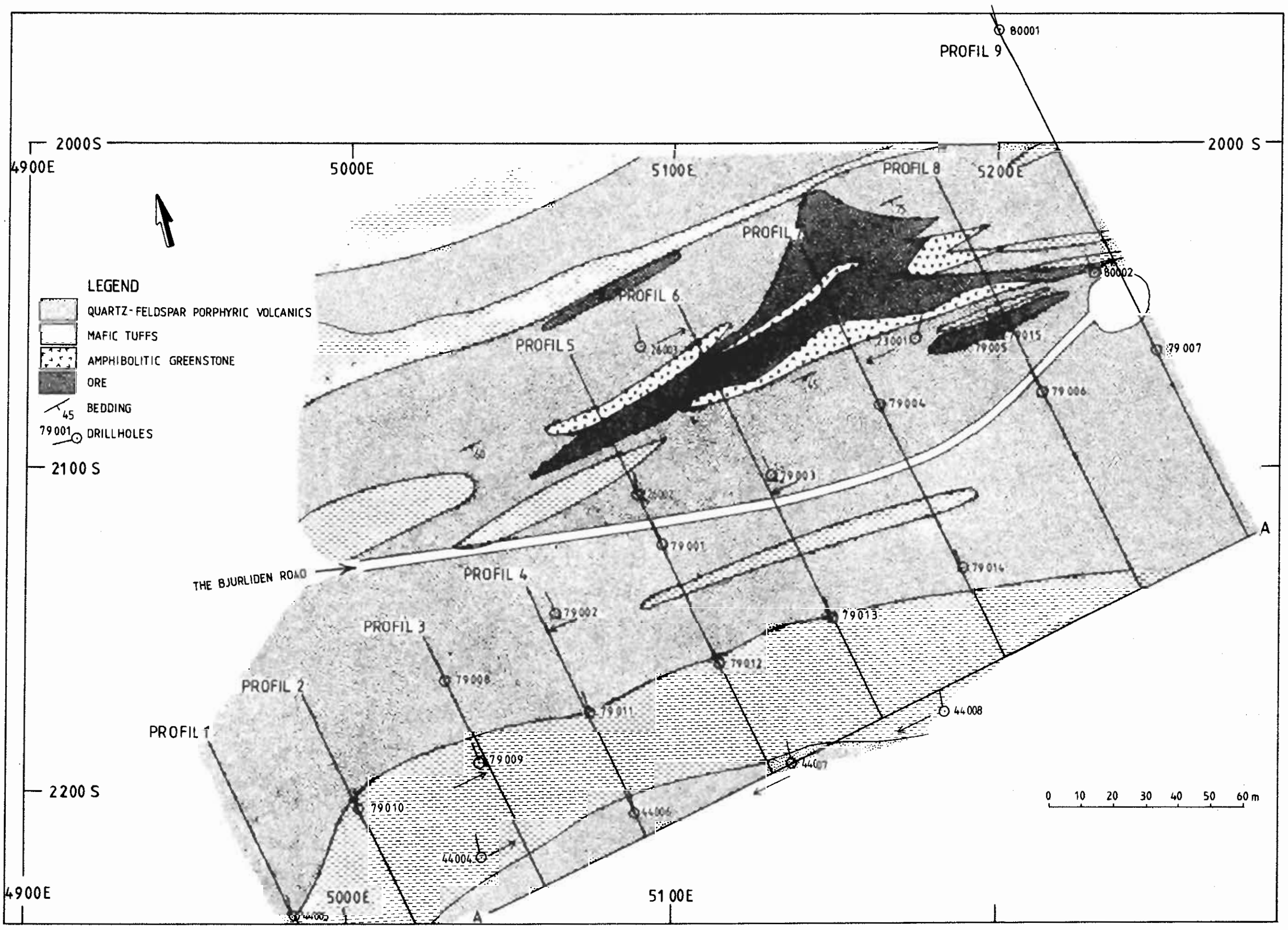


Fig. 13. Plan of the Bjurliden deposit.

intense hydrothermal alteration has affected the rock with different intensity in different parts, but as a whole there is one alteration zone on both sides of the ore with one or more of the following minerals: magnetite, hornblende, gahnite, garnet, andalusite and biotite. In the coarse–grained greenstone hornblende has changed to cummingtonite.

The Bjurliden deposit seems to be related to a synvolcanic faultzone. Together with several other deposits, e.g. Norrliden, Bjurfors, Bjurträsk, Snåttermyran and Svansele, the Bjurliden deposit shows the same alteration zone on both sides of the ores, which suggests the proximal nature of deposition in a fissure. All these deposits are situated in the bimodal sequence of basalts and rhyolites.

The rhyolites are often found as fragmental rocks or banded tuffs, indicating their deposition under high water/rock ratios, i.e. in a submarine environment. Among rhyolites are both Na-enriched, quartz keratophyres, and K-enriched types. The first probably affected by seawater interaction and the later by intense hydrothermal activity. The basaltic rocks of this bimodal sequence are just Na-enriched spilites. This together with the fact that the metamorphic grade is varying (greenschist-amphibolite facies) in coexisting horizons (probably caused by the synvolcanic faulting), indicates that the massive sulphide has deposited along synvolcanic fault zones before most of the basalts were erupted along the same fault system.

Stop 4. – North of Örträsk village. Amygdaloidal basaltic lavas of the Skellefte Group.

The lava of this locality is partly rich in feldspar phenocrysts. Amygdules are filled with calcite or chlorite rimmed by quartz. The lavas occur together with tuffs interstratified in felsic pyroclastic rocks. Felsic fragments in a basaltic matrix and quartz porphyric tuffs within the basaltic sequence indicate alternating volcanic eruption products. The metamorphic grade ranges from low greenschist to amphibolite facies.

Stop 5. – The Vargfors dam. Lime-cemented volcanogenic conglomerate.

At this locality a poorly sorted conglomerate is exposed with clasts and lenses of coarse material in fine-grained layers, indicating a fluviatile environment (Dumas 1985). Volcanic clasts of quartz porphyry dominate and are mostly

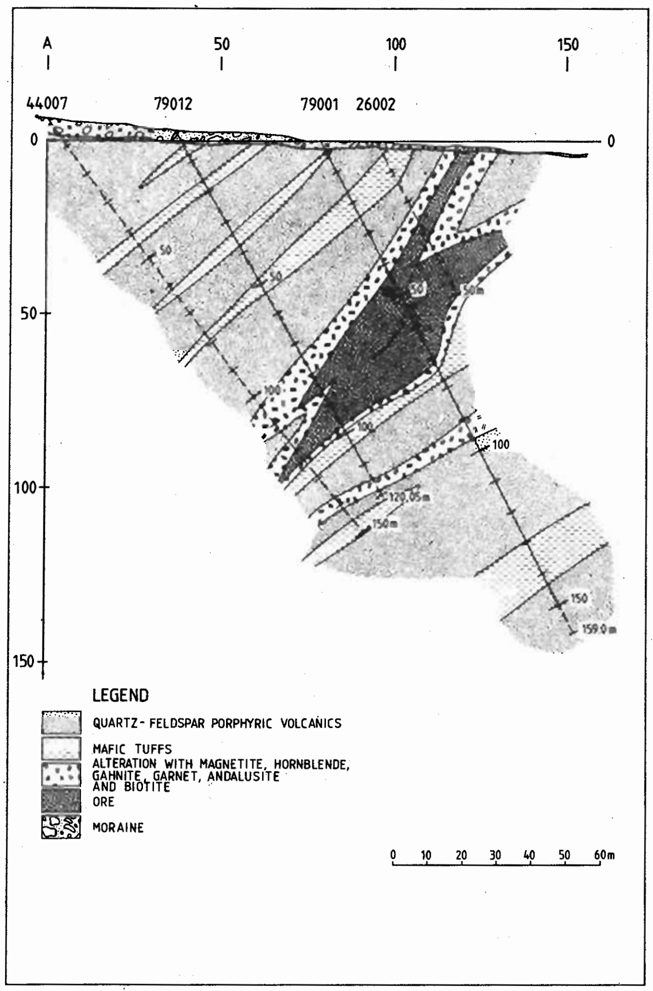


Fig. 14. Section through the Bjurliden deposit.

well rounded. The matrix is a sometimes well bedded lime-rich siltstone. In the surroundings siltstones, mudstones and conglomerates with granite boulders are exposed.

Stop 6. – Exposures south of the Vargfors dam. Siltstones and mudstones with komatiitic greenstones.

The metasedimentary formation at this stop shows turbulent streams, small channels and slumping indicating an agitated environment of deposition, which probably took place on a continental shelf not far from the shore (Dumas 1985).

"Komatiitic" greenstones occur as stratiform lavas or sills in the metasediments. They show a porphyritic texture but are completely altered to Mg-chlorite schists.

Stop 7. – Skavbergstjärn. Siltstones and mudstones of the Skellefte Group.

Slumping, small turbulent streams, graded bedding and fragments of slates indicating the very unstable environment at the time of deposition, which probably took place on a continental shelf not far from the shore (Dumas 1985).

TABLE 5. Composition of selected rock types demonstrated on day 2.

	Stop 1 Felsic tuff	Stop 2 Quartz porphyry	Stop 2 Greenstone tuff	Stop 4 Basaltic lava	Stop 5 Komatiitic greenstone
SiO_2 wt %	70.4	75.2	51.5	49.1	48.0
TiO_2	0.30	0.43	0.80	0.80	0.48
Al_2O_3	13.6	11.6	18.1	17.3	10.0
Fe_2O_3*	2.89	2.67	10.1	8.75	8.37
MnO	0.06	0.11	0.10	0.14	0.17
MgO	0.96	1.31	4.73	3.08	18.4
CaO	1.67	2.71	6.85	12.0	6.2
Na_2O	4.83	2.91	2.68	2.27	0.3
K_2O	1.79	2.51	0.93	0.28	0.5
P_2O_5	0.09	0.03	0.20	0.21	0.12
H_2O^+				2.1	6.2
H_2O^-				0.2	0.2
CO_2				4.5	0.63
Cr ppm	–	30	110	120	1 900
V	60	140	420	450	150
Ni	40	85	<11	<11	480
Y	30	75	16	21	2
Zr	190	290	76	62	30
Cu	10	<30	94	67	10
Zn	80	110	100	90	10
Ba	3 100	350	230	140	10

DAY 3. THE LÅNGDAL AND RENSTRÖM SULPHIDE DEPOSITS IN THE EASTERN PART OF THE SKELLEFTE FIELD

R. Jonsson and R. Larsson

THE LÅNGDAL MINE

The Långdal ore is a stratiform sulphide deposit situated at the contact between an underlying quartz porphyry and basic tuffites overlain by volcanics of dacitic-basaltic composition (Fig. 15). The tuffites include calcareous skarns and cherts mainly at the margins of the ore horizon. Four different ore types are distinguished. The central, massive pyrite ore changes laterally into compact banded sphalerite-pyrite ore. Below the compact ore, there is a sphalerite-chalcopyrite-pyrrhotite stringer brecciating the strongly altered quartz porphyry. Outside the margins of the compact ore there are sulphosalts disseminated in calcareous skarn sediments. The area is folded by at least three phases. The ore horizon is thrusted and displaced into three main lenses. The original tonnage of the Långdal ore was 4 million metric tons with 0.14 % Cu, 5.7 % Zn, 1.7 % Pb, 12 % S, 1.9 ppm Au and 160 ppm Ag.

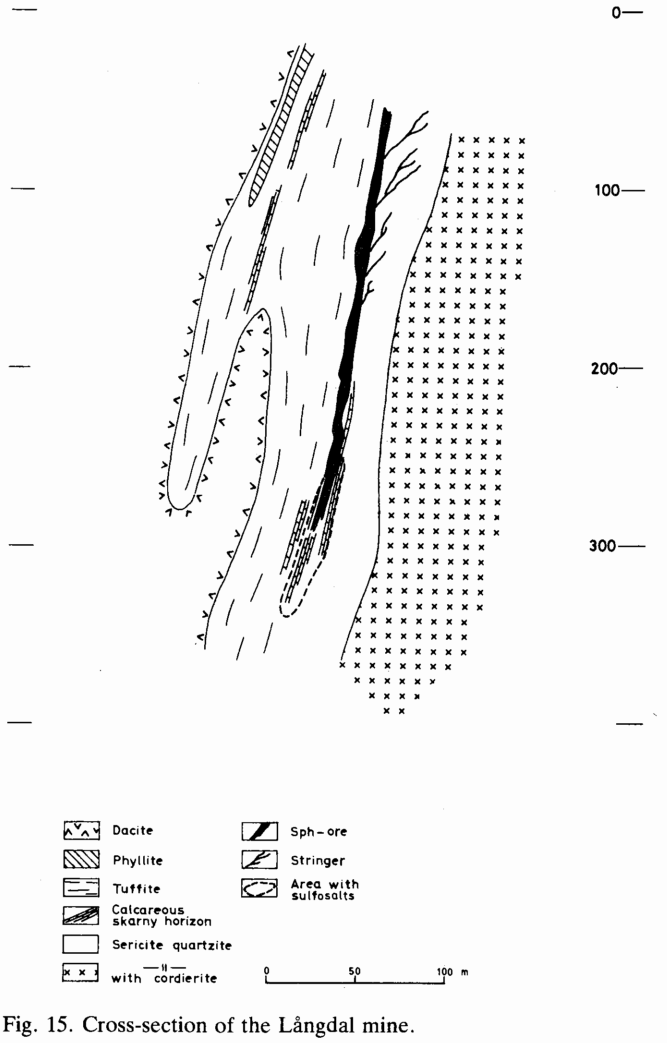


Fig. 15. Cross-section of the Långdal mine.

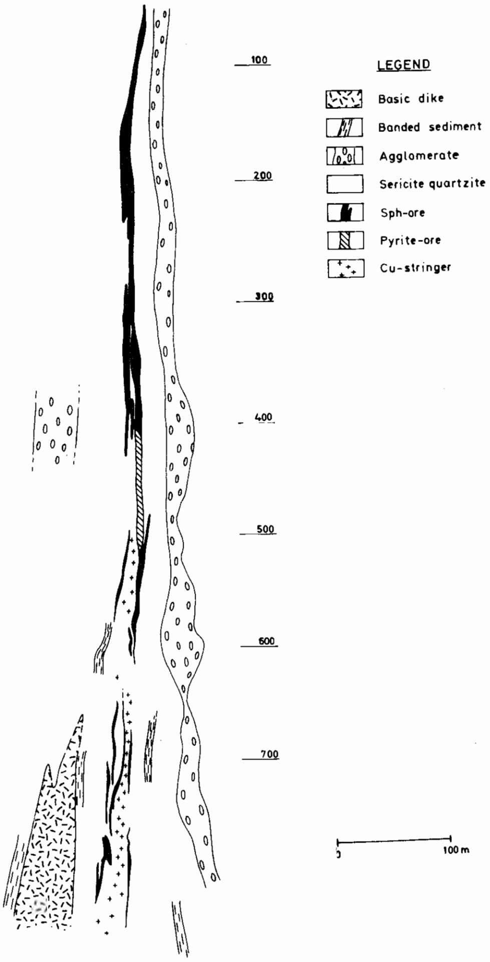


Fig. 16. Cross-section through the Renstrøm deposit.

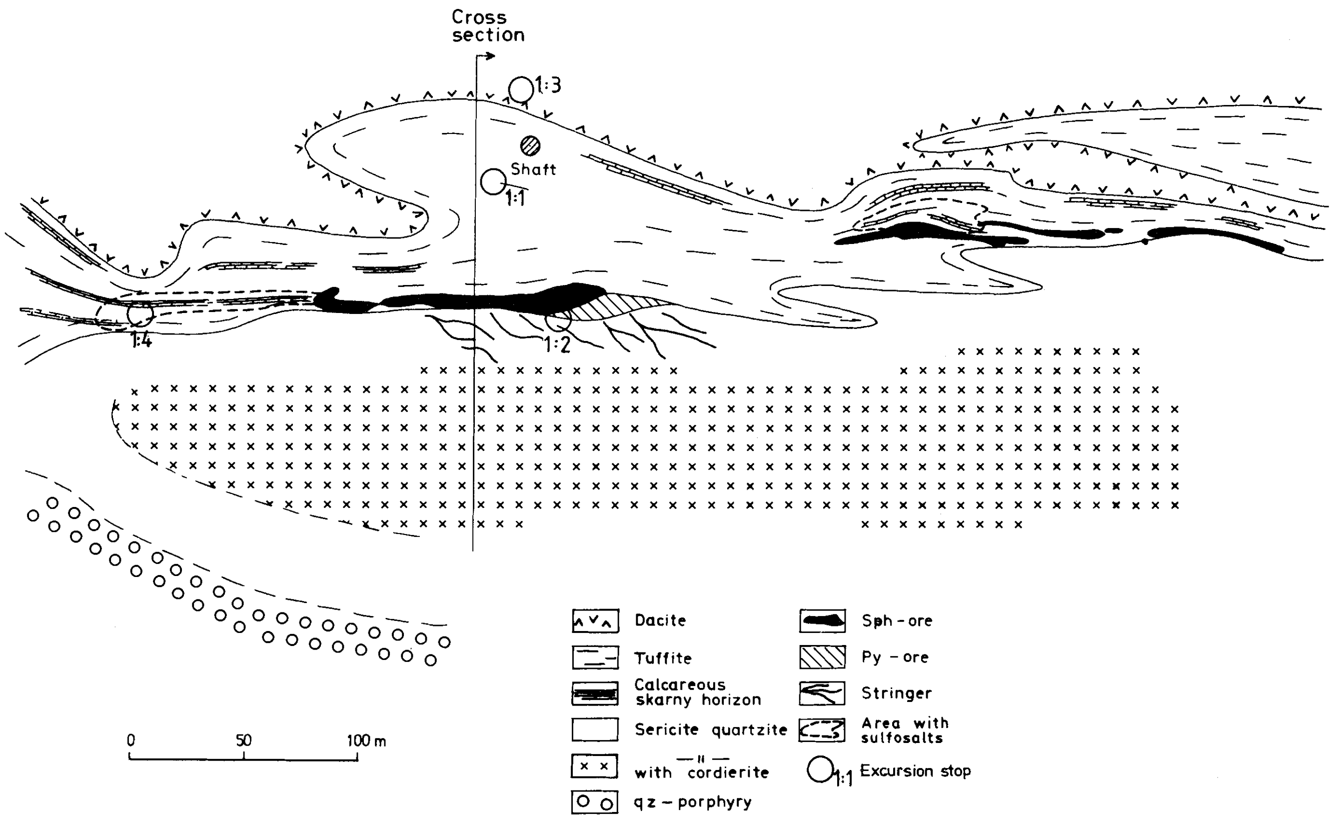


Fig. 17. Plan of the Långdal mine at the 150 m level, showing underground tour stops.

THE RENSTRÖM MINE

The Renström area is located about 15 km northwest of Boliden. Three massive sulphide deposits have been discovered there. The main units around these ores are (oldest first): acid pyroclastics (tuffs and agglomerates), quartz porphyry, massive sulphide, reworked volcanics and tuffite, tuffs and andesitic agglomerates and lavas.

The Renström ore body (Fig. 16) is a stratabound sulphide deposit settled in a volcano-sedimentary environment in the Skellefte Volcanics. The rocks around the ore are tuffs, agglomerates, porphyries and tuffites with calcareous and chert horizons. Two basic dikes occur in the mine. The rocks are strongly altered and folded and primary features are mostly obliterated. The ore seems to be situated between the pyroclastic and the sedimentary part of the sequence. Three different ore types are distinguished; massive, banded sphalerite-pyrite ore with compact pyrite lenses overlies a chalcopyrite-pyrite-pyrrhotite stringer zone, which at its deeper parts brecciates a felsic rock. The original tonnage of the Renström ore was 9 million metric tons with 0.8% Cu, 6.5 % Zn, 1.5 % Pb, 0.16 % As, 14 % S, 2.8 ppm Au and 155 ppm Ag.

STOPS

Stop 1. – Långdal mine (Fig. 17).
Stop 1.1 – Tuffite.
Stop 1.2 – Compact ore and stringer ore.
Stop 1.3 – Basic volcanics.
Stop 1.4 – Disseminated sulphosalts in calcareous skarns.

Stop 2. – Revsund granitoid.

Stop 3. – Renström mine (Fig. 18).
Stop 3.1 – Agglomerate.
Stop 3.2 – Basic dike.
Stop 3.3 – Compact ore.
Stop 3.4 – Stringer ore.

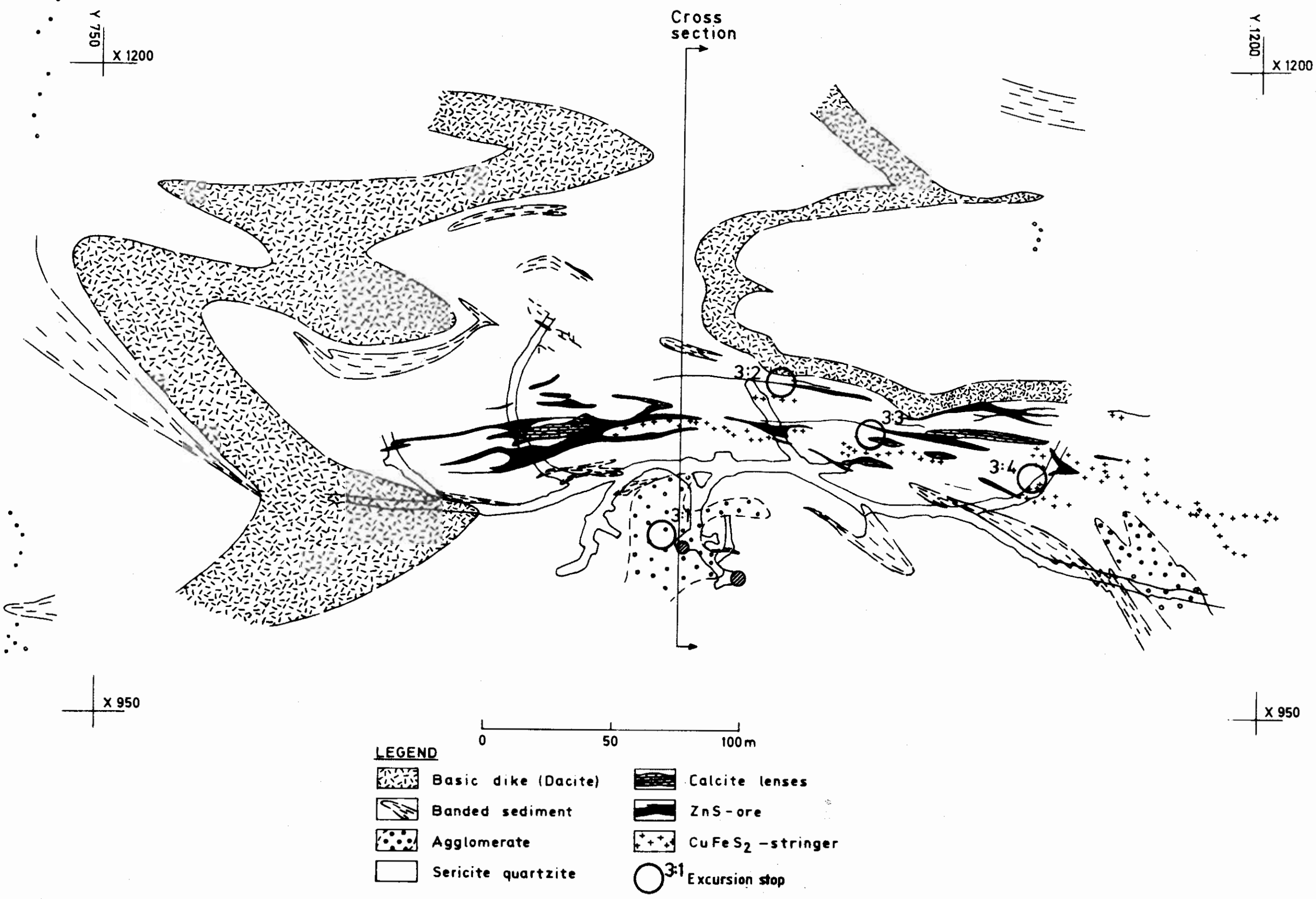


Fig. 18. Plan of the Renström mine at the 600 m level, showing tour stops.

DAY 4. THE NÄSLIDEN AND HOLMTJÄRN SULPHIDE DEPOSITS IN THE CENTRAL PART OF THE SKELLEFTE FIELD

S.Å. Svensson and M. Willdén

THE NÄSLIDEN MINE

Näsliden (Fig. 19) is a massive sulphide deposit in the central part of the Skellefte Field.

The country rock consists mainly of acid metavolcanics of pyroclastic origin, which have calc-alkaline affinity. Phyllites and greywackes overlie the volcanic rocks. The supracrustals were metamorphosed to greenschist facies and folded during two phases of deformation. In the mine area, they are almost isoclinally folded around steeply dipping axes.

The ore deposit is situated in the border zone between the volcanic and sedimentary rocks. In the strongly altered footwall volcanics, sulphides occur as disseminations and stringers. Primary features in the massive ore include macrobanding, stratigraphic compositional zoning and a variety of relic colloform textures, which characterize much of the pyrite content. Folding, boudinage and faulting are features caused by dynamo-metamorphism. Other secondary ore features include the formation of pyrite micro-mosaics, recrystallization of relic colloform pyrite, development of subgrains in pyrrhotite and twinning of sphalerite.

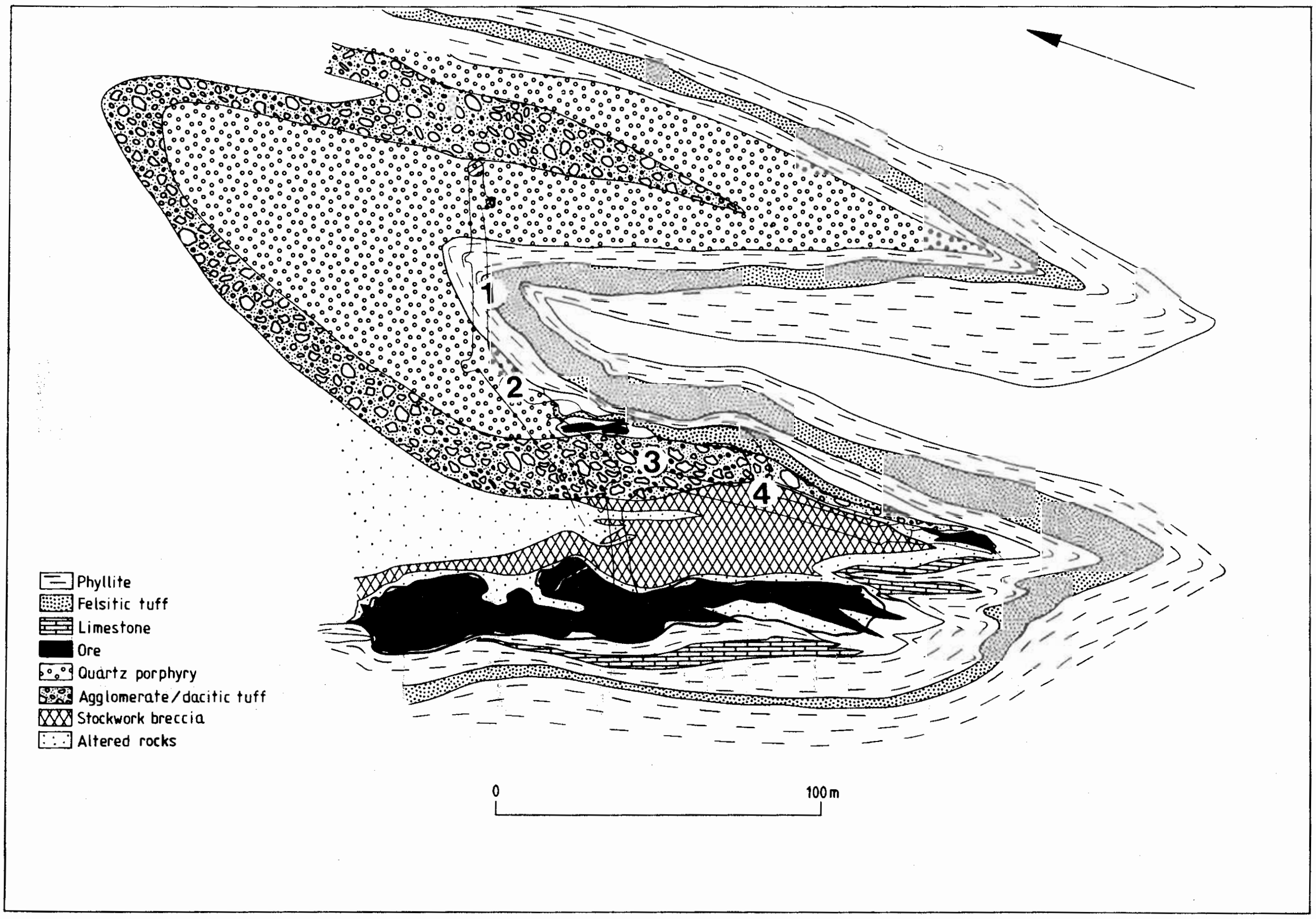


Fig. 19. Geology of the Näsliden deposit, showing tour stops.

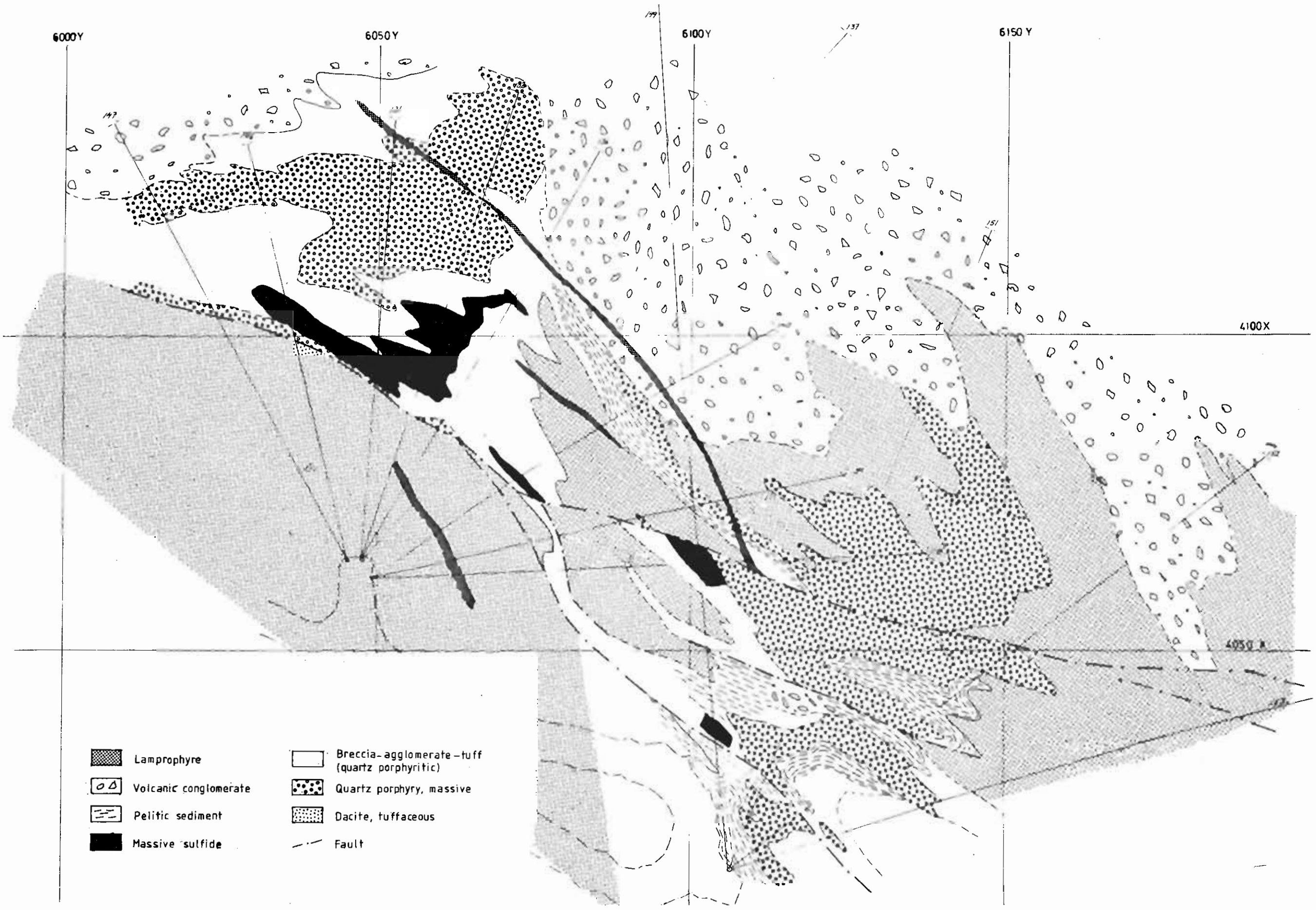


Fig. 20. Geology of the Holmtjärn deposit at the 160 m level.

THE HOLMTJÄRN MINE

The Holmtjärn ore body is a minor massive sulphide deposit rich in gold. The deposit was indicated by Boliden in 1924. After a short period of mining between 1924–25, the ore reserves were exhausted. As a result of prospecting activities in the beginning of the 1980's, additional ore was found. The ore body was investigated by underground workings during 1983–85, and at the end of 1985 Boliden decided to bring the deposit into permanent operation. Current prospecting activities below the 160 m level indicate that the ore zone continues at depth.

The geology of the Holmtjärn Mine consists of a complexly folded sequence of various volcanic rocks (Fig. 20). The oldest rocks are tuffaceous and mainly dacitic in composition. This part of the sequence is intruded by a quartz porphyry. Apparently accompanying the quartz porphyry intrusion the area was tectonically deformed, producing a rough topography in the area. In this type of environment volcanic eruptions took place as evidenced by the presence of breccias and agglomerates of predominantly quartz porphyry components. The uppermost part of the sequence consists of various types of redeposited volcanics such as for instance volcanic conglomerates.

The main sulphide concentration occurs in close connection with the quartz porphyry and associated pyroclastic rocks. The ore forming environment is further characterized by the presence of local lenses of mostly strongly pyrite-impregnated fine-grained sediments. Geometrically the Holmtjärn deposit appears as an elongated body plunging NNE at about 70° (Fig. 21).

The original ore reserve above the 160 m level is estimated at about 0.2 Mt with 8 g/t Au, 120 g/t Ag, 0.4 % Cu, 4.8 % Zn, 0.6 % Pb and 32.1 % S. Three different ore types can be distinguished, namely:

a) pyrite ore, fine-grained and massive
b) sphalerite ore, commonly finely banded with pyrite
c) arsenopyrite ore, normally brecciated by chalcopyrite

Among these ore types, the arsenopyrite ore is locally extremely rich in gold with Au-contents up to 200 g/t. In addition to the major ore minerals, the deposit is characterized by the presence of various sulphosalts and magnetite.

The stratigraphic footwall of the ore body is intensively sericitized. Chlorite alteration has been observed mainly in the interval between the 150 and 180 m levels. Directly below the massive sulphide ore, silicified portions are frequently met with.

The ore body as well as surrounding rocks are cut by dikes of a presumed lamprophyric composition (Fig. 20). The rock

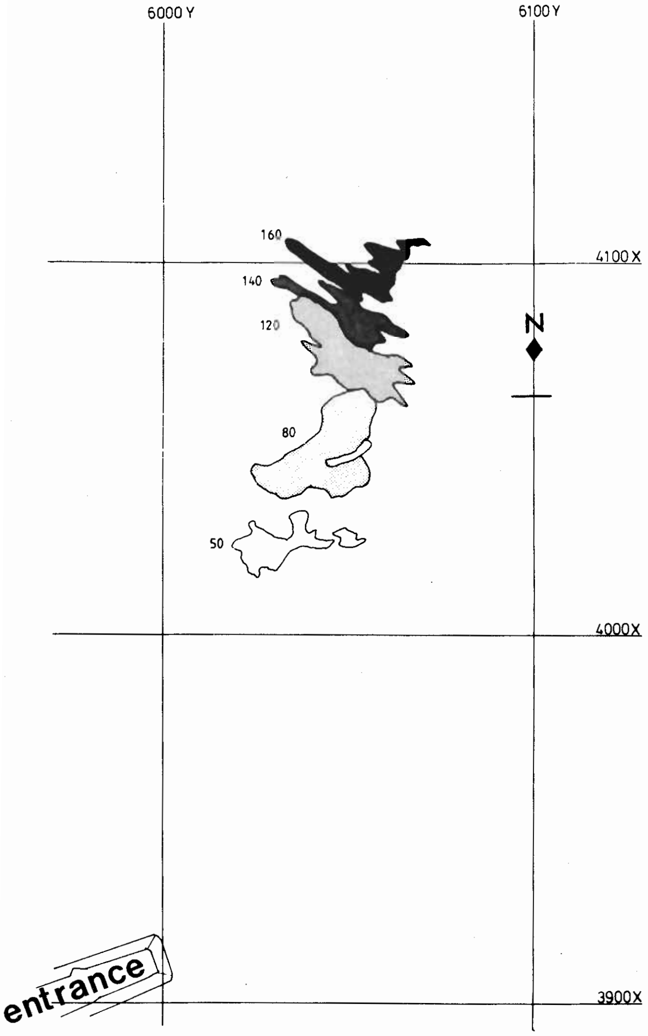


Fig. 21. Sections through the Holmtjärn deposit.

is greyish and fine-grained with the following average composition:

SiO_2	51.2 %
Al_2O_3	17.9 %
MgO	4.7 %
CaO	9.4 %
K_2O	1.5 %
Na_2O	1.0 %

The folded rock sequence has been affected by faulting representing the latest tectonic event in the mine area.

STOP DESCRIPTIONS

Stop 1. – Näsliden mine

210 m level (Fig. 19)

All the principal rock types in the mine are exposed in the adit. Lowermost in the stratigraphy a dacitic agglomerate and tuff occurs, which is partly overlain by a porphyry with quartz and plagioclase phenocrysts. Under the ore body, which is now poorly exposed on this level, the original rocks are strongly altered to sericite and/or chlorite schists partly containing stringers and impregnation of mainly pyrite. Within the alteration zone there is also a stockwork or breccia of strongly silicified rocks. The porphyry (and the main ore body) is overlain by pyrrhotite-bearing, partly graphitic phyllites. In the lower parts of the thick pile of metasediments overlying the metavolcanics there are also felsic tuffs, probably deposited as ash flows.

1.1 – Phyllite and very fine-grained psammitic rocks, partly carbonaceous and with pyrrhotite impregation. These rocks constitute the stratigraphically lowermost part of the pile of metasediments overlying the metavolcanics (and ore) in the mine.

1.2 – Intercalation of felsic metavolcanite consisting mainly of feldspar, quartz, chlorite, sericite and biotite. Opaque minerals and calcite occur in accessory amounts. The intercalation has a grain size in the range of 0.02–0.03 mm, and occasionally contains about 0.5 mm large microlites of plagioclase and quartz. The felsite shows no bedding structures and is regarded as a submarine pyroclastic flow.

1.3 – Sericitized porphyry with 1–2 mm large phenocrysts of quartz and plagioclase, constituting about 5 % of the rock volume. The quartz phenocrysts characteristically show blue opalescence. They are usually more or less rounded, but dihexagonal forms and crystal fragments also occur. The microcrystalline matrix consists mainly of feldspar, quartz and sericite with subordinate chlorite, calcite and biotite. Ore minerals, apatite and zircon are present in accessory amounts.

In the mine the porphyry occurs as a layer in the stratigraphy, but drillholes a couple of hundred metres to the north indicate that the porphyry has a more stock-like appearance.

1.4 – Agglomerate with felsic bombs and lapilli in a dacitic matrix. The groundmass in the agglomerate is fine-grained and consists mainly of feldspar, chlorite, biotite, quartz, sericite, and small amounts of calcite, apatite and ore minerals. In the groundmass there are plagioclase phenocrysts and volcanic rock fragments. The fragments are usually acid and light grey, but there are also small, darker and more mafic fragments. The fragments reach a size of about 0.3 m and are oriented with their longest axes in the direction of the regional lineation.

1.5 – The agglomerate is overlain by a dacitic tuff with a composition similar to the groundmass of the agglomerate.

1.6 – Stockwork breccia consisting of grey or yellowish grey fragments composed of microcrystalline sericite quartzite with minor amounts of pyrite, especially towards the margins, resulting in a diffuse zonation. Between the fragments, which fit together well, there is a matrix of quartz, calcite and pyrite with subordinate sphalerite and chalcopyrite. The breccia represents a zone of strongly silicified, fractured metavolcanics.

Stope on the 60 m level (Fig. 22)

1.7 – In the footwall there are metavolcanics transformed into chlorite schist. They are overlain by the massive, banded ore. The contact between ore and wall rocks is very distinct. The compositional banding of the ore is caused by alternating layers of varying sulphide content and composition. The layers only rarely exceed a couple of centimetres in width. Pyrite is by far the most abundant sulphide with subordinate amounts of pyrrhotite, sphalerite, chalcopyrite, galena, arsenopyrite and sulphosalts. Among the gangue minerals, carbonates dominate completely. However, especially within the stratigraphically upper parts, towards the hanging wall, there are also intercalations of phyllites and fine-grained psammitic rocks. The ore is overlain by graphitic phyllite, which occurs in the hanging wall.

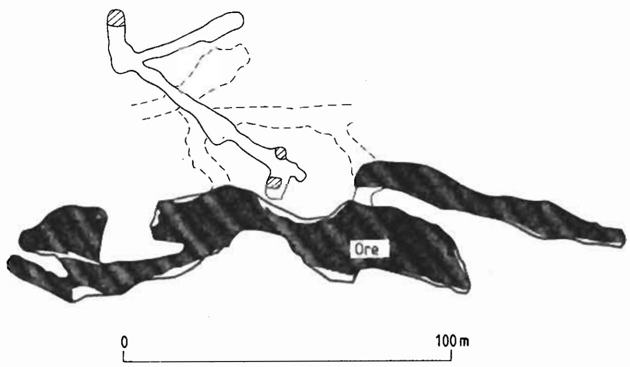


Fig. 22. The Näsliden ore body at the 60 m level.

Stop 2. – The Holmtjärn mine

2.1 – Stratigraphic sequence just east of the mine entrance (Fig. 23). Coarse quartz porphyry breccia at the bottom overlain by reworked tuffaceous and agglomeratic components. Note the rounded shape of quartz porphyry fragments. The sequence is lithologically similar to the ore forming environment in the mine.

2.2 – Mine visit. The various ore types will be demonstrated as well as their relationship to the country rocks.

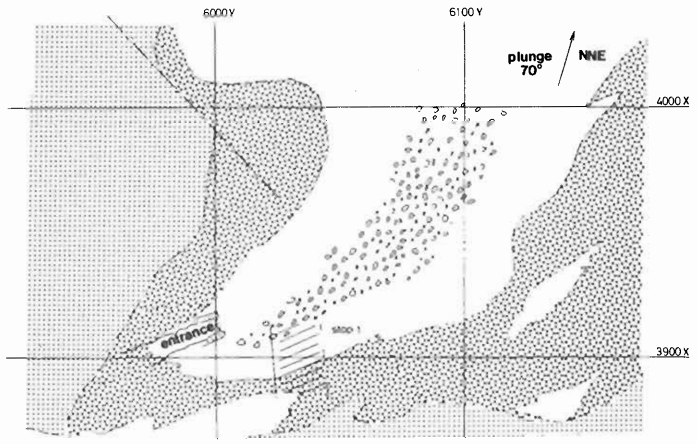


Fig. 23. Surface geology of Holmtjärn showing location of tour stop 1.

DAY 5A. THE EARLY OROGENIC GRANITOID COMPLEX AND ASSOCIATED MINERALIZATION

THE JÖRN GRANITOID COMPLEX

L.Å. Claesson

The Jörn Granitoid Complex is located some 20–50 km northwest of Boliden (Fig. 7). The complex is an early Svecokarelian granitoid suite, which intrude into a volcanic arc environment on the southern margin of a major Proterozoic continental area. Both the complex and its country rocks have been affected by hydrothermal alteration and low-grade regional metamorphism. Four phases (Fig. 24) can be distinguished on geological, chemical and geophysical criteria, in particular a heterogeneous, calcic outer zone and a more evolved central diapir. The rock types vary from granodiorite to granite and have major and trace element abundances similar to those of Phanerozoic subduction-related granitoids from relatively immature volcanic arcs (Wilson *et al.,* in press.).

Zircon populations from the different phases are rather heterogeneous but do not show significant differences in U distribution of U-Pb age between the phases. While pooled U-Pb data (13 points) give an upper intercept of 1890 Ma, a two-stage model assuming an age difference between cores and rims gives a more probable crystallization age of 1876±2 Ma with significant lead loss at 1720 Ma and 410 Ma (Wilson *et al.,* in press.).

ε_{Nd} values range from +1.8 to +3.2 indicating that the source material for the Jörn Granitoid Complex was derived from a LREE depleted mantle with a small contribution of older crustal material and had had a relatively short crustal residence period. Metaluminous compositions and oxygen isotope ratios suggest non-pelitic sources. The Jörn Granitoid Complex probably originated as a series of subduction-related melts of basic to intermediate composition which underwent varying degrees of subsequent differentiation and secondary alteration.

THE TALLBERG MINERALIZATION

P. Weihed

The Tallberg mineralization is situated in the outer, older zone (GI zone) of the Jörn Granitoid Complex (Fig. 24). It has a compositional range from tonalite to granodiorite, some gabbroic intrusions also occur (Fig. 25). The regional geology of the Tallberg area is outlined in Fig. 26 (enclosed area in Fig. 25). The mineralization is of porphyry type, with the following characteristics:

- Low grade, 0.27 % Cu (cut off 0.20 % Cu) and large tonnage, 43.8 million metric tons.
- Ore minerals: chalcopyrite, pyrite, molybdenite, sphalerite, galena and magnetite.
- Ore minerals in veins, i.e. stockwork mineralization (gangue minerals: quartz, calcite and chlorite) and disseminated, mainly chalcopyrite and pyrite.
- Hydrothermal alteration: phyllic (quartz, pyrite and sericite); propylitic (chlorite, epidote and calcite).
- Associated with quartz-feldspar porphyritic granitoid stocks.
- A weak metal zonation with Cu-Mo in the central parts and higher Zn-Pb contents in the outer zones.
- Probably related to syngenetic faults or lines of weakness.

At the interception of an WNW-ESE and a NE–SW trending line of crustal weakness the granodioritic border zone is intruded by a number of small quartz-feldspar porphyritic stocks less than 50 m wide and slightly elongated in an ENE direction, see Figs. 26 and 27. Around these stocks an intense quartz veining occurs, which is mineralized in its central parts. The area was later intruded by mafic postmineralization dikes, <20 m wide, trending in an ENE direction. The mineralization is separated into two bodies, a larger one, approximately 500×300 m in size, NW of a smaller one with somewhat higher Au-content, 2–3 g/ton. The Mo-content is approximately 0.01–0.02 % in both bodies. The Zn-content varies, but sometimes reaches 2.5 % in analysed sections (c. 5 m). The higher Au-content seems to be related to strongly schistose zones, parallel and adjacent to the postmineralization dikes. These zones often show a phyllic alteration in contrast to the main mineralization which shows a propylitic to mixed phyllic-propylitic alteration. The Au-content is interpreted as remobilized into these shear zones.

Because of the many similarities with Phanerozoic porphyry copper deposits the mineralization is interpreted as being a Proterozoic equivalent. However, some differences exist, e.g. no supracrustal host rocks occur; the grade is lower and there is no obvious alteration zoning. These discrepancies may be explained by a deeper erosion level compared to modern porphyry deposits and the fact that a number of small porphyritic stocks with associated hydrothermal systems have intruded, and overprint each other.

STOP DESCRIPTIONS

Stop 1. – Haraliden. L.Å. Claesson.

Phase GI of the Jörn Granitoid Complex.

GI, the outer zone of the Jörn Granitoid Complex, is dominated by a heterogeneous coarse-grained grey granodiorite. Quartz, oligoclase, biotite, hornblende and

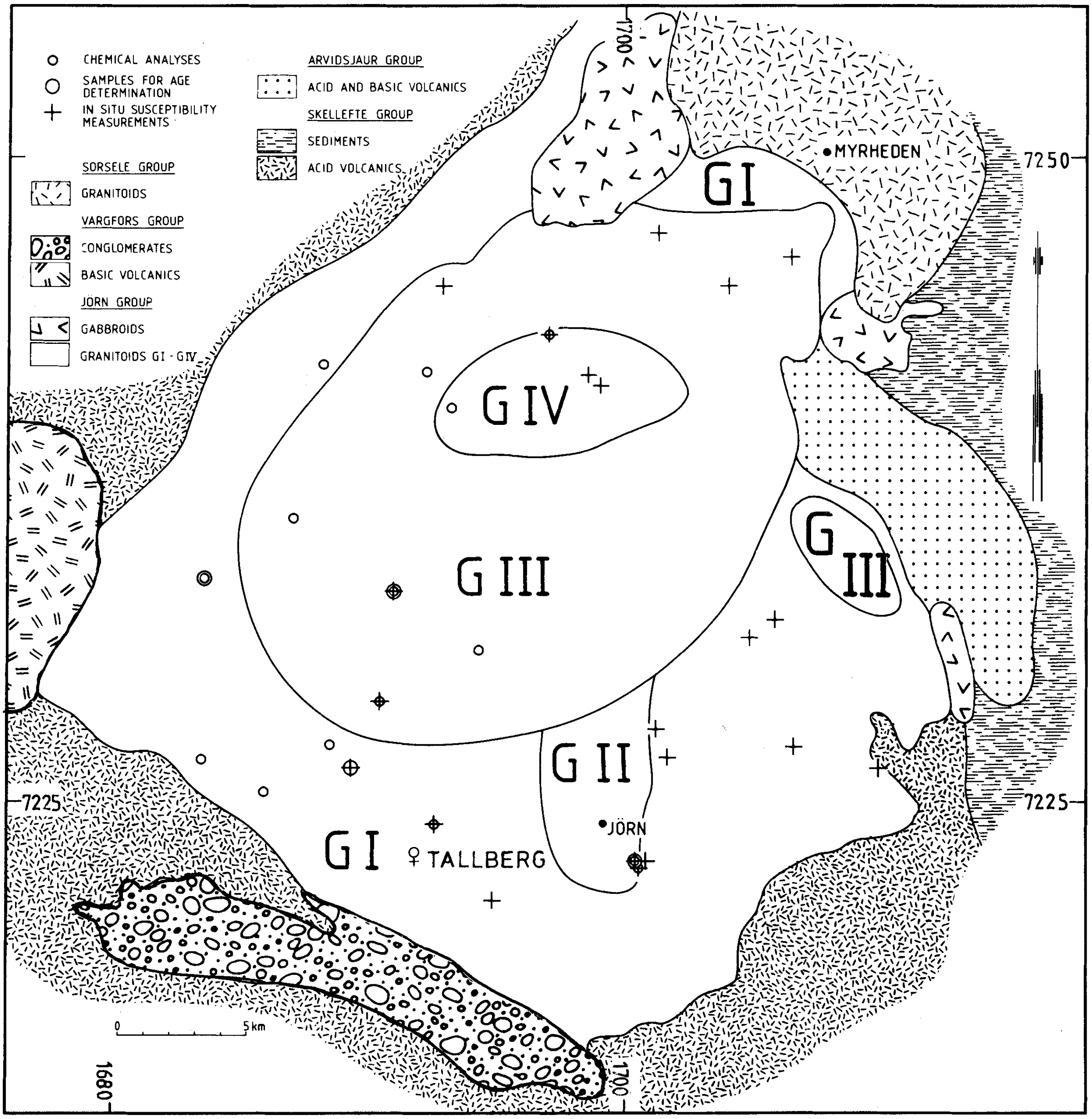


Fig. 24. Major units of the Jörn Complex, based on geological and geophysical observations (after Wilson *et al.*, in press).

microcline are the main minerals while epidote, apatite, sphene, zircon and ore minerals occur as accessories. There is evidence of secondary alteration; the feldspars are sericitized and hornblende is sometimes replaced by biotite and chlorite. Near to the contacts with the surrounding volcanites quartz appears as rounded porphyroblastic aggregates which are 10–20 mm in size and exhibit an opalescent bluish colour due to narrow crystals of rutile. Within a zone a few hundred metres wide around the granitoid, the volcanic host-rock sometimes displays the same large quartz porphyroblasts. Numerous xenoliths of fine-grained diorite occur rather frequently in this locality.

Stop 2. – The Tallberg mineralization. P. Weihed.

At this stop, we will see a GI type granodiorite unaffected by hydrothermal alteration. The rock has however been altered by regional greenschist metamorphism which often is difficult to distinguish from granodiorite with a propylitic alteration. Mineralogically it is composed of quartz, oligoclase, biotite, hornblende and microcline as main minerals and epidote, apatite, sphene, zircon and ore minerals as accessories (Wilson *et al.*, in press). The regional metamorphism is evident in sericitic alteration of the feldspars and chloritic alteration of biotite and hornblende.

The mineralization is situated in a topographically low area under bogs and is not exposed. A cross section through the southern mineralization can be seen in Fig. 27. At the stop, Ddh 91 will be demonstrated. The different lithological units can be seen in this drillcore as well as mineralization and alterations.

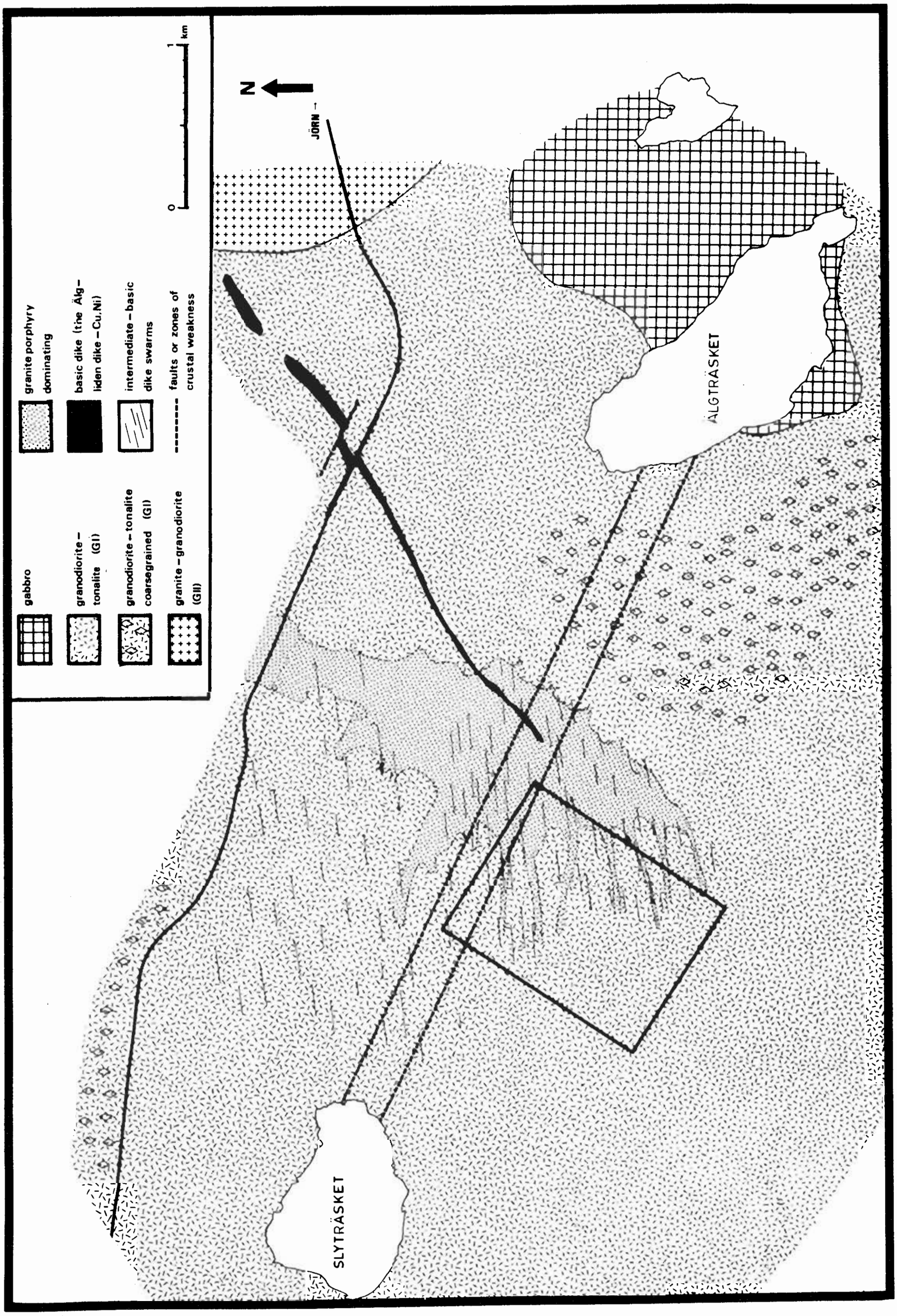


Fig. 25. Location of the Tallberg porphyry Cu-Mo mineralization.

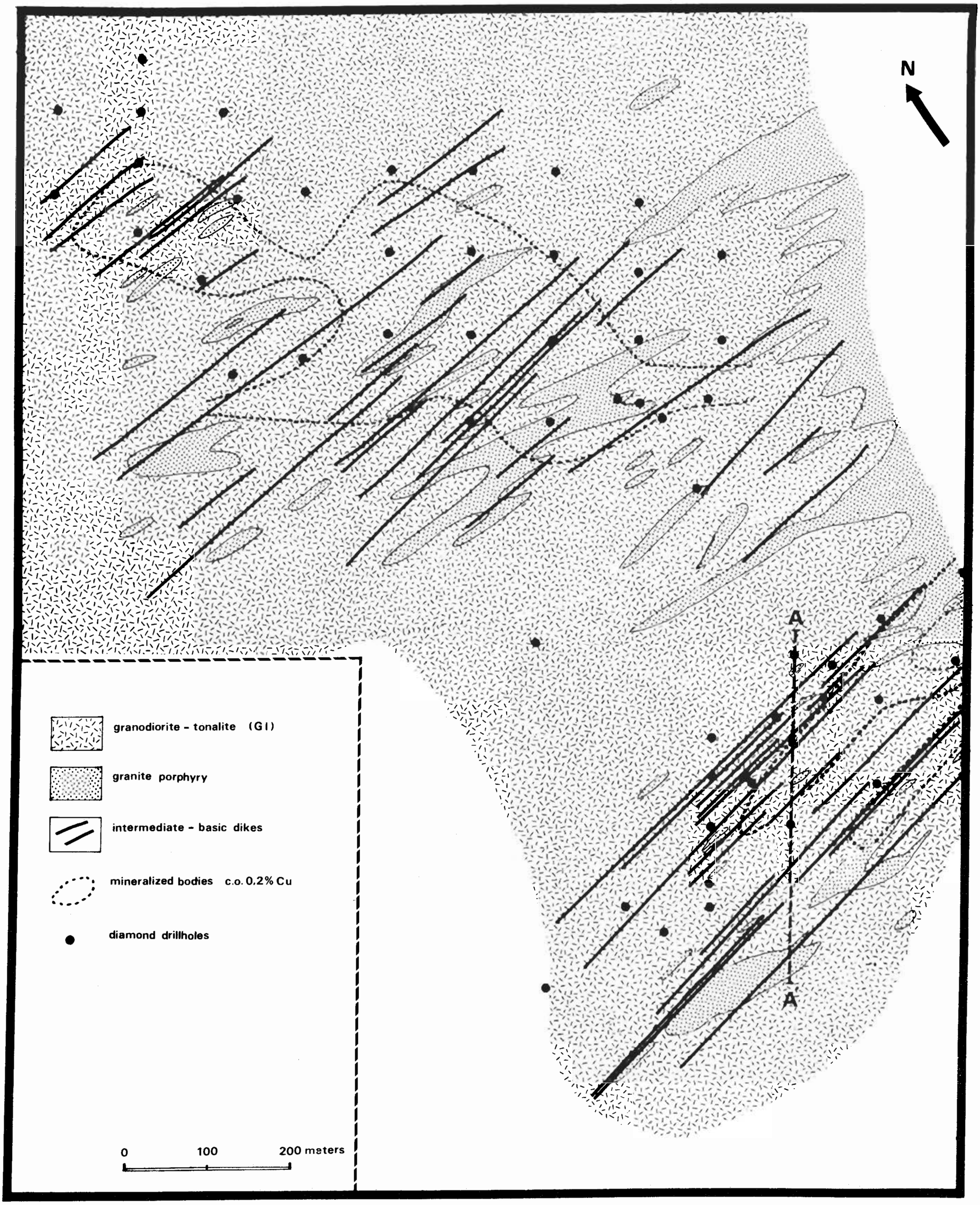


Fig. 26. Detail of Tallberg mineralization from Fig. 25.

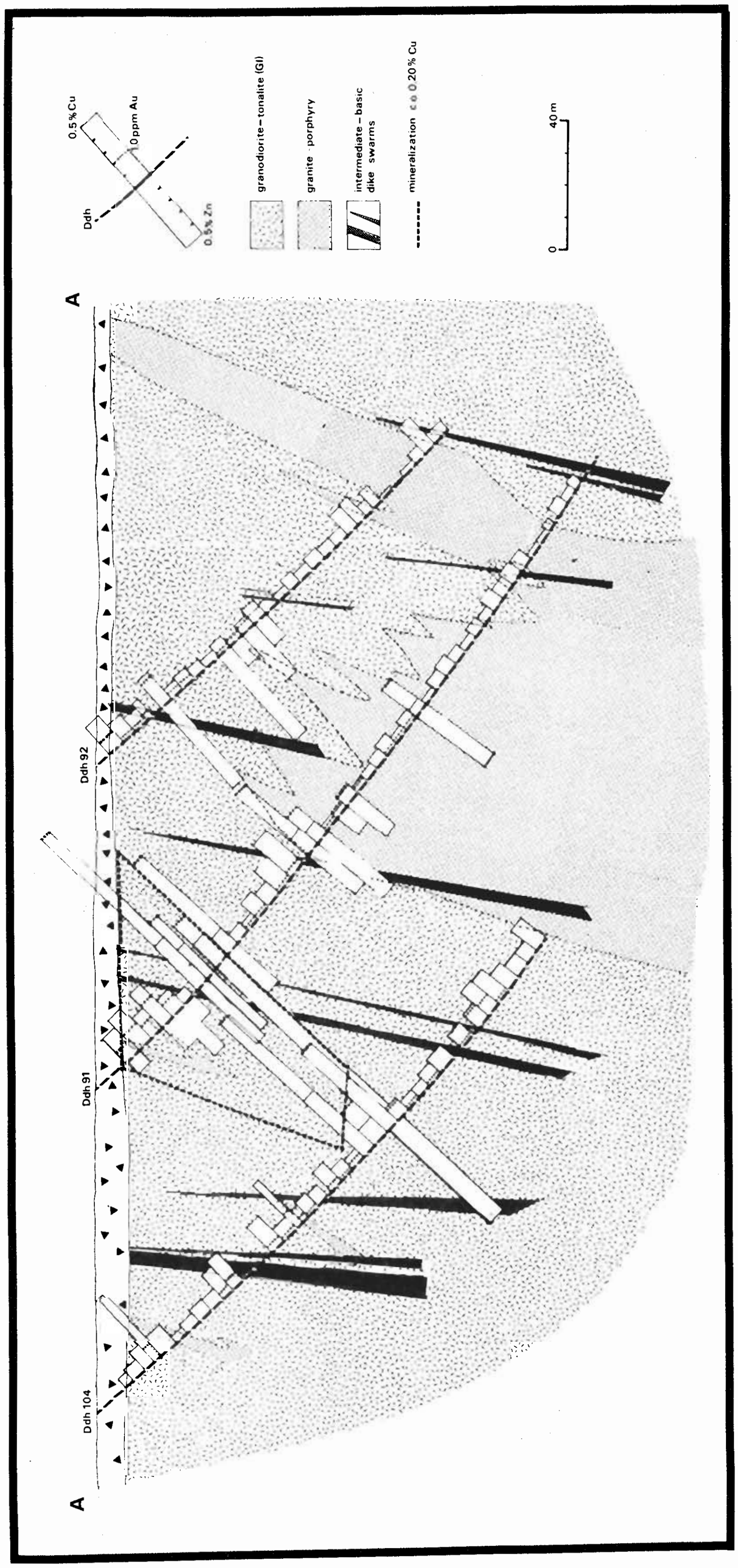


Fig. 27. Section through the Tallberg mineralization along profile A–A on Fig. 25.

Stop 3. – The ski mountain at Jörn. L.Å. Claesson.
Phase GII of the Jörn Granitoid Complex.

GII is a homogeneous grey granodiorite. It is similar to GI but can be outlined very well on the aeromagnetic maps as a separate intrusion slightly younger than GI.

Stop 4. – Road cut at Vargliden. L.Å. Claesson.
Phase GIII of the Jörn Granitoid Complex.

GIII is an oval-shaped diapir some 17 by 25 km occupying the centre of the complex. It consists of homogeneous red to brown-grey granite. The major constituents are quartz, perthitic microcline, oligoclase and biotite, while accessory minerals include epidote, sphene, zircon, apatite and ore minerals. Quartz is subhedral and exhibits undulatory extinction. Oligoclase appears as euhedral-subhedral, weakly zoned and sericitized crystals. Biotite is green to light brown and occurs as euhedral crystals with ragged edges where hornblende has formed. Epidote normally occurs as small crystals associated with biotite flakes. Narrow fissures and small cavities are filled with hydrous iron oxide.

Stop 5. – Roadstop south of Petikträsk. L.Å. Claesson.
Conglomerate with clasts of the Jörn Granitoid GI-Phase (The Abborrtjärn Conglomerate).

The typical conglomerates of Abborrtjärn type are mainly characterized by the abundance of granitoid derived clasts from the GI phase. The textures suggest rather short transport but probably very agitated, and local and sudden deposition, not influenced by a flow direction. This conglomeratic facies is a clast-transported conglomerate, showing commonly imbricated pebbles and a poorly subhorizontal bedding. Those conditions of deposition are very similar to that typical of the formation of alluvial fans (Dumas 1985).

TABLE 6. Composition of selected rock types within the Jörn Granitoid Complex as demonstrated on day 5A.

	Stop 1 GI–I	Stop 3 GII–II	Stop 4 GIII–13
SiO_2 wt %	62.2	66.0	73.0
TiO_2	0.33	0.58	0.26
Al_2O_3*	14.6	14.7	13.1
Fe_2O_3	1.7	1.4	0.9
FeO	3.2	2.7	0.7
MnO	0.09	0.07	0.05
MgO	2.10	1.74	0.38
CaO	4.3	3.2	1.2
Na_2O	3.1	4.2	4.0
K_2O	1.4	3.6	4.5
H_2O^+	–	0.7	0.5
P_2O_5	0.7	0.19	0.07
CO_2	–	0.21	0.06
F	–	0.10	0.08
Rb ppm	46	28	108
Sr	169	321	249
Th	5.9	11	14.8
U	2.7	6.4	2.1

DAY 5B. THE WESTERN SECTION OF THE CENTRAL PART OF THE SKELLEFTE FIELD AND THE RAKKEJAUR SULPHIDE DEPOSIT

S.Å. Svensson

GENERAL GEOLOGY

The stratigraphy of the area can be summarized as follows:

Youngest	Revsund granite
	Gabbro/Ultramafic
	Granodiorite/Quartz diorite and andesite
	Vargfors conglomerates
	Skellefte metasediments
Oldest	Skellefte metavolcanites

The Skellefte metavolcanites form two major antiformal areas: north of Näsliden and from Mensträsk to the northwest up to Rakkejaur (Fig. 28). Skellefte metasediments occur in major synforms between the antiforms and west and south of Näsliden. The northeastern parts of the area are mainly occupied by Vargfors volcanites, with intercalations of conglomerates, and a granodiorite – quartz diorite. In the Näsliden-Rakkejaur area gabbroic and ultramafic rocks have intruded the supracrustals. A domal intrusion of Revsund granite occupies the westernmost part of the area.

The supracrustal rocks were first tightly folded around gently plunging axes with fold planes striking WNW–ESE. A second fold phase deformed the rocks around steeply plunging axes. The two deformations resulted in a tightly folded, steeply dipping rock complex. However, there is a general trend towards less intense folding towards NE.

The general strike of the separate lithologic units, like the orientation of the Skellefte district as a whole, is WNW–ESE. In the western part of the area the predominant strike of the rocks is NNW–SSE which is probably due to a distortion of the general strike associated with the intrusion of the Revsund granite.

There was probably also a third phase of folding around sub-horizontal axes roughly perpendicular to the belt, which produced open, longwaved folds.

The regional metamorphism is of greenschist facies.

The Skellefte metavolcanites are chemically classified as calc-alkaline rocks. Except for a minor area with mafic rocks around Näsliden, the volcanites are acid in composition. Regional chloritization and sericitization and reworking of the rocks have, however, largely changed the original chemical composition.

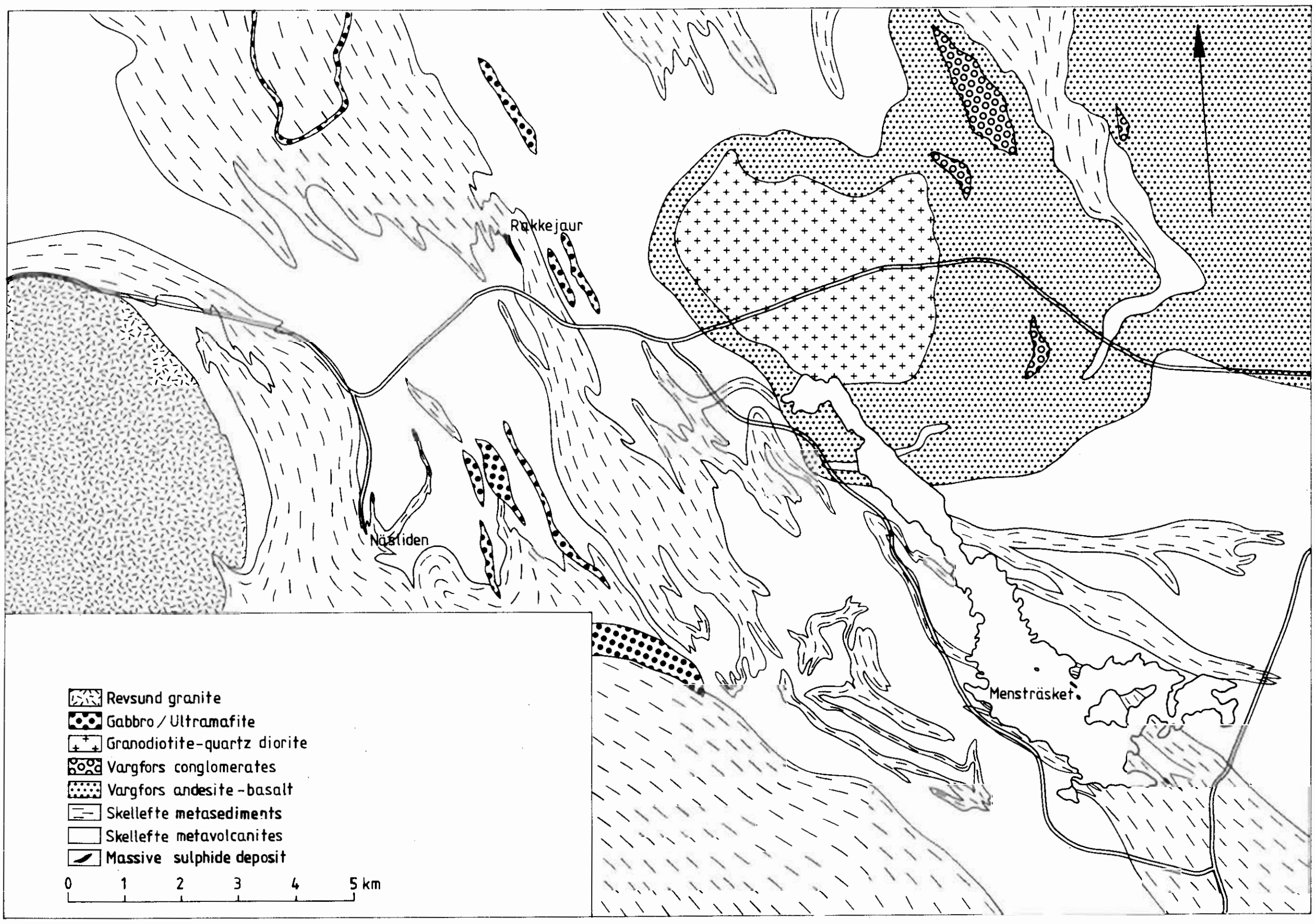


Fig. 28. Geology of the Central Skellefte Field, western section.

Tuffs with plagioclase and quartz phenocrysts, 1–2 mm large, is the dominating rock type in the area. Coarser pyroclastic varieties are also common and in the Näsliden-Rakkejaur area tuffs without phenocrysts and rock fragments occur. Lavas and sub-volcanic intrusions seem to be rare. Reworked tuffs-agglomerates are common, especially close to the overlying metasediments. The area north of Mensträsket is dominated by agglomerates, more or less reworked and partly grading into volcanic conglomerates.

Fine-grained psammites and phyllitic rocks, often containing pyrrhotite and/or graphite, tuffites, redeposited tuffs, greywackes and other types of turbidites form a thick sequence of rocks, Skellefte metasediments, conformably overlying the Skellefte metavolcanites. The transition from volcanites to sediments is sharp or gradational, with the more rapidly deposited sediments relatively more frequent in the lower parts. Intercalated in the metasediments are mafic tuffaceous rocks.

In the northeastern part of the area, Vargfors volcanites of andesitic-basaltic composition outcrop. They are porphyritic with hornblende and plagioclase phenocrysts. There are both fairly homogeneous flows and agglomeratic types with relatively big mafic rock fragments with a composition nearly identical to the matrix and also small, scattered fragments of acid volcanites.

Intercalated in the volcanites are small lenses of conglomerates with pebbles of Skellefte volcanites and also granitoid pebbles (Abborrtjärn Conglomerate), presumably derived from the Jörn suite of intrusions now outcropping east of the area under consideration. More common in the Vargfors volcanites are conglomerates with often colourful volcanite pebbles (Dömanberg Conglomerate) derived from the terrestrial Arvidsjaur volcanites occurring to the north of the Skellefte district proper.

Within the area of Vargfors volcanites there is a granodioritic intrusion partly rimmed by quartz diorite. The intrusion is suggested to be co-magmatic with the volcanites and to have intruded at a volcanic centre.

In the Näsliden and Rakkejaur areas medium-grained, gabbroic rocks occur mainly composed of hornblende, plagioclase and actinolite with minor alteration products of these minerals. They intruded in zones of structural weakness, subparallel to the regional schistosity and layering. Northwest of Rakkejaur there is a folded, ultramafic intrusion strongly altered to a chlorite-, calcite-, talc- and serpentine-rich rock with magnetite.

The Revsund granite in the westernmost part of the area is light grey with 1–2 cm large microcline megacrysts in a medium-grained matrix of microcline, plagioclase, quartz and biotite. Xenoliths of the surrounding rocks are common, but the thermal effect on the intruded rocks is very faint. As mentioned before, the Revsund granite has also deformed the supracrustal rocks, which curve round the granite massive.

Within the map area, nine massive sulphide deposits have been found. The Näsliden and Rakkejaur deposits are described elsewhere in the excursion guide. In the Näsliden area there is one more deposit, and at Mensträsk six deposits have been discovered. All these deposits, although varying in size and grades, show many similarities. They were deposited at the same stratigraphic horizon, the border zone between Skellefte Group metavolcanites and metasediments. Siliceous, coarse pyroclastic volcanites are common in the altered footwall. They are proximal massive pyrite deposits with Zn, Cu, Pb and with a typical high As-content of 1.0–2.3 % in the better known deposits.

The initial volcanism in the Näsliden-Mensträsk area was submarine and produced siliceous, largely pyroclastic volcanites. During the waning stage of volcanism "submarine exhalative" deposits were formed and sedimentary processes became more prominent, resulting in the Skellefte metasediments. Partial up-lift had probably started already during the volcanic episode and the still unconsolidated Skellefte volcanites were redeposited as e.g. north of Mensträsk. Northwest of the Mensträsk area those rocks are gradually replaced by conglomerates with pebbles of the Jörn granitoid. These shallow Jörn intrusions were co-magmatic with the Skellefte volcanites and had been quickly uncovered by weathering and erosion.

In connection with uplift and faulting the Vargfors volcanites extruded and mixed with the conglomerates. A granodiorite-quartz diorite intruded in vent areas of Vargfors volcanoes.

Later the whole rock complex was intensely folded (through collision?). Finally the Revsund granite intruded and added even more to the deformation.

Whether the Skellefte district originated in a "simple" rift basin or if subduction was involved is still under debate. Ore lead isotope ratios from the Näsliden deposit are mantle-like in terms of the idealized plumbotectonic model (Rickard & Svensson 1984). They suggest that the Näsliden deposit was formed in the Proterozoic equivalent of a Phanerozoic primitive island arc. However, the Skellefte Field was formed during a transition stage in earth history where Archaean block tectonics were developing into Phanerozoic plate tectonics. The geology of the district combines both rift and arc characteristics, possibly reflecting this stage of development.

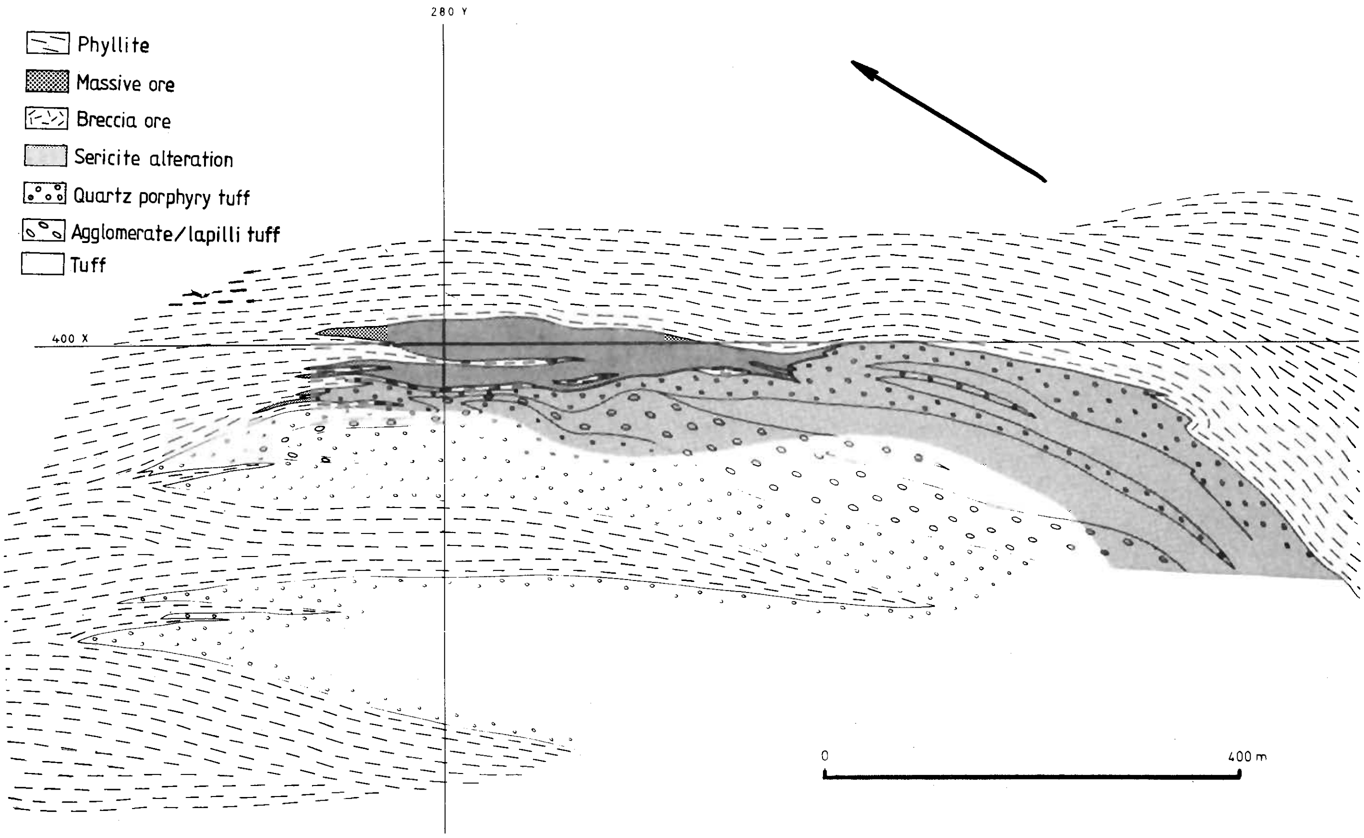


Fig. 29. Geology of the Rakkejaur deposit.

THE RAKKEJAUR MINE

The Rakkejaur deposit was found in 1922. It was drilled from 1922–1925 and investigated by a gallery on the 10 m level in 1933–1934. During 1938–1941 a shaft was sunk to 332 m level and the deposit was investigated through galleries and drilling on the 160, 240 and 320 m levels. Minor test quantities of ore were produced from those levels and from an open pit. The intended mining was found not to be viable. From 1965–1970 c. 0.5 Mt tons of ore were mined in the open pit.

The country rock in the stratigraphic footwall of the Rakkejaur deposit is composed of polymict agglomerate, quartz porphyritic tuff and a very fine-grained volcanite (Fig. 29). These rocks belong to the Skellefte Group volcanites. Immediately under the ore body there are also lenses of limestone with "oolitic structure". In the hanging wall occur pyrrhotite-bearing phyllites, partly with graphite, tuffites and greywackes.

The metavolcanites, originally below the massive sulphide body, have been strongly silicified and sericitized. They also contain a stockwork and stringer mineralization of mainly pyrite and chalcopyrite which is now part of so-called copper-breccia ore. The banded massive sulphides were deposited above the alteration zone, at the rock-seawater interface, as a blanket-shaped, stratiform body. The lower part of this body has a quartzitic matrix, while the matrix in the upper part consists of phyllitic material.

Beside the morphologic zonation described above, there is also a mineralogic-chemical zonation of base metals and precious metals in the ore. The breccia ore is relatively rich in Cu, while the Zn- and Pb-content is low. In the banded, massive-semimassive ore Zn, Pb, Ag and Sb increase stratigraphically upwards and laterally away towards the more distal parts.

The ore body has a maximum length of 550 m, a maximum width of 65 m and it is known down to about 400 m below surface. The latest ore reserve calculation has proved 10.4 million metric tons of ore with 0.2 % Cu, 2.9 % Zn, 0.2 % Pb, 1.3 % As, 26.9 % S, 1.1 ppm Au and 62 ppm Ag down to the 360 m level.

The Rakkejaur area, including the ore deposit, has been intensely folded during at least two phases of deformation. During the first phase the rocks were folded around gently plunging axes with fold planes roughly parallel to the strike of the supracrustals. The second fold phase deformed the rocks around steeply plunging axes (cf. Fig. 30).

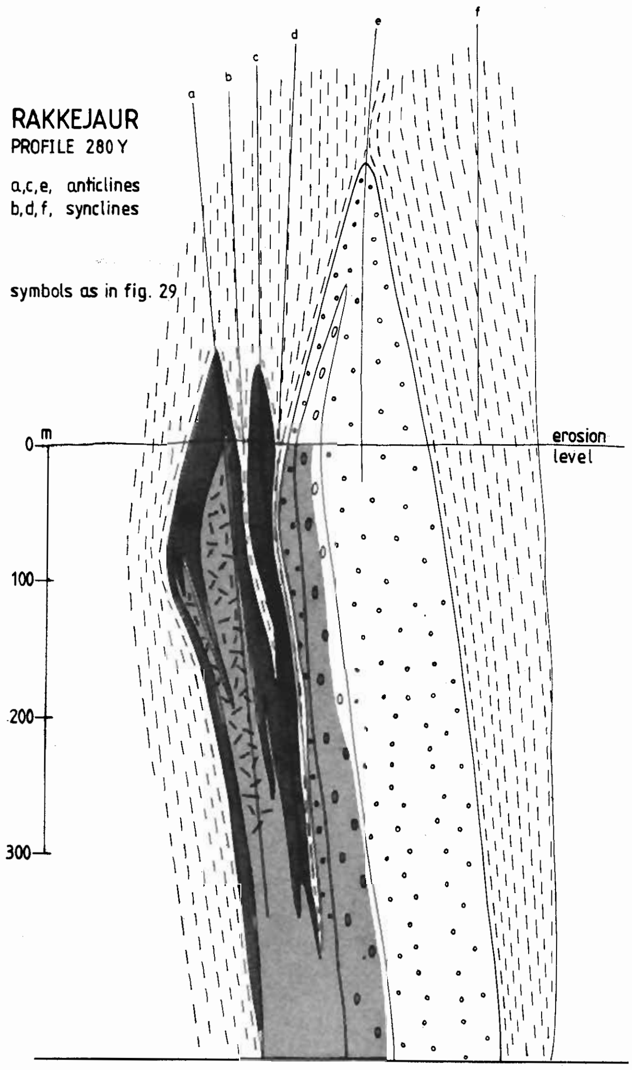


Fig. 30. Section and structure of the Rakkejaur deposit. Legend, see Fig. 29.

STOP DESCRIPTIONS

Stop 6. – At the tunnel close to Nicknoret. L.Å. Claesson. Fine-grained sedimentary strata grading upwards into conglomerates of the Abborrtjärn type with granitoid clasts. Fine-grained sedimentary strata conformably underlie the conglomerates. These sediments consist mostly of mudstone layers at the base and of sandstone beds at the top just below the conglomeratic unit. The transition zone is characterized by the abundance of slumping, small scale cross beddings and channels, which indicate an agitated environment of depositions, perhaps a shoreline. A characteristic of its lithic components is their double origin: Skellefte felsic volcanics and Jörn granitoids. During the deposition of this sedimentary formation a regression took place. The sandy unit was probably a beach deposit, and the conglomeratic upper part an alluvial fan, deposited on a littoral plain, which prograded over the shelf accumulation products (Dumas 1985).

Stop 7. – Rakkejaur open pit. S.Å. Svensson.

At this stop (cf. Fig. 29), a banded and deformed massive sulphide body will be demonstrated. The sulphide body is overlain by metasediments, which partly have been folded into the ore. In the footwall altered metavolcanics can be seen.

DAY 6–7. GEOLOGY OF THE WESTERN PART OF THE SKELLEFTE FIELD AND THE KRISTINEBERG AND HORNTRÄSK SULPHIDE DEPOSITS

M. Willdén

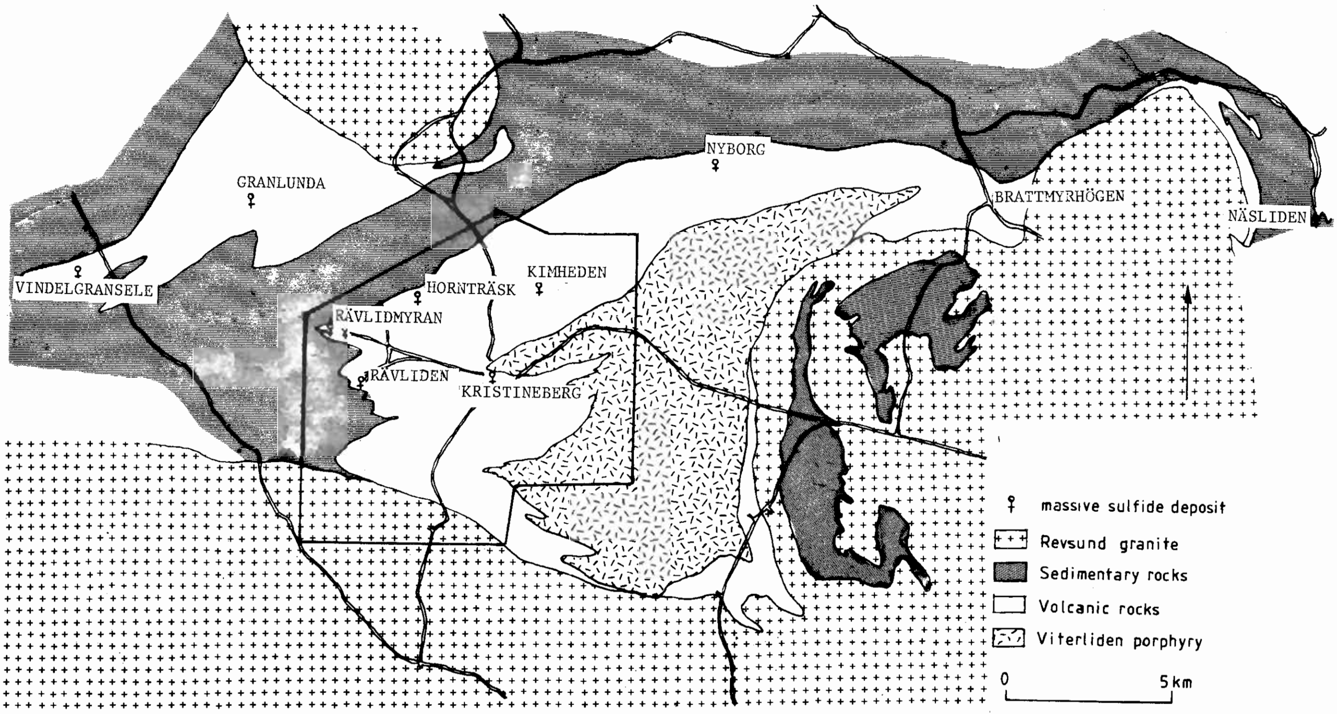


Fig. 31. Geology of the western Skellefte Field.

GENERAL GEOLOGY

The western part of the Skellefte Field consists of two volcanic areas, divided by an E–W running synform and surrounded to the N and S by granitic rocks (Fig. 31). Major massive sulphide deposits occur in the southern area. Five mines are at the present in operation, namely four at Rävliden and one at Kristineberg. The annual ore production is about 0.8 Mt tons with an average combined grade of 1.2 g/t Au, 54 g/t Ag, 1.2 % Cu, 5.2 % Zn, 0.4 % Pb and 22 % S. In the following, the geology of the southern volcanic area (the Kristineberg area) will be described in some detail.

The bedrock in the Kristineberg area consists of volcanic rocks overlain by sedimentary rocks (Fig. 32). The supracrustal sequence is intruded by a young granite, the Revsund granite. The tectonic style of the area is strongly influenced by the intrusion of the Revsund granite. This granite intruded as a number of domes. The intrusion of the granite in the E resulted in a westerly plunge of the area. This was followed by N–S compression accompanying the intrusion of the granite in the S. As a result the area is characterized by a strong east–westerly schistosity and isoclinal folding with axes plunging about 30° to the W.

The metamorphic grade of the area corresponds to greenschist facies. However, where approaching the Revsund granite the grade increases as reflected by the presence of biotite, cordierite, andalusite and garnet.

The volcanic sequence has been divided into a number of stratigraphic units (Fig. 32). Most of the volcanic terrain consists of rhyolitic volcanics intruded by a felsic porphyry, referred to as the Viterliden porphyry. Restricted to elongated belts stratigraphically above the rhyolite unit a variety of volcanic and sedimentary rocks occur which are included in the Kimheden formation.

Fig. 33 is a simplified model summarizing the volcanic stratigraphy in the Kristineberg area.

The rhyolite unit consists of rhyolite tuff and massive rhyolite. The tuffaceous rocks are greyish and fine-grained, commonly with albite phenocrysts 1–2 mm in size. The exposed part of the tuff sequence is about 500 m thick. This is certainly a minimum, however, since the base of the unit is unknown.

The massive rhyolite occurs as geometrically restricted bodies interpreted as intrusive domes which in some places probably extend into extrusive flows. The rocks are greyish pink and dense with sporadically occurring quartz and albite phenocrysts.

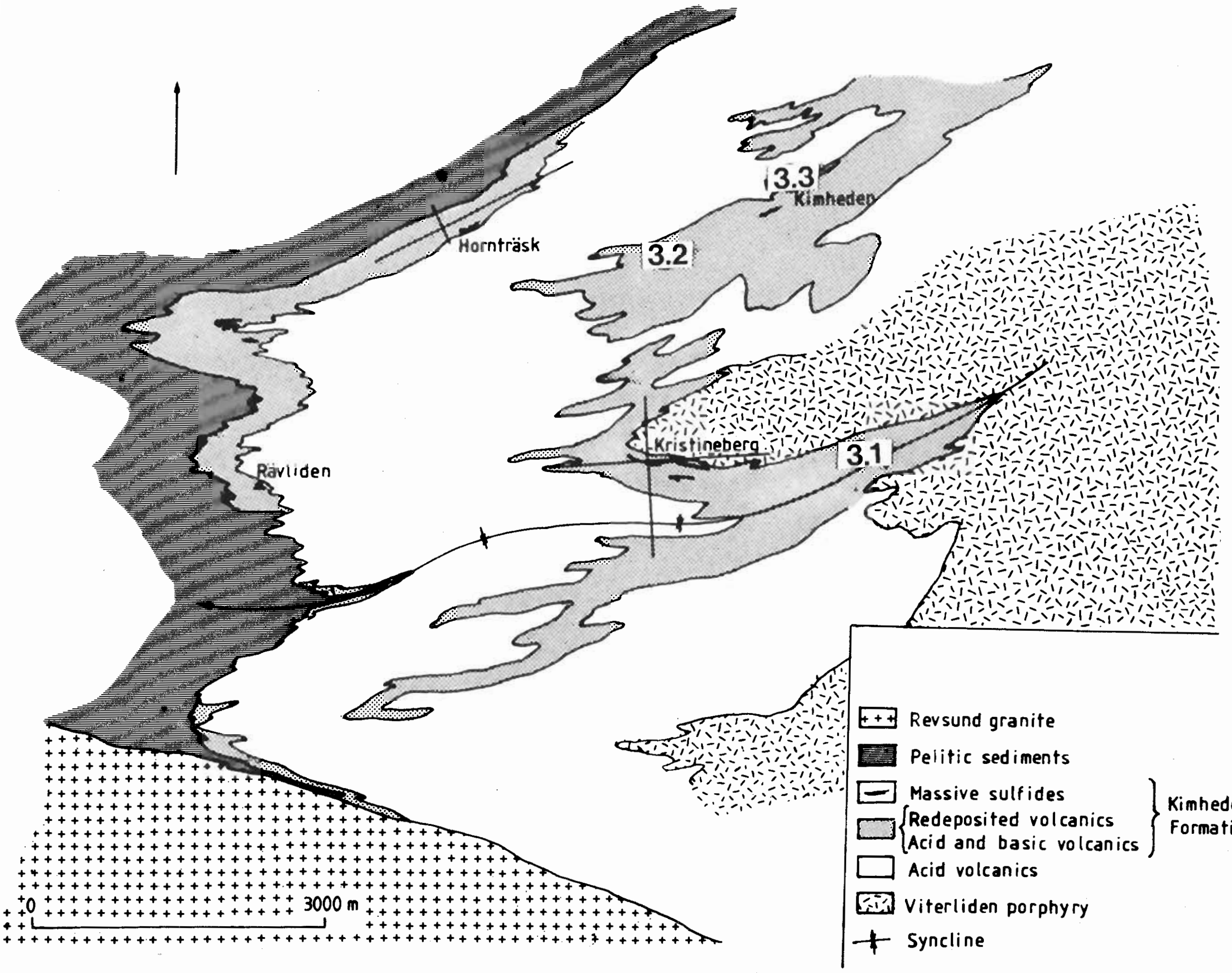


Fig. 32. Geology of the Kristineberg area, showing day 7 tour stops and main locations.

The felsic porphyry in the E is granitic to quartzdioritic in composition. The grain size is 1–3 mm and granophyric textures are common.

The Kimheden formation is trough-shaped and transitional into the rhyolite unit. Lithologically it consists of coarse rhyolitic pyroclastics, basaltic/andesitic tuff and dikes, redeposited volcanics such as arenaceous debris flows, bedded tuffites, slumped breccias and argillaceous sediments. Moreover, massive sulphides occur in the unit accompanied by chlorite and carbonate rocks. Two belts with rocks belonging to the Kimheden formation have been identified, namely one in the centre of the area and one in the easternmost part. Although appearing in a folded manner, the general strike of the belts is NE–SW (Fig. 32).

The rhyolite unit probably represents an environment characterized by subsidence and continuous tuff deposition, interrupted by periods of local lava dome intrusions and uplift. The Viterliden porphyry is considered to be a subvolcanic intrusion. No major eruptive centre seems to have developed in the area during the formation of the rhyolite unit.

The presence of the Kimheden formation has been taken as denoting a period of tension in the area, resulting in the formation of trough-shaped and elongated basins. This is indicated by the restricted distribution of the unit, the bimodal character of the volcanism and the type of sediments included, reflecting a pronounced negative topography. Among the two basins identified, the central one seems to have subsided to a deeper level compared to the easternmost one, judging by the thickness of the layers included. The present shape of the basins resulted from later tectonic processes caused by the intrusion of the Revsund granite.

The ore deposits are stratiform massive sulphides with mostly well-defined metal zoning and alteration zones. However, the size of the deposits as well as their metal ratios vary. The largest ore body is the Kristineberg deposit which originally contained about 20 million metric tons of ore.

The bedrock surrounding the ore deposits has been affected by various types of hydrothermal alteration. Sericite alteration is ubiquitous. Below the stratiform deposits there is commonly a silicified zone.

The silicified zone may be brecciated and cemented by

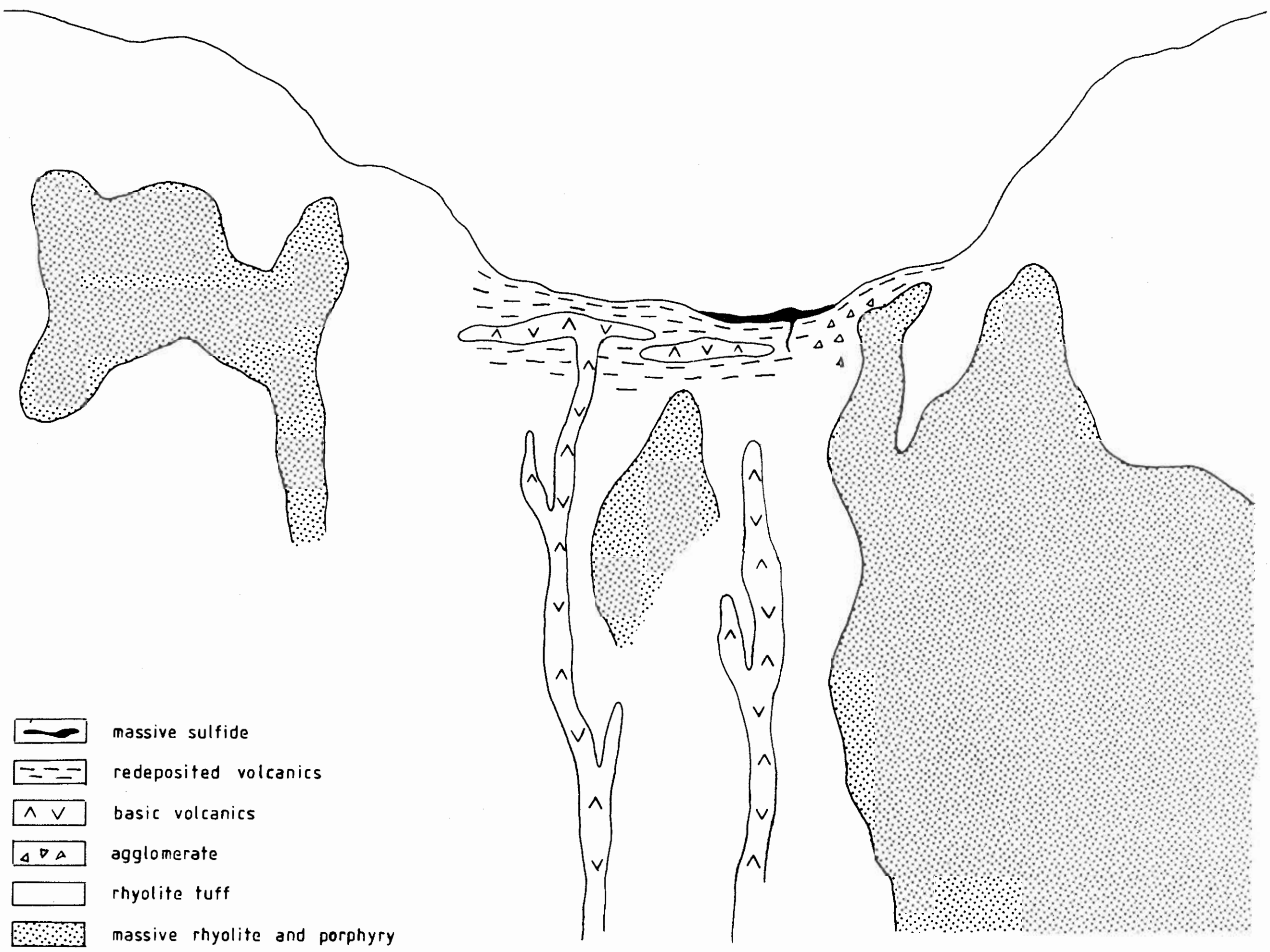


Fig. 33. Palaeographic model of the Kristineberg area.

chlorite, $CuFeS_2$ and FeS. The amount of chlorite normally increases upwards, where grading into stratiform layers of strongly chloritized rocks with sulphide dissemination occur. The chlorite is high in magnesium. Talc-rich portions may occur, especially in the uppermost parts of the ore deposits.

In some places, particularly in the Rävliden deposits in the east, carbonate constitutes a conspicuous component in the ore-bearing zone. The carbonate, which either overlies or occupies a laterally distal position relative to the chlorite rocks, consists of limestone and dolomite.

The ore bodies may display various primary structures such as bedding. Characteristically, however, the ore bodies have been affected by severe deformation, resulting in folding, shearing and mylonitization.

In summarizing the ore genesis in the Kristineberg area we may conclude that the ore deposition took place at the waning stage of the volcanic activity during a period characterized by tension. The ore bodies are restricted entirely to tectonic basins. Faulting related to the formation of the basins probably triggered the hydrothermal activity. Likewise, when formed, the basins constituted suitable environments for ore deposition. It is believed that the presence of subvolcanic intrusions, such as for instance the Viterliden porphyry, strongly influenced the heat flow necessary to generate the hydrothermal systems.

THE KRISTINEBERG MINE

The Kristineberg ore deposit is located on the northern flank of a major E–W trending syncline, plunging about 30° to the W (Fig. 32). The ore consists of massive pyrite with varying amounts of sphalerite and chalcopyrite as major components. The present ore reserves are about 8.9 million metric tons of ore grading 1.2 % Cu, 5.2 % Zn, 0.4 % Pb, 25.2 % S, 1.4 ppm Au and 53 ppm Ag. The arsenic, antimony and bismuth contents are low.

The local mine geology consists of rhyolites with minor andesitic inliers, intruded by a fine-grained porphyry belonging to the Viterliden subvolcanic intrusion (Fig. 34). Most of the volcanics are probably tuffaceous. Much of the primary rock texture is, however, obliterated due to the sericite alteration and the schistosity.

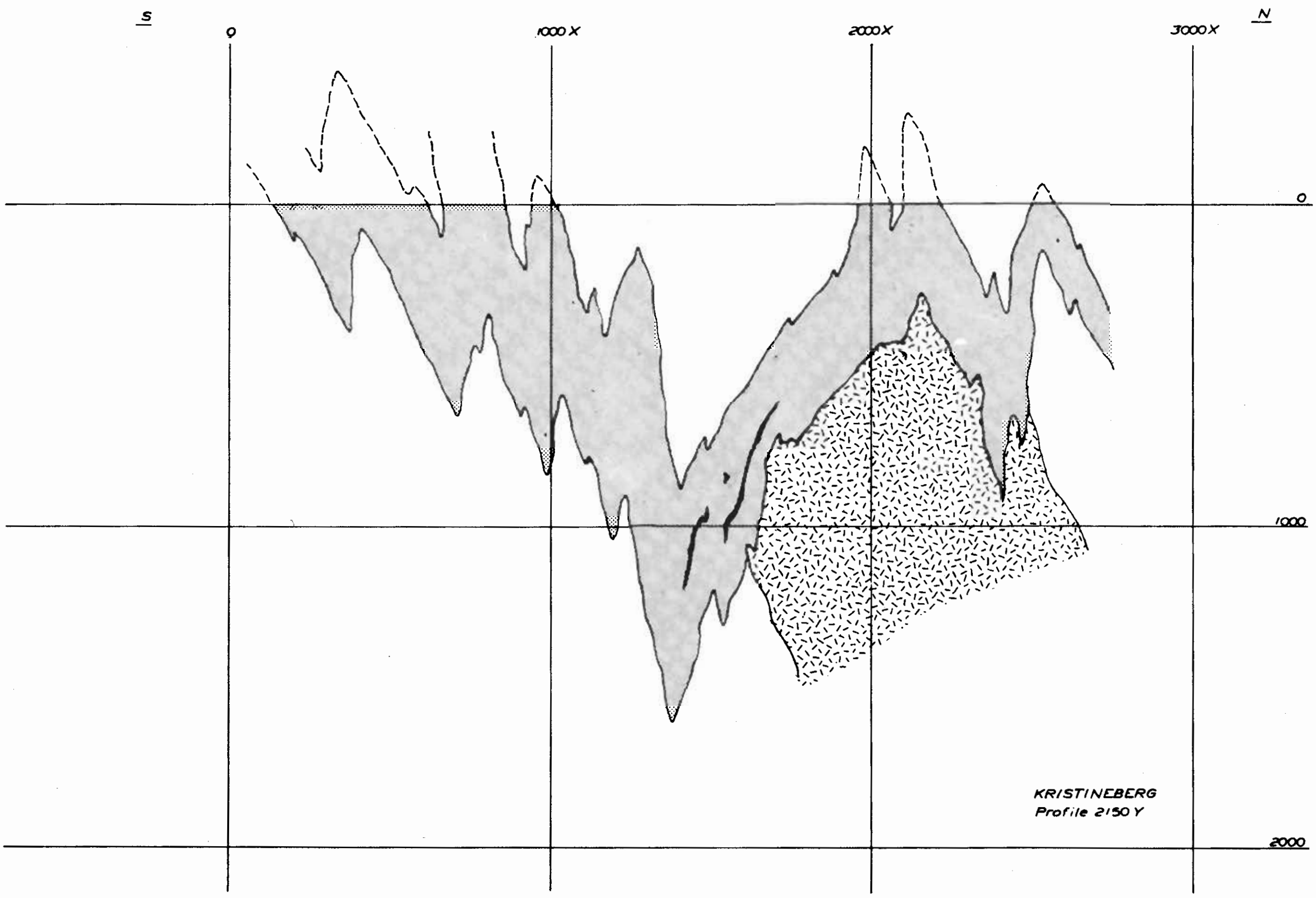


Fig. 34. Section through the Kristineberg ore, showing relationship with the Viterliden porphyry. Legend as in Fig. 32.

Most of the sulphide ore occurs as an extensive sheet comformable to the stratigraphy. Stringer type pyrite/chalcopyrite ore is weakly developed and restricted to a few places. The sulphides are accompanied by chlorite schist. Pyrite and chalcopyrite dominate on the footwall side of the deposit. In the central part of the deposit the amount of sphalerite increases towards the hanging wall. The sphalerite is normally greyish brown. However, a light-yellow sphalerite has been noted accompanied by galena.

The ore-bearing horizon is elongated and plunges about 45° to the SW, thus it occupies a discordant orientation relative to the more gently plunging synclinal axes of about 30° to the W. It is believed that the ore horizon originally was formed in a NE–SW trending basinal structure (cf. p. 47). During the folding this structure was up-turned and forced to gradually adopt to the general trend of the syncline. This is also indicated by the presence of numerous folds and shear zones parallelling the synclinal axes and obliquely transecting the plunge of the ore horizon. Below the 700 m level in the mine, where approaching the bottom of the syncline, the plunge of the ore horizon gradually levels out and the ore is split up into two major lenses.

This tectonic situation has strongly influenced the present shape and framework of the ore. Due to folding and shearing the thickness of the ore may vary from a few metres up to about 25 m. In some parts of the deposit, disruptions due to folding of the ore horizon have resulted in the formation of separate ore lenses.

Scattered quartz/quartz-tourmaline veins cut all the rock units in the mine. Although frequently appearing in an irregular manner, the quartz seems to fill shear-zones formed during the latest deformation of the bedrock, being thus probably contemporaneous with the Revsund granite in the area.

THE HORNTRÄSK MINE

The Hornträsk ore deposit is located on the northern flank of a major anticlinal structure plunging gently to the W. The mining of the deposit is a small-scale operation that started in 1981. At that time the ore reserve amounted to about 0.4 Mt tons grading 0.6 g/t Au, 113 g/t Ag, 0.9 % Cu, 7.4 % Zn, 1.0 % Pb and 12.7 % S. In spite of continuous mining, these figures are still valid because of successful prospecting activities.

The local mine geology consists of tuffaceous rhyolites with andesitic intercalations, overlain by a calcareous horizon carrying the ore. This is followed by 2–300 m of mainly

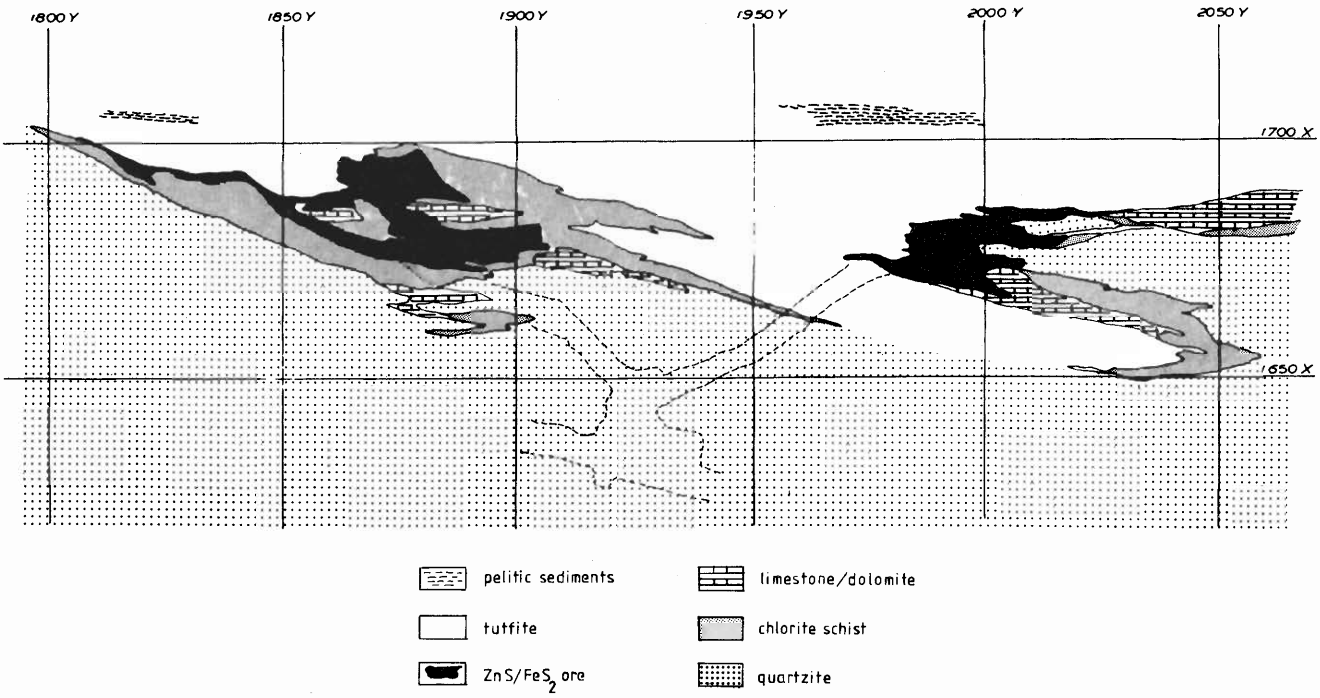


Fig. 35. Geology of the Hornträsk deposit at the 100 m level.

tuffitic layers with argillaceous inliers, reflecting the transition into a wide-spread sedimentary environment.

The ore deposit consists of two separate lenses plunging about 30° to the W (Fig. 35). Three types of ore are present, namely 1) stringer ore with chalcopyrite, 2) pyrite ore with chalcopyrite and chlorite, 3) massive sphalerite ore in limestone, dolomite and tremolite-skarn. Due to tectonic deformations, the different ore types frequently occur intermingled.

STOP DESCRIPTIONS

Stop 1. – The Kristineberg mine.
The stops 1.1, 1.2 and 1.3 demonstrate a section on the footwall side of the Kristineberg ore body at the 490 m level (Fig. 36). Stop 1.4 is a section across the A-ore at approximately the 520 m level.

1.1– Fine-grained granite porphyry representing the marginal part of a subvolcanic intrusion (the Viterliden porphyry) that occupies the central part of the Kristineberg area. Scattered inclusions of basic metavolcanics may occur. The porphyry is cut locally by aplite dikes and quartz tourmaline veins.

1.2 – The same as stop 1.1. Numerous inclusions of basic metavolcanics.

1.3 – Contact between the Viterliden porphyry and volcanic rocks. A basic volcanic rock occurs at the contact with the porphyry. The contact zone is magnetic with magnetite occurring mainly in the porphyry. The volcanic rocks as well as the outermost part of the porphyry are hydrothermally altered.

1.4 – Section across the A-ore (Fig. 37). The sections starts with acid volcanics showing strong sericite alteration. Stratigraphically upwards follows a sequence with pyrite ore alternating with chlorite schist. The main part of the section consists of pyrite ore with varying amounts of sphalerite and chalcopyrite. Sporadic lenses with ZnS/PbS ore may occur associated with talc-schist. Small dolomite fragments have been observed locally. The ore body is overlain by sericitic rocks, probably representing reworked tuffaceous material.

Stop 2. – The Hornträsk mine
2.1 – *Mine entrance* (Fig. 38). Stratigraphic section through the ore zone. Thin PbS/ZnS lenses occur in a folded sequence consisting of limestone and chlorite schist. The footwall is represented by felsitic acid volcanics. The formation of the ore-bearing sequence was followed by the deposition of reworked tuffaceous material (tuffite) with pelitic inliers.

2.2 – *Mine visit.* The various ore types will be demonstrated as well as their relationship to the carbonate, skarn and chlorite components accompanying the ore.

Stop 3. – The Kristineberg area
3.1 – *Viterliden.* Diffusely banded tuffaceous rocks, mainly acid in composition and belonging to the Kimheden Formation. The rocks are somewhat chloritic and characterized by a strong schistosity. The outcrop is located on the north-eastern fringe of the Kristineberg syncline. The sequence exposed is a lateral equivalent to the ore sequence in the Kristineberg mine.

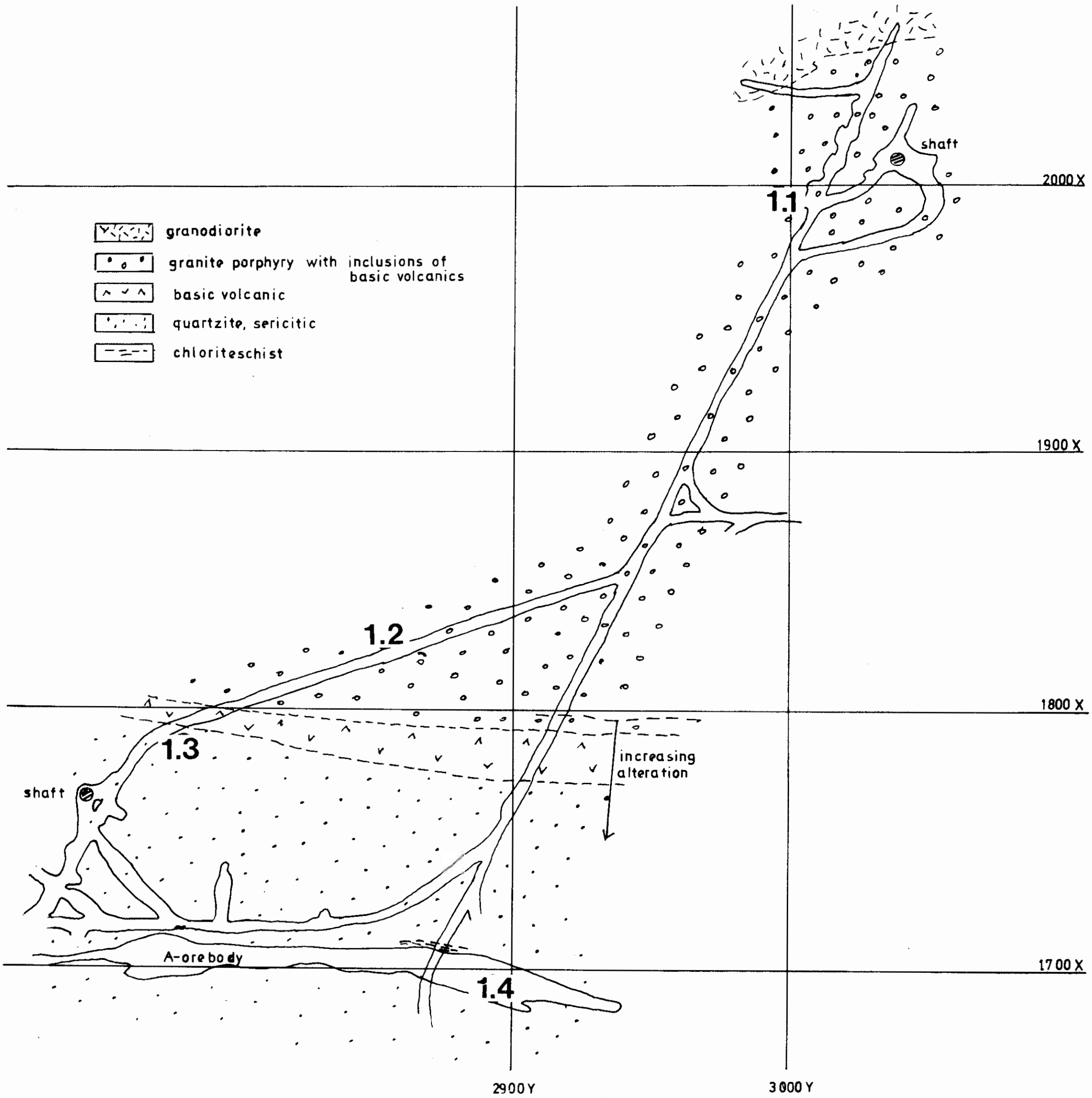


Fig. 36. Geology and tour stops in the Kristineberg mine at 490 m level.

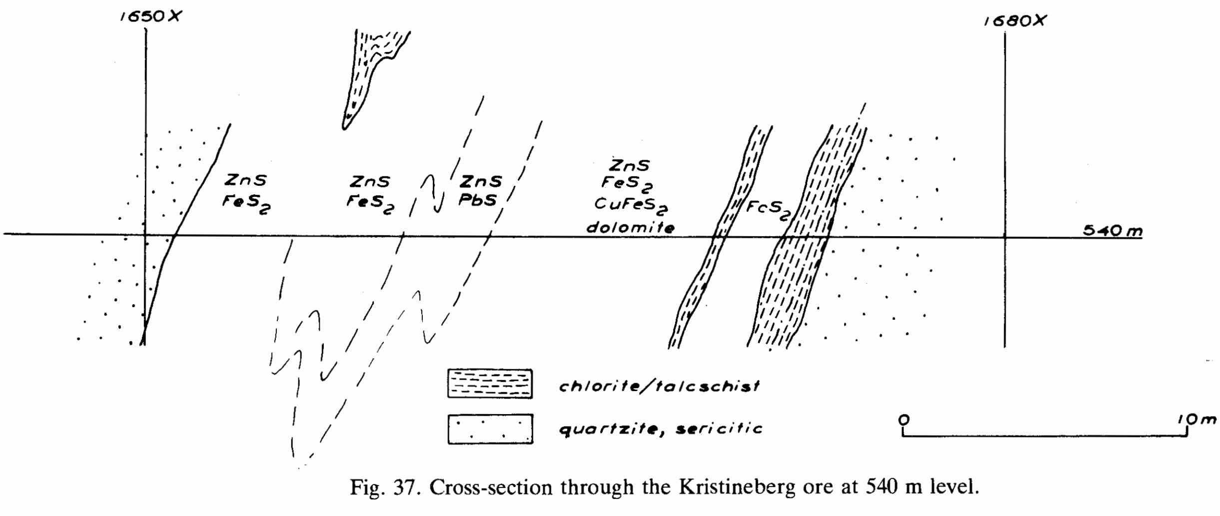


Fig. 37. Cross-section through the Kristineberg ore at 540 m level.

3.2 – *SW of Kimheden* (Fig. 39). Kimheden Formation represented by a banded tuffaceous lithology. The banded structure consists of acid felsitic layers alternating with arenaceous layers. In addition to quartz and feldspar, the latter may contain a chloritic component. To the S and SE of the present locality scattered inliers of basic tuff occur, indicating the transition into a lithology of dominating basic volcanics.

3.3 – *Kimheden open pit* (Fig. 39). Pyrite ore in chlorite schist. The mineralization consists of a number of tectonically displaced almost vertical lenses that gradually pinch out at approximately the 200 m level. The ore zone is developed in a sequence of strongly sericitic and partly banded acid tuff with inliers of basic tuff (see stop 2). Stratigraphically the Kimheden deposit is correlated with the Kristineberg ore body.

The Kimheden mineralization was indicated geophysically in 1944. Underground investigations took place in the middle of the 1960's. The ore reserve has been estimated at about 1 Mt grading 0.4 g/t Au, 6 g/t Ag, 1.1 % Cu, 0.08 % Zn and 19.6 % S. A minor open pit mining operation was carried out in the middle of the 1970's. Because of the low grade no further mining is planned.

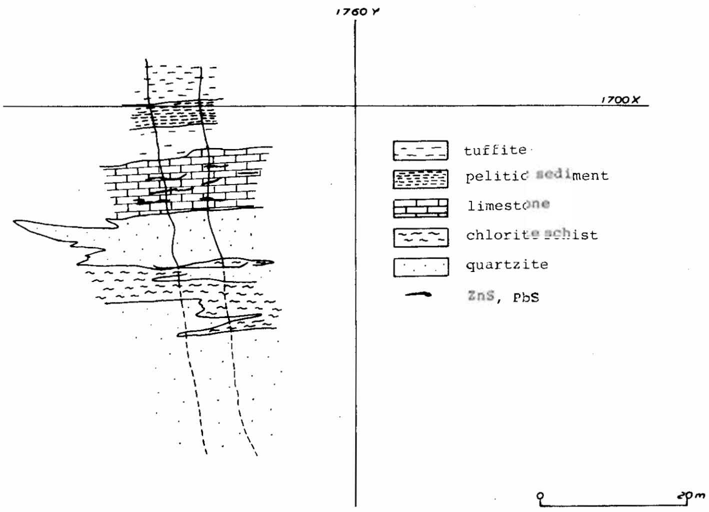


Fig. 38. Geology of the Hornträsk mine entrance.

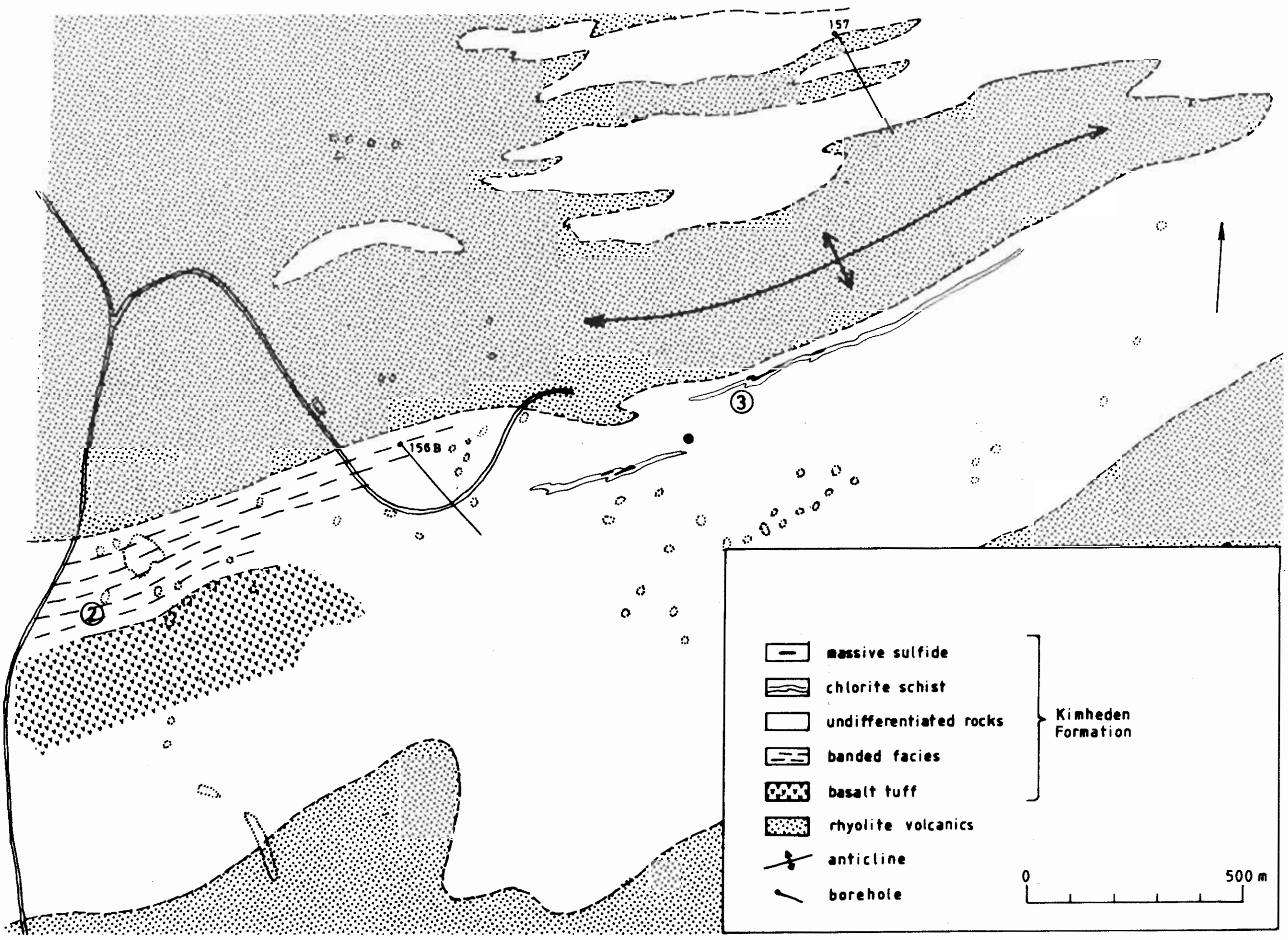


Fig. 39. Geology of the Kimheden area.

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REFERENCES

GFF = Geologiska föreningens i Stockholm förhandlingar
SGU = Sveriges geologiska undersökning

Cathles, L.M., Guber, A.L., Lenagh, T.C. & Dudas, F.D., 1983: Kuroko-type massive sulfide deposits of Japan: products of an aborted island arc rift. *In* H. Ohmoto and B. Skinner (eds): The Kuroko and related Massive Sulfide Deposits. – Econ. Geol. Mono. 5: 96–114.

Chappell, B.W. & White, A.J.R., 1974: Two contrasting granite types. – Pacific Geology 8:173–174.

Claesson, L. Å., 1982: Stratigraphy and petrochemistry of the ore-bearing Skellefte Group volcanites. – GFF 104: 378–379.

– 1985: The geochemistry of Early Proterozoic metavolcanic rocks hosting massive sulphide deposits in the Skellefte district, northern Sweden. – J. Geol. Soc. London 142:899–909.

Claesson, L.Å., Wilson, M.R., Lundberg, B., Sehlstedt, S., Nisca, D., Smellie, J.A.T., Aftalion, M., Hamilton, P.J. & Fallick, A.E., (in press): Jörn: an early Svecokarelian granitoid complex from northern Sweden. – Prec. Res.

Dumas, H., 1985: Sedimentary lithofacies of the central part of the Skellefte field. – Unpublished report. University of Luleå.

Du Rietz, T., 1953: Geology and ores of the Kristineberg deposit, Västerbotten, Sweden. – SCU C 524.

Eklund, J., 1923: Skelleftefältets geologi. – GFF 45:219–223.

Eriksson, L & Henkel, H., 1981: Fundamental deep structures in the Precambrian bedrock of Scandinavia; a preliminary discussion based on magnetic and gravity maps. – GFF 103:178–186.

Gaál, G., Koistinen, T. & Mattila, E., 1975: Tectonics and stratigraphy of the vicinity of Outokumpu, North Karelia, Finland. – Bull. Geol. Sur. Finland 271:1–67.

Gavelin, S., 1939: Geology and ores of the Malånäs District, Västerbotten, Sweden. – SGU C 524.

– 1955a: Sulfide mineralization in the Skellefte District, Sweden and its relationship to regional granitization. – Econ. Geol. 50:814–831.

– 1955b: Beskrivning till bergartskarta över Västerbottens län. – SGU Ca 37.

Gavelin, S. & Grip, E., 1946: Skellefte och Arvidsjaur fälten. – GFF 68:152–170.

Grip, E., 1935: Die Arvidsjaurporphyre. – Bull. Geol. Inst. Uppsala 25:135–229.

– 1951: Geology of the sulphide deposits at Mensträsk and a comparison with other deposits in the Skellefte District. – SGU C 515.

– 1973: Skelleftefältets sulfidmalmer. *In* E. Grip and R. Frietsch, (eds.): Malm i Sverige, vol. 2, pp. 194–273. – Almquist and Wiksell, Stockholm.

– 1980: Sweden. *In* S.W. Bowie, A. Kvalheim, H.W. Haslam (eds.): Mineral Deposits of Europe. Vol. 1. Northwest Europe, pp. 93–198. – Institution of Mining and Metallurgy, London.

Grip, E. & Wirstam, Å., 1970: The Boliden sulfide deposit. – SGU C 651.

Helfrich, H.K., 1971: Stratigraphische, tektonische, petrochemische und montangeologische Zuge am Nordrand der zentralen "Norrlandsgeosynklinale". – SGU C 654.

Hermelin, S.G., 1804: Mineralhistoria öfver Lappmarken och Westerbotten. Stockholm.

Hietanen, A., 1975: Generation of potassium-poor magmas in the northern Sierra Nevada and the Svecofennian of Finland. – J.Res. US Geol. Surv. 3:631–645.

Hodgson, C.J. & Lydon, J.W., 1977: Geological setting of volcanogenic massive sulfide deposits and active hydrothermal systems. Some implications for exploration. – Can. Inst. Min. Met. Bull. 70:95–106.

Högbom, A.G., 1899: Skelleftefältets geologi och bergarter. – GFF 21.

Högbom, A., 1935: Skelleftefältet. – SGU C 389.

Karig, D.E., 1972: Remnant Arcs. – Geol. Soc. America Bull. 83:1057–1068.

– 1974: Evolution of arc systems in the western Pacific. – Earth Planet Sci. Ann. Rev. 2:51–75.

Kautsky, G., 1957: Ein Beitrag zur Stratigraphie und dem Bau des Skellefte-feldes Nordschweden. – SGU C 543.

Lundberg, B., 1983: Aspects of the geology of the Skellefte Field, northern Sweden. – GFF 102:156–166.

Lundegårdh, P.H., 1973: Svecofenno-karelian of Central and Southern Sweden. *In* E. Zachrisson (ed.): The Precambrian of Sweden, its Platform Cover and Platform magmatism. International Tectonic Map of Europe. Chapter III-2: The Baltic Shield.

MacGeehan, P.J. & Maclean, W.H., 1980: An Archean subseafloor geothermal system, "calc-alkali" trends and massive sulphide genesis. – Nature 286:767–771.

Munha, J., 1979: Blue amphiboles, metamorphic regime and plate tectonic modelling in the Iberian pyrite belt. – Contr. Min. Pet. 69:279–289.

Nilsson, C.A., 1968: Wallrock alteration at the Boliden deposit, Sweden. – Econ. Geol. 63:472–494.

– 1985: Nickel-copper deposits in Sweden. – Geol. Surv. Finland Bull. 333:316–362.

Nyström, J.O., 1982: Post-svecokarelian Andinotype evolution in Central Sweden. – Geol. Rundsch. 71:141–157.

Ödman, O., 1941: Geology and ores of the Boliden deposit, Sweden. – SGU C 438.

– 1957: Beskrivning till bergartskarta över Norrbottens län. – SGU Ca 41.

Ohmoto, H., 1983: The geological setting of Kuroko deposits. *In* H. Ohmoto and B. Skinner (eds.): The Kuroko and related Massive Sulfide Deposits. – Econ. Geol. Mono 5:9–24.

Ohmoto, H. & Takahashi, T., 1983: Submarine calderas and Kuroko genesis. *In* H. Ohmoto and B. Skinner (eds.): The Kuroko and related Volcanogenic Massive Sulfide Deposits. – Econ. Geol. Mono 5:39–54.

Park, A.F., 1985: Accretion tectonism in the Proterozoic svecokarelides of the Baltic Shield. – Geology 13:725–729.

Pharaoh, T. & Pearce, J.A., 1984: Geochemical evidence for the geotectonic setting of early Proterozoic metavolcanic sequences in Lapland. – Precambrian Res. 25:283–308.

Quensel, P., 1956: The paragenesis of the Varuträsk pegmatite including a review of its mineral assemblage. – Arkiv f. min. geol. Bd2:2.

–1960: The Varuträsk pegmatite. *In* E. Grip, P. Quensel, P. Geijer and S. Ljunggren: Sulphide and iron ores of Västerbotten and Lappland, northern Sweden. Guide to excursions A27 and C22. International geological congress, Norden 1960. Geological Survey of Sweden.

Rankama, K. & Welin, E., 1972: Joint meeting of the Precambrian stratigraphy group of Denmark, Finland, Norway and Sweden in Turku, Finland, March 1972. – Geological Newsletter 1972 4: 19–30.

Rickard, D.T., 1978: The Svecofennian anomalous ore lead line. – GFF 100:19–29.

– 1979: Scandinavian Metallogenesis. – Geojournal 3:235–252.

– 1985: The first Wilson cycle. – Unpublished lecture of Geological Society of Belgium, Liege 1985.

Rickard, D.T. & Svensson, S.Å., 1984: Ore lead isotope variations in the Proterozoic massive pyrite deposit at Näsliden, Skellefte District, Sweden. – Mineral. Deposita 19:145–151.

Rickard, D.T. & Zweifel, H., 1975: Genesis of Precambrian sulphide ores, Skellefte district, Sweden. – Econ. Geol. 70:255–274.

RICKARD, D.T., ZWEIFEL, H. & DONNELLY, T.H., 1979: Sulfur isotope systematics in the Åsen pyrite-barite deposits, Skellefte District, Sweden. – Econ. Geol. 74:1060–1068.
SCHEIBNER, E. & MARKHAM, N.L., 1976: Tectonic setting of some stratabound massive sulfide deposits in New South Wales. *In* K.H. Wolf (ed.): Handbook of Stratabound and Stratiform ore deposits. – Elsevier. 6:56–77.
SUNDBERG, K., LUNDBERG, H. & EKLUND, J., 1923: Electrical Prospecting in Sweden. – SGU C 327.
SVENSSON, S.Å., 1983: Näsliden. A volcanogenic massive sulphide deposit in the Skellefte District, northern Sweden. – SGU C 790.
UYEDA, S. & NISHIWAKI, C., 1980: Stress field, metallogenesis and mode of subduction. – Geol. Soc. Canada Spec. Paper 20: 323–339.
VIVALLO, W. & RICKARD, D.T., 1985: Early Proterozoic ensialic spreading subsidence in the Garpenberg Enclave, central Sweden. – Prec. Res. 26:203–221.
WELIN, E., 1979: Tabulation of recalculated radiometric ages published 1960–1979 from rocks and minerals in Sweden. – GFF 101:309–320.
WELIN, E., CHRISTIANSSON, K. & NILSSON, O., 1971: Rb-Sr radiometric ages of extrusive and intrusive rocks in northern Sweden. – SGU C 666.
WIDENFALK, L., 1979: Mercury as an indicator of stratigraphy and metamorphism in the Skellefte Ore district. – Econ. Geol. 74:1307–1314.
WILSON, M.R., 1980: Granite types in Sweden. – GFF 102:167–176.
– 1982: Magma types and the tectonic evolution of the Swedish Proterozoic. – Geol. Rundsch. 71:120–129.
WILSON, M., HAMILTON, P.J., FALLICK, A.E., AFTALION, M. & MICHARD, A., 1985: Granites and Early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics. – Earth Planet. Sci. lett. 72:376–388.
WILSON, M.R., CLAESSON, L.Å., SEHLSTEDT, S., SMELLIE, J.A.T., AFTALION, M., HAMILTON, P.J. FALLIC, A.E., (in press): Jörn: an early Svecokarelian granitoid complex from northern Sweden. – Prec. Res.
WITSCHARD, F., 1984: The geological and tectonic evolution of the Precambrian of northern Sweden – a case for basement activation. – Prec. Res. 23:273–315.
ZWEIFEL, H., 1982: Ore deposits in the Skellefte Field – volcanic activity and depositional environment. – GFF 104:369.