Ba 57

Description of regional geological and geophysical maps of the Skellefte District and surrounding areas

Editors: Benno Kathol & Pär Weihed



SGU
Sveriges geologiska undersökning
Geological Survey of Sweden

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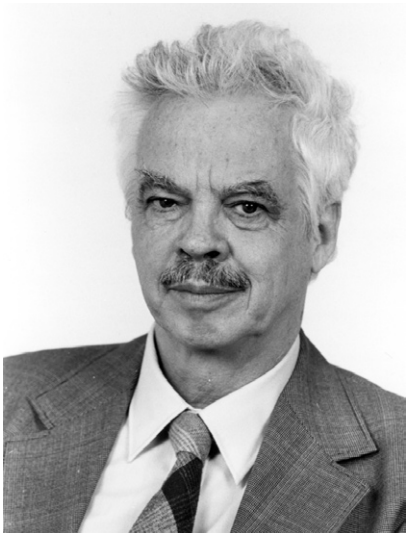
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Jeanette Bergman Weihed, Ulf Bergström, Kjell Billström, Leif Björk,
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Lars Kristian Stølen, Johan Söderman, Carl-Axel Triumf,
Anders Wikström, Torbjörn Wikström & Hans Årebäck

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Dedication

Gunnar Kautsky
1921–2002



This publication is dedicated to the late professor Gunnar Kautsky. For many decades Gunnar led and inspired generations of geologists at the Geological Survey of Sweden. His work in the Skellefte District roughly half a century ago and his publications on the stratigraphy paved the way for subsequent geological research in this area. Much of the current thinking on the evolution of the Skellefte District ows its merits from the work of Gunnar Kautsky.

Benno Kathol & Pär Weihed
editors

Cover: Boksel farm from the middle of the 19th century, about 27 km south-east of Arvidsjaur. Photo Benno Kathol.
Boksel gård från 1850-talet, ca 27 km sydost om Arvidsjaur.

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Abstract

The Precambrian bedrock of the Fennoscandian Shield in the northern Västerbotten and southern Norrbotten counties of northern Sweden is described with regard to rock types, stratigraphy, structure, metamorphism, mineralizations, geophysical properties, mining history, geochemistry, and geological evolution. A field excursion guide is included.

In view of the aim of this project, less importance has been attributed to the description of the Neoproterozoic to Early Palaeozoic autochthonous cover sequence and the allochthonous units of the Caledonian orogen. The description is accompanied by six printed maps: a bedrock map, a metamorphic, structural and isotope age map, a map of mineral and bedrock resources and hydrothermal alterations, a magnetic anomaly map, a Bouguer anomaly map, and one sheet containing a gamma radiation map, an electromagnetic map (VLF), a topographic relief map and Euler solutions on gravity data. All maps and databases are available at the Geological Survey of Sweden (SGU).

The Precambrian rocks in the map area, except the Mesoproterozoic dolerites and supracrustal rocks, were formed between c. 2.7 and 1.76 Ga ago. Archaean rocks are restricted to the north-easternmost part of the map area, where they form the basement of the Palaeoproterozoic Svecokarelian units. They consist mainly of c. 2.7 Ga old tonalitic to trondhjemitic gneisses, porphyritic metagranodiorites and subordinate metagabbros.

The Palaeoproterozoic Svecokarelian orogen comprises Svecofennian supracrustal rocks, early and late to post Svecokarelian intrusive rocks, including intrusive and supracrustal rocks of the Transscandinavian Igneous Belt (TIB). The Svecofennian supracrustal rocks are divided into the Bothnian Supergroup, consisting mainly of more or less gneissic or migmatized metagreywackes of the Bothnian Basin, and the Skellefte, Arvidsjaur and Vargfors Groups. The latter groups represent subaqueous (Skellefte Group) and subaerial (Arvidsjaur Group) volcanic arc environments and arc-derived, turbiditic to coarse clastic sedimentary sequences with intercalations of predominantly mafic volcanic rocks (Vargfors Group). Within the transition zone between the island arc and the Bothnian Basin, rocks of the Bothnian Supergroup interfinger with subaqueous volcanic rocks and sedimentary rocks of the Skellefte and Vargfors Groups. Upwards and laterally to the north, the Skellefte Group rocks pass into mainly subaerial volcanic sequences of the Arvidsjaur Group. The Vargfors Group is the marine, sequence-stratigraphical equivalent of the Arvidsjaur Group and is deposited on rocks of the Skellefte and Bothnian Groups or the lower parts of the Arvidsjaur Group.

During the Svecokarelian orogeny these supracrustal sequences have been intruded by several generations and at several levels by early Svecokarelian, c. 1.96 to 1.86 Ga old intrusive rocks. These are divided into calc-alkaline metagranitoids with associated mafic rocks and into more alkaline metaintrusive rocks such as granites, syenites, monzonites, and subordinate gabbros, here included in the Perthite monzonite suite. The calc-alkaline assemblages comprise the Knaften massif (c. 1950 Ma), 1920 to 1900 Ma metagranitoids (Björkdal, 7211490/1728060, Blåviksjön, 7192780/1606930, and Kristineberg, 7220490/1630480) and the 1900 to 1860 Ma metagranitoids and associated mafic rocks of the Jörn GI suite. The rocks of the Perthite monzonite suite of the map area range in age from 1.88 to 1.86 Ga.

In a later stage of the Svecokarelian orogeny, the early Svecokarelian intrusive assemblages – and especially the Svecofennian supracrustal units – were affected by partial melting and formation of migmatite granites prograding into intrusion of late to post Svecokarelian granites of the Skellefte-Härnö suite. During the latest phase of the orogeny, large volumes of mainly acidic melts intruded the consolidated early to late Svecokarelian crust and formed the Revsund, Sorsele, Adak, Edefors and Ale suites of the Transscandinavian Igneous Belt (TIB). Related extrusive phases are preserved only in the Dobblon area (7275960/1557000) and are together with an underlying sedimentary sequence denoted as the Dobblon Group.

Mesoproterozoic dolerites occur as dykes and relatively voluminous sills mainly in the south-western part of the map area. Jotnian supracrustal rocks form parts of the bedrock beneath the Bothnian Bay, but are not shown on the maps.

In the western part of the map area, the Fennoscandian Shield is covered by an autochthonous sequence of Neoproterozoic to Early Palaeozoic sedimentary rocks (Dividal Group) and westerly derived, Caledonian nappes of the Lower, Middle, and Upper Allochthons.

Svecokarelian deformation and regional metamorphism affected the Svecofennian supracrustal rocks (Bothnian, Skellefte, Arvidsjaur, and Vargfors Groups) and the 1.96 to 1.86 Ga old early Svecokarelian intrusive rocks. In time, the deformational and metamorphic events of the Svecokarelian orogeny are bracketed by the age of the youngest, deformed supracrustal or calc-alkaline intrusive rocks on the one hand, and on the other hand, the oldest undeformed intrusions of the late to post Svecokarelian intrusive rocks of the Skel-

lefte-Härnö suite and the Transscandinavian Igneous Belt (TIB). For the map area, these rock assemblages define a time interval for Svecokarelian deformation and metamorphism between approximately 1850 and 1810 Ma.

However, older phases of deformation, before 1875–1860 Ma, have been suggested at least for the northern and north-eastern parts of the map area, and from the area south of Skellefteå, deformation structures and migmatization events from the time interval 1900–1890 Ma and a younger phase of deformation and veining around 1860 Ma are described.

Deformation and degree of metamorphism increase in general towards the south and east. Low metamorphic grade and well-preserved primary structures are found mainly in the north-central part of the map area, especially within the rocks of the Arvidsjaur, Vargfors, and Dobblon Groups. High-strain zones alternate with zones of little deformation, and the early Svecokarelian calc-alkaline metagranitoids are affected by deformation to a varying degree. Rocks of the Perthite monzonite suite normally lack penetrative deformation.

Two major phases of folding affected the rocks of the Skellefte District. The first phase of regional deformation resulted in upright, tight to isoclinal folds. These folds have north-east striking axial surfaces in the western and eastern parts of the Skellefte District, whereas folds with north-west striking axial surfaces dominate the central part of the district. An early foliation probably formed as an axial planar cleavage, which is related to the folds of the first deformation phase. Within the central Skellefte District, the early folds occur in lower-strain lenses, which are confined by north-west striking shear zones, whereas shearing along the north-east striking axial surfaces is less intense within the western and eastern parts of the district.

The pronounced east-northeast–west-southwest striking structural trend in the Nickel zone in the south-eastern part of the map area is caused by foliations, lithological boundaries, and shear zones that are subparallel.

The second major phase of folding produced open folds with steep north to north-east striking axial surfaces. The intensity of this second folding phase increases towards the south within the central Skellefte District. During and after the second folding phase and after peak metamorphism, north-striking shear zones with reverse dip-slip components formed in the Skellefte District and surrounding areas.

Large-scale tectonic events in the Mesoproterozoic are indicated by the intrusions of mafic, gently dipping sills and dykes of the Central Scandinavian Dolerite Group (CSDG) at c. 1.27 Ga. This tectonic event affected the south-western part of the map area; dolerites with the same magnetization have not been identified north of the Skellefte District.

The autochthonous cover sequence is almost undeformed. The Lower Allochthon is dominated by "thin skin tectonic" style thrusting with imbricate fans, duplex structures and out of sequence thrusts. It has undergone exclusively Middle to Late Silurian, Scandian phase deformation, whereas the Middle Allochthon and the Seve nappes of the Upper Allochthon show traces of Early Ordovician, Finnmarkian events. The Caledonian nappe pile shows inverted metamorphic grade from low-grade conditions within the Lower Allochthon to amphibolite grade conditions within the Seve nappes of the Upper Allochthon.

The Skellefte District has long been regarded as a massive sulphide ore district with mining of complex base metal ores. To date, about 20 different volcanogenic massive sulphide (VMS) deposits (of which some contain several ore bodies) have been, or are presently being mined. During recent decades, intensive gold exploration in the area has resulted in the mining of two gold lode deposits: Björkdal and Åkerberg. Apart from these gold discoveries, a new gold mine, Svartliden, was opened in 2004 in the so called "gold line" south of the Skellefte district. From the VMS mining and exploration, a total of over 160 million tonnes of pre-mining ore reserves with average contents of 1.9 g/t gold, 47 g/t silver, 0.7% copper, 3.0% zinc, 0.4% lead, 0.8% arsenic, and 25.6% sulphur have been outlined.

Beside the economic deposits of VMS and gold lode type, mining has been carried out on one nickel deposit in the north-western part of the district, Lainijaur, and on a lithium-bearing pegmatitic deposit, Varuträsk, in the eastern-most part.

Introduction

The Skellefte District and surrounding areas is one of Sweden's major ore-producing regions. This area of investigation is located in northern Västerbotten and southern Norrbotten counties, northern Sweden. It comprises crystalline bedrock of the Fennoscandian Shield, Neoproterozoic to Early Palaeozoic cover rocks and allochthonous units of the Caledonian orogen (Fig. 1). The area for "Regional geological and geophysical maps of the Skellefte District and surrounding areas" is confined by the Swedish grid coordinates 7125000/ 1500000, 7125000/1825000, 7300000/1825000 and 7300000/1500000 (Fig. 2).

The objective of this project was to compile bedrock information, mainly from the bedrock mapping results obtained by the Geological Survey of Sweden (SGU) in northern Västerbotten and southern Norrbotten counties (SGU series Ai). Within the mapping programme on a scale of 1:50,000, the bedrock (in different topographic map areas, see section Base data, Geology) was investigated with respect to rock types and their spatial distribution, composition, structure, and internal age relationships. Bedrock relationships in three dimensions are illustrated by geological profiles on the different map sheets. Primary geological information is stored in different databases on outcrops, lithogeochemistry, radiometric ages, mineral and bedrock resources, and petrophysical and geophysical properties. Here, information from these databases has been combined and in some cases complemented and updated. In order to correlate different geological units between different areas and to synthesize bedrock information, limited fieldwork, mostly in the form of excursions and workshops on different topics, has been carried out. Emphasis was placed on revision and synthesis of 1) the stratigraphy of and internal relationship between different supracrustal units, 2) division and subdivision of intrusive rocks, 3) mineral deposit information and classification, 4) the structural framework and metamorphic conditions, 5) geophysical information, and 6) the geological evolution of the Skellefte District and surrounding areas.

This report describes and gives additional information on the geological and geophysical features, which are presented on the different printed maps (Ba 57:1–6). These are 1) a bedrock map, 2) a metamorphic, structural and isotope age map, 3) a map of mineral and bedrock resources and hydrothermal alterations, 4) a magnetic anomaly map, 5) a Bouguer anomaly map (maps 1, 2, 4, and 5 on the scale 1:250,000), and 6) one sheet containing four 1:500,000 scale maps: gamma radiation map, electromagnetic map (VLF), topographic relief map and Euler solutions on gravity data. All maps and databases are available at SGU in both printed (maps) and digital (maps and databases) form. This description is a compilation of contributions by different authors, which inevitably results in some repetition.

Methods

GEOLOGICAL METHODS

The bedrock map of the Skellefte District and surrounding areas (Ba 57:1) is a compilation from bedrock maps on a scale of 1:50,000 over the different topographic map sheets of the project area, which have been produced by the bedrock mapping programme of the Geological Survey of Sweden (SGU) in northern Västerbotten and southern Norrbotten counties (SGU series Ai). The geological observations on outcrops comprise determination of rock types and their kind of occurrence, as well as description and measuring of structures and textures. The occurrence of inclusions and dykes has been noted. On most outcrops, measurements of the magnetic susceptibility of the different rock types have been carried out. In crucial cases, field observations have been complemented by thin sections, lithogeochemical analyses, and radiometric datings. Information about outcrop locations has been derived from older investigations and acquired by interpretation of aerial photographs. Additionally, new road cuts have been taken into account. The geological information has been correlated with geophysical data obtained by both airborne and ground measurements. The compilation of geological maps, in most cases with a brief geological description, is based on primary information and presented in the form of printed maps on a scale of 1:50,000 and as map databases.

Within this project, several excursions were undertaken in order to correlate areas mapped by different geologists. Another aim of these excursions was to synthesize stratigraphic information and to insert different stratigraphic units or formations into the stratigraphic scheme, presented below. Some areas or items of special interest have been examined by external geologists or working groups on behalf of SGU.

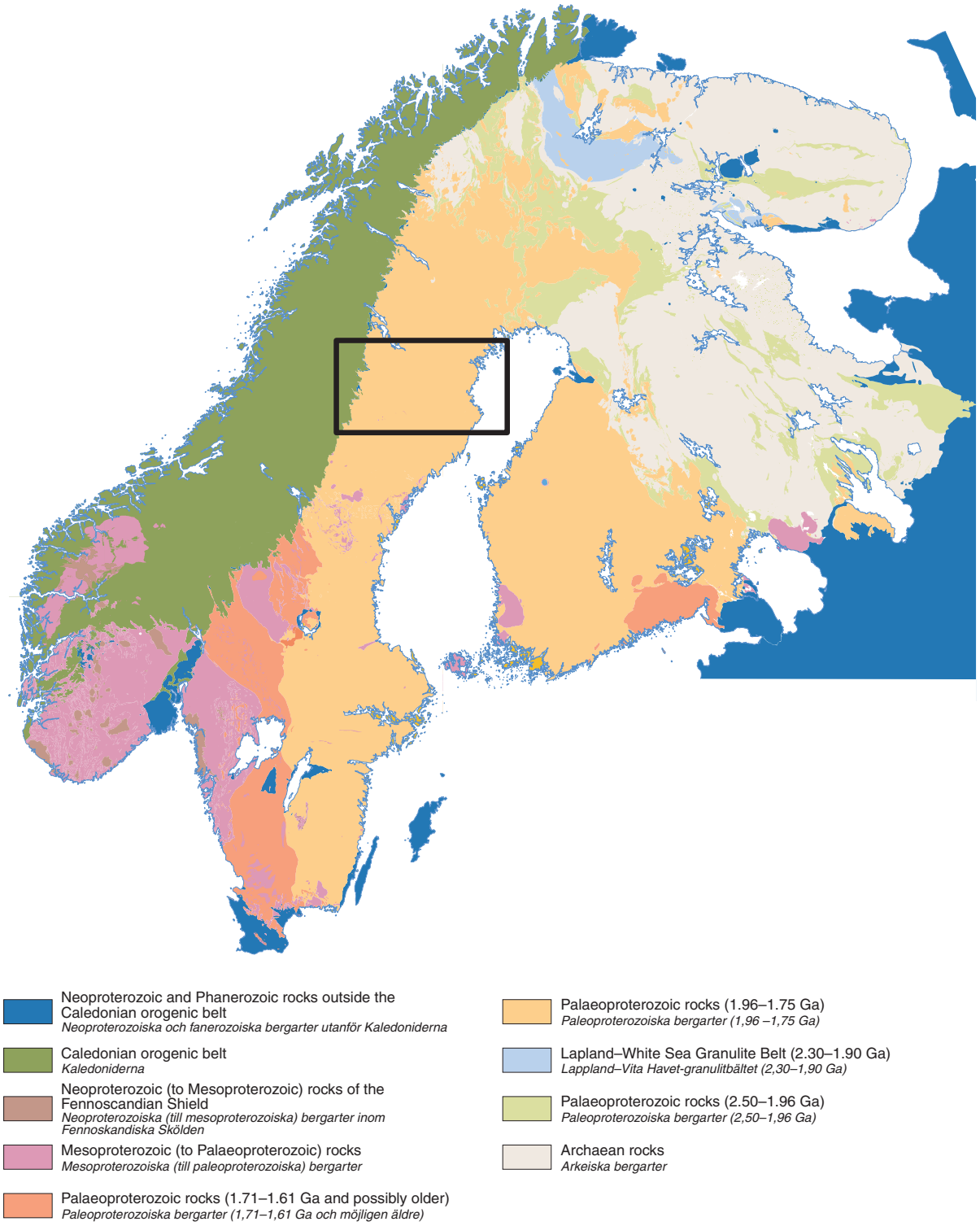


Fig. 1. Major geological units in the Fennoscandian Shield and surrounding areas. From "Geological map of the Fennoscandian Shield, scale 1:2,000,000" (Koistinen et al. 2001). The project area is marked by a rectangle.

Geologiska huvudenheter i den Fennoskandiska Skölden och omgivande områden. Från "Geological map of the Fennoscandian Shield, scale 1:2 000 000" (Koistinen m.fl. 2001). Projektområdet är markerat med en rektangel.

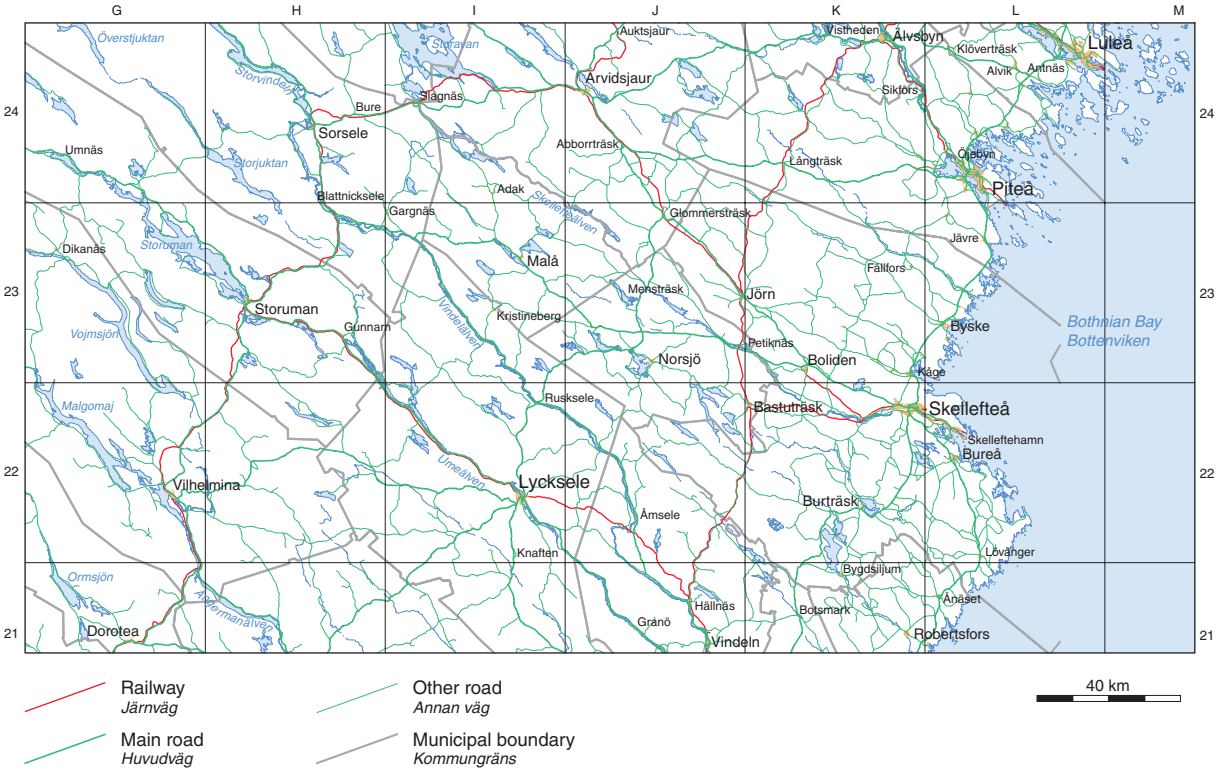


Fig. 2. General topographic map of the project area, showing the larger municipalities and roads.
Översiktlig topografisk karta över projektområdet. Kartan visar större samhällen och vägar i projektområdet.

In order to compile the bedrock map of the Skellefte District and surrounding areas (Ba 57:1), the 1:50,000 scale maps have been reduced by photographic or digital processes to the scale of 1:125,000 and digitized on a digitizing table. During the digitizing process the geological information has been accommodated for presentation on the final map scale. Elongated, less than c. 150 m wide bedrock areas, which represent important marker horizons, have been somewhat exaggerated during this process. Otherwise, they have been omitted, i.e. amalgamated with the surrounding or the most suitable adjacent bedrock area. Isolated bedrock areas, less than c. 0.5 mm^2 on final map scale, have been amalgamated with the surrounding bedrock.

Locality names not shown on the bedrock map (Ba 57:1) or on the metamorphic, structural and isotope age map (Ba 57:2) of the Skellefte District and surrounding areas, are annotated with coordinates, given in the Swedish National Grid RT90. The coordinates of mineral deposits and occurrences of bedrock resources, which are mentioned in this description, especially in chapters "Explanation to the map of mineral and bedrock resources and hydrothermal alterations" and "Ores and mineralizations", are given in Table 3 on page 77 and in the "Table of mineral deposits" on the "Map of mineral and bedrock resources and hydrothermal alterations" (Ba 57:3).

GEOPHYSICAL METHODS

Application of geophysical methods in metal exploration started more than three centuries ago in Sweden. Magnetic methods were in use as early as 1640. Development of electromagnetic methods around 1920 led to several discoveries in the Skellefte District, as most ore bodies are good electrical conductors. Fixed-wing airborne electromagnetic surveys were introduced as early as 1948 when successful flights in USA and Canada showed what was to come. These surveys were done with a system developed by the two companies Stanmac and McPhar. The Swedish company ABEM introduced the Rotary Field Two Plane System in 1955, while the Geological Survey of Sweden (SGU) began with airborne magnetic surveys in 1960. Fixed-wing airborne EM surveys started in the Skellefte District in the 1960s under the auspices of Boliden Mineral AB.

In 1967, airborne gamma ray spectrometry was introduced at SGU in connection with uranium prospecting. Regular airborne EM surveys by SGU were initiated in 1973 when it had successfully developed its own elec-

tromagnetic system called RAMA. SGU commenced systematic gravity measurements in the late 1950s in connection with the iron ore inventory in northern Sweden. Regional gravity surveys on a national scale were initiated in the mid-1960s, mainly to support bedrock mapping. At that time, Boliden Mineral AB had already made gravity surveys in the Skellefte District for nearly twenty years.

Airborne geophysical surveys, comprising magnetics, electromagnetics and gamma ray spectrometry, have provided geological mapping with important base data. The net of observations of gravity is rather dense in the Skellefte District, which implies that density changes in the rocks are effectively reflected. Interpretation of all the datasets provides the geometrical frame of lithology and tectonics later complemented by geological observations on outcrops. A model of brittle tectonics was constructed using elevation data from Lantmäteriet (the national Land Survey.

Since 1984, gamma ray spectrometry on outcrops has been used as a tool in the bedrock mapping programme at SGU. It effectively differentiates lithology once the individual variation patterns in content of K, U and Th have been established. It also aids the identification of any alteration.

Sampling of outcrops for the determination of petrophysical parameters, such as density and magnetic properties, was introduced at SGU in the 1970s. Pioneering work was done by SGU, where several important papers were published regarding petrophysical parameters in Swedish rocks. At that time the basis was laid for an ordered incorporation of geophysical information into geological mapping. More than a thousand rock samples are processed annually at the petrophysical laboratory of SGU, where measurements of density, magnetic properties and gamma ray spectrometry are carried out.

Geophysical fieldwork aims essentially at geological interpretation of geophysical data. Measurements of electromagnetic (VLF) or magnetic field variations along profiles, or in grids, are made by the field geophysicist whenever specific problems motivate it.

Image processing is routinely applied in the qualitative phase of the interpretation. Quantitative modelling of magnetic potential field, gravity and electromagnetic field-data is used chiefly to strengthen the qualitative interpretation.

In the interpretation work, even analogue and digital geo-data from earlier investigations were extensively employed. These data are found mainly in reports and publications, available at the Mineral Information Office at Malå.

Base data

GEOLOGY

The main sources of geological information have been bedrock maps (Ai series), prepared by the regular mapping programme of the Geological Survey of Sweden (SGU) in northern Västerbotten and southern Norrbotten counties between 1983 and 2000. The published maps are on a scale of 1:50,000 and are in most cases accompanied by brief geological descriptions, including geophysical interpretations. Maps or digital map databases, used for the compilation of the bedrock map of the Skellefte District and surrounding areas are: 21J Vindeln NV, NO (Nilsson & Kero 1986), 21I Fredrika NV, NO (Björk & Kero 1988), 22G Vilhelmina NV (Zachrisson & Greiling 1996), 22G Vilhelmina SV (Zachrisson 1996), 22G Vilhelmina NO (Greiling et al. 1996), 22I Kalvträsk (Weihed & Antal 1998), 22K Skellefteå (Nilsson & Kero 1998a), 22L Rönnskär NV, SV, SO (Nilsson & Kero 1998b), 23I Malå (Bergström & Sträng 1999b), 23G Dikanäs NV, SV (Greiling & Zachrisson 1999), 23G Dikanäs NO, SO (Greiling et al. 1999), 22G Vilhelmina SO (Björk et al. 2000), 21H Åsele NV, NO (Björk & Kero 2000), 23K Boliden (Lundström & Antal 2000), 24L Luleå (Wikström & Söderman 2000), 23H Stensele (Eliasson et al. 2001), 22H Järvsjö (Björk & Kero 2001), 24I Storavan (Bergström & Triumf 2002), 22I Lycksele (Björk & Kero 2002), 23J Norsjö (Bergström et al. 2003), 24H Sorsele (Eliasson et al. 2003), 24J Arvidsjaur (Kathol & Triumf 2004), 21K Robertsfors NV, NO (Thelander & Kero 2004a) and 21L Ånäset NV (Thelander & Kero 2004b).

During the bedrock mapping between 1983 and 2000, about 50,000 outcrops were investigated in the Skellefte District and surrounding areas, which corresponds to an outcrop density of just over one per square kilometre. Normally, the outcrop density is greater in areas below the highest coastline, i.e. in areas close to the coast of the Bothnian Bay. Within the till-covered areas above the highest coastline, outcrops are often concentrated in mountainous areas or in outwashed areas along streams and rivers. Several parts of the project area are completely covered by Quaternary deposits, and

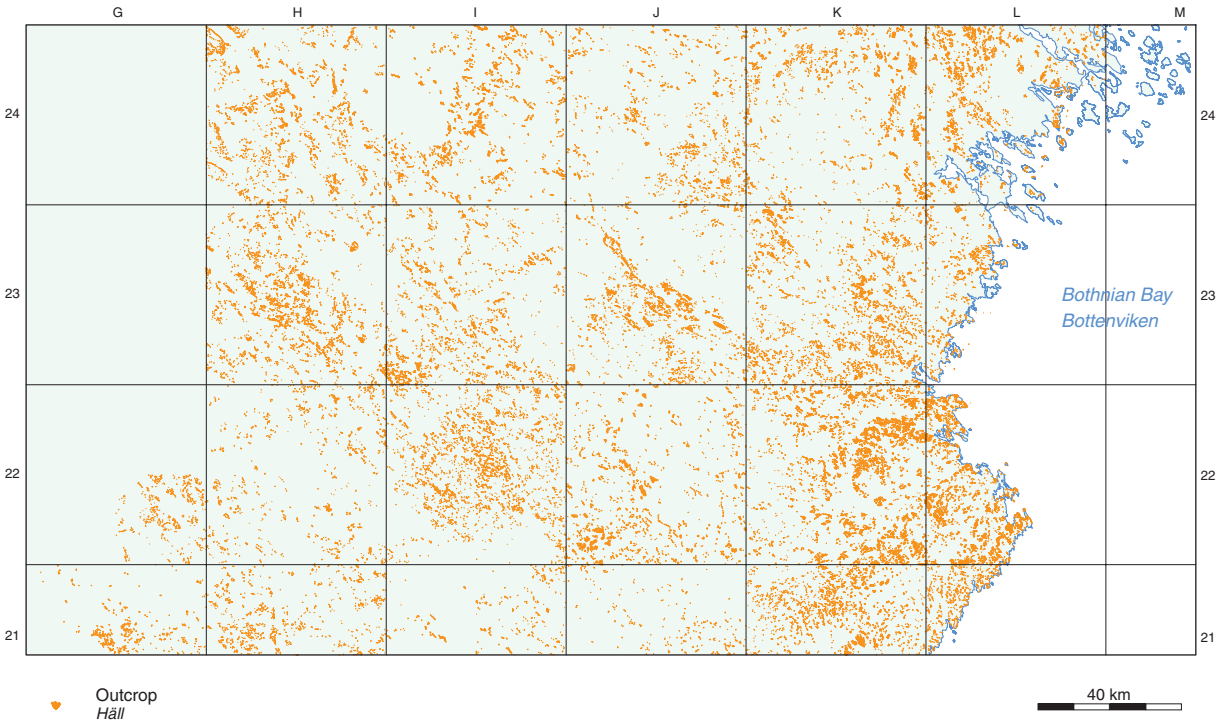


Fig. 3. Outcrop map of the Skellefte District and surrounding areas, showing outcrops visited during the regular mapping programme of the Geological Survey of Sweden (SGU), except for map sheets 21I Fredrika NV, NO and 23L Byske SV where the outcrops have been interpreted from aerial photographs.

Hällkarta över Skelleftefältet med omnejd. Kartan visar hällar som besökts under SGUs baskartering, med undantag för kartbladen 21I Fredrika NV, NO och 23L Byske SV, där hällarna har tolkats från flygbilder.

the geological map in these areas is based mainly on geophysical data. The distribution of outcrops within the Fennoscandian part of the map area is shown in Figure 3. Bedrock information from about 36,000 of the investigated outcrops is stored in the outcrop database of SGU.

In areas where bedrock maps on a scale of 1:50,000 (Ai-maps) were not available, the geological information was obtained from the following sources: map sheets 24G Umnäs NV and NO and 23L Byske NV, NO and SV (Lundqvist et al. 1996a); Fennoscandian Shield part of map sheets 21G Dorotea NV and NO (Lundqvist et al. 1996a), revised summer 1998; the Caledonian orogen on map sheets 21G Dorotea NV and NO (Gee et al. 1978). Map sheets 24G Umnäs SV and SO (Caledonian orogen) from Febbroni (1997) and unpublished manuscripts from Prof. Reinhard Greiling, University of Heidelberg, Germany; map sheets 24K Älvsbyn NV, NO, SV and SO: a digital map of northern Sweden on a scale of 1:250,000, prepared at SGU in the late 1980s by T. Sjöstrand and H. Henkel, including maps of the Swedish Geological Company (SGAB; Lundmark 1984, 1985a, b), revised during summer 1998.

GEOCHEMISTRY

Within the Skellefte District and surrounding areas, more than 1000 geochemical analyses have been carried out both by the bedrock mapping programme of the Geological Survey of Sweden (SGU) and by this project. The distribution of the collected samples is shown in Figure 4. The results of these analyses are stored in the lithogeochemistry database at SGU. This database contains also older analyses carried out prior to the SGU bedrock mapping programme, but these are not shown in Figure 4.

ORES AND MINERALIZATIONS

Mineral and bedrock resources, shown on the "Map of mineral and bedrock resources and hydrothermal alterations" were extracted from the "Mineral and bedrock resources database" at the Geological Survey of Sweden (SGU). For further information on this topic see chapter "Explanation to the map of mineral and bedrock resources and hydrothermal alterations" (p. 74) and chapter "Ores and mineralizations" (p. 118).

RADIOMETRIC DATA

Apart from the radiometric age determinations, which have been carried out by the bedrock mapping programme of the Geological Survey of sweden (SGU), additional Sm-Nd, U-Pb, and Pb-Pb analyses have been made by this project. They were carried out at the Laboratory for Isotope Geology (LIG) at the Swedish Museum of Natural History in Stockholm. The laboratory routines followed established standard techniques, and only a few brief comments are given below. Table 1a lists the results of all available radiometric (U-Pb) age determinations in the map area (77 samples), and the locations of the sample points is shown in Figure 5.

Sm-Nd analyses

The Sm-Nd analyses, presented in Table 1b, include mainly rocks of sedimentary origin, and those magmatic rocks that also have been dated by the U-Pb tech-

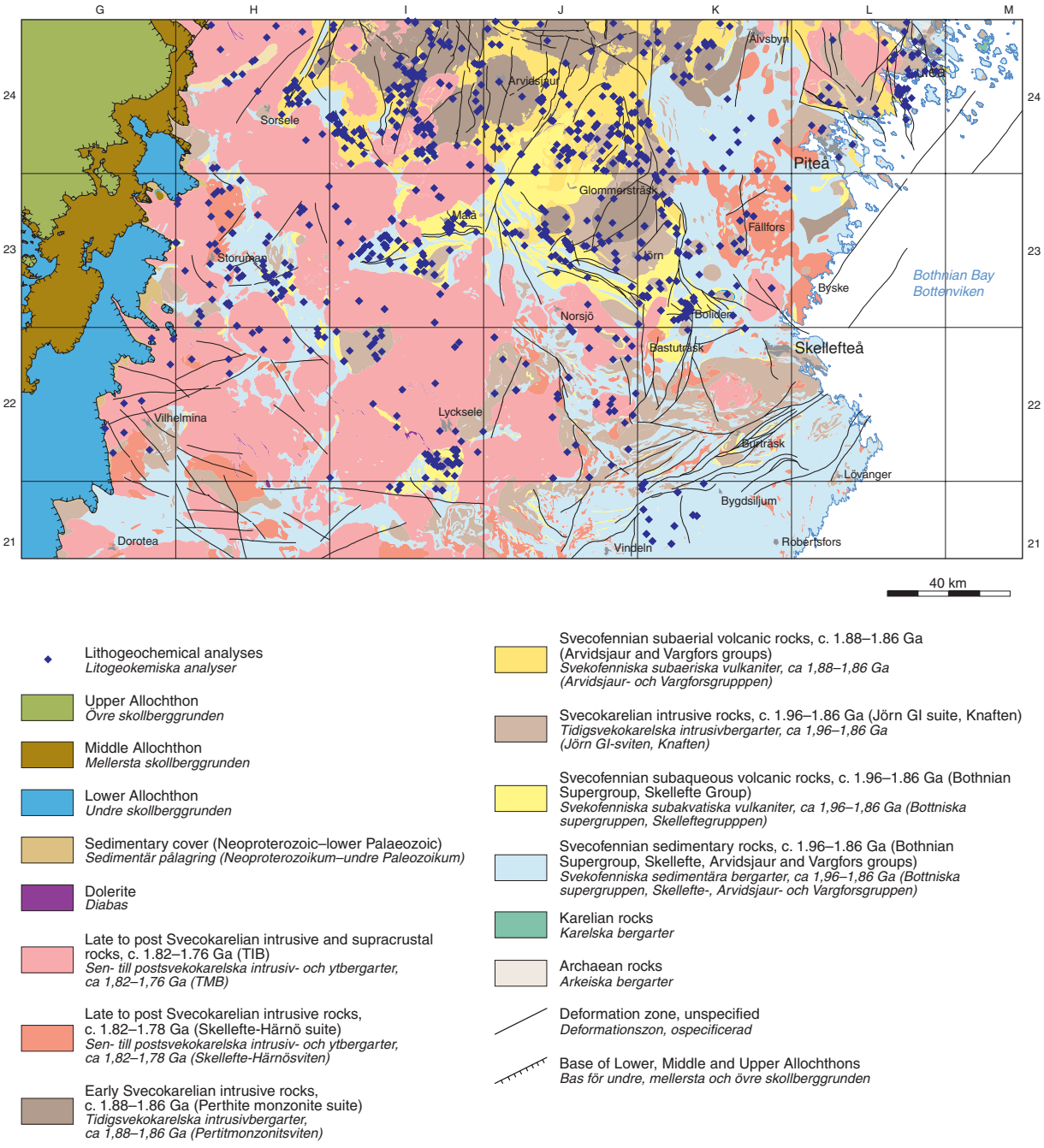


Fig. 4. Simplified bedrock map of the Skellefte District and surrounding areas with locations of geochemical samples. The analyses are stored in the lithogeochemistry database at SGU.

Förenklad berggrundskarta över Skelleftefältet med omnejd med provpunkter för geokemiprover. Analyserna är lagrade i SGUs litogeokemidatabas.

nique on zircon, as well as certain rocks of importance for stratigraphic correlations. The analytical treatment has involved dissolution, spiking with a mixed ^{147}Sm–^{150}Nd tracer, and separation of Sm and Nd using an ALFA–HIBA solution. The final mass spectrometric analyses were made with a Finnigan MAT 261 spectrometer, equipped with multiple Faraday cups, operating in static mode. The reproducibility of the results was monitored by running the La Jolla Nd standard on a regular basis.

U-Pb analyses

U-Pb dating of zircon, titanite, and monazite (Table 1a) has been carried out essentially following the methods set up by Krogh (1973). Samples were spiked with either a $^{208}Pb/^{233}U$–^{235}U tracer or a $^{205}Pb/^{233}U$–^{235}U tracer and run on a Finnigan MAT 261 spectrometer using the silica gel–phosphoric acid loading technique.

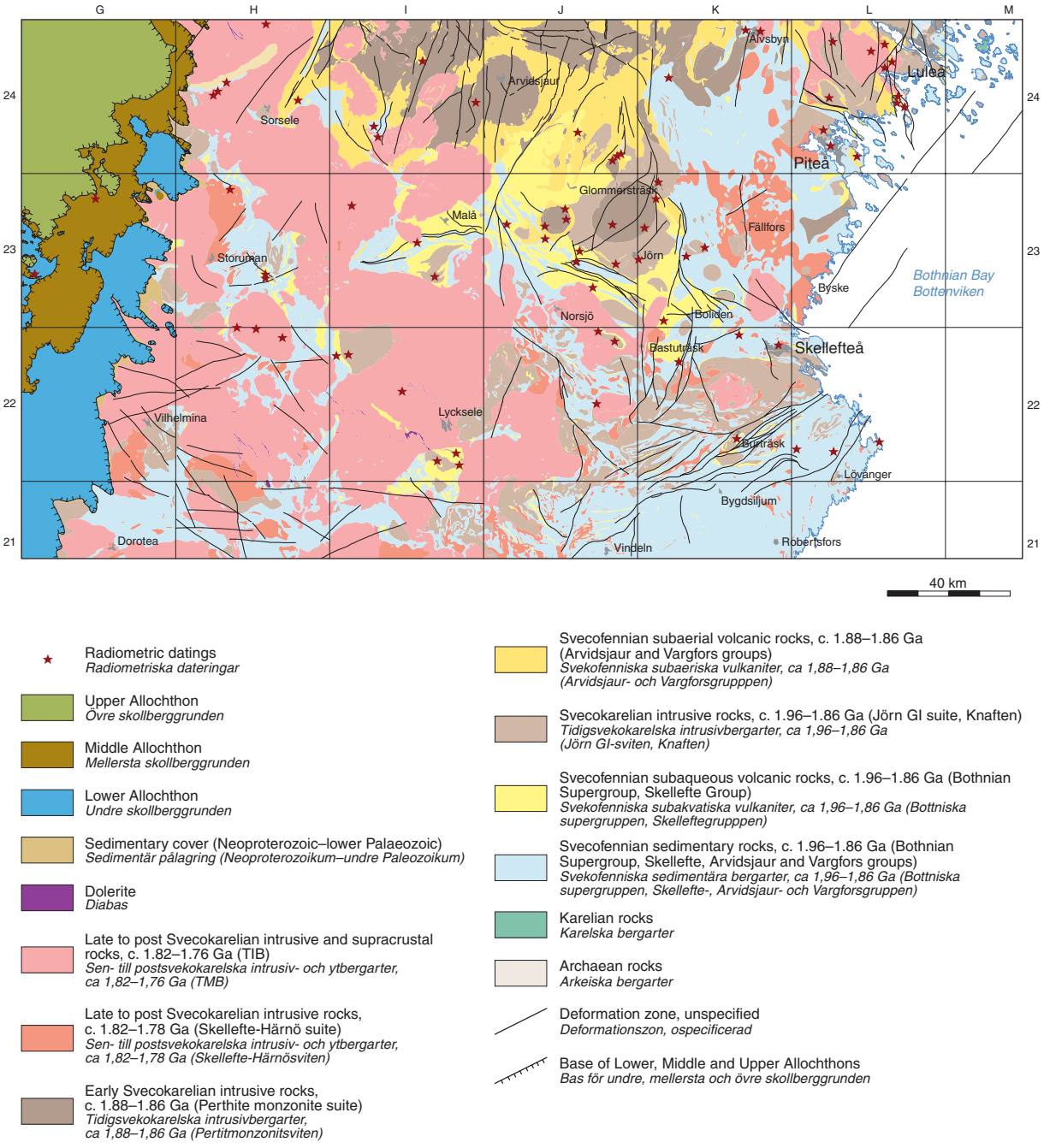


Fig. 5. Simplified bedrock map of the Skellefte District and surrounding areas showing locations of radiometric age determinations (U-Pb). The analyses are stored in the database of radiometric age determinations at SGU.

Förenklad berggrundskarta över Skelleftefältet med omnejd med provpunkter för radiometriska åldersdateringar (U-Pb). Analyserna är lagrade i SGUs åldersdatabas.

Table 1a. Radiometric age determinations (U-Pb) in the project area. Abbreviations: CAL: Caledonides, TIB: Transscandinavian Igneous Belt, DG: Dobblon Group, SHS: Skellefte–Härnö suite, PMS: Perthite monzonite suite, VG: Vargfors Group, AG: Arvidsjaur Group, ESC: Early Svecokarelian calc–alkaline intrusive rocks, SG: Skellefte Group, BSG: Bothnian Supergroup, ARC: Archaean rocks, Pg: Pegmatite, Dy: Dyke, Cl: Clast.

Radiometriska åldersbestämningar (U-Pb) inom projektområdet. Förkortningar: CAL: Fjällkedjan, TIB: Transskandinaviska magmatiska bältet, DG: Dobblongruppen, SHS: Skellefte–Härnösviten, PMS: Pertitmonzonitsviten, VG: Vargforsgruppen, AG: Arvidsjaurgruppen, ESC: Tidigsvekokarelska kalkalkalina intrusivbergarter, SG: Skelleftegruppen, BSG: Bottniska supergruppen, ARC: Arkeiska bergarter, Pg: Pegmatit, Dy: Gång, Cl: Klast.

Object	Unit	Age (Ma)	Mineral	Map	N-coord	E-coord	Reference
Meta-quartz syenite, Middle Allochthon, Harrvik	CAL	1766^{+15}_{-12}	Zircon	23G	7242220	1524030	Greiling et al. (2002)
Quartz syenite, Lower Allochthon, Mörrösjöbäcken	CAL	1798±6	Zircon	23G	7217850	1504290	Greiling et al. (2002)
Granite, Sorsele suite, Brännberget	TIB	1766±8	Zircon	24H	7277200	1563700	Skiöld (1988)
Ledfat granite, Adak suite, Gråberget, Ledvattnet	TIB	1772±14	Zircon	24I	7262300	1615770	Skiöld (1988)
Granite, Revsund suite, Holmfors	TIB	1778±16	Zircon	23I	7240000	1607200	Skiöld (1988)
Granite, Sorsele suite, Stor-Gidna	TIB	1791±22	Zircon	24H	7299000	1579400	Skiöld (1988)
Granite, Ale suite, Måttsund	TIB	1796±2		24L	7284850	1780330	Öhlander & Schöberg (1991)
Granite, Adak suite, Släppträsk	TIB	1802±3	Zircon	23I	7227950	1628510	Bergström & Sträng (1999a)
Granite, Ale suite, Alvik	TIB	1802±3		24L	7290110	1775870	Öhlander & Schöberg (1991)
Syenite, Edefors suite, Hundberget, Älvsbyn	TIB	1803±4	Zircon	24K	7296680	1739929	SGU, unpublished
Granite, Revsund suite, Jora dome, Hästliden	TIB	1805±8	Zircon	23H	7200440	1570000	Eliasson et al. (2001)
Charnockitic granite, Revsund suite, Kalvträsk	TIB	1805±7	Zircon	22J	7175700	1686750	Weihed et al. (2002a)
Granite, Revsund suite, Umgransele	TIB	1806±2	Zircon	22I	7179695	1623609	Björk & Kero (2002)
Granitoid, Revsund suite, Björnberget	TIB	1817–1830	Zircon	22H	7197150	1584750	Björk & Kero (2001)
Quartz porphyritic rhyolite	DG	1803±15	Zircon	24H	7280045	1566600	Skiöld (1988)
Neosome in migmatitic greywacke, Gamla vattentornet, Piteå	SHS	1784±5	Monazite	24L	7259450	1762750	SGU, unpublished
Granite, Vitberget, Skellefteå	SHS	1798±4	Zircon + titanite	22K	7194750	1745850	Weihed et al. (2002a)
Granite, Blaiksjön	SHS	1809±8	Monazite	23H	7245220	1567730	Eliasson et al. (2001)
Granite, Hobergsliden	PMS	1862±14	Titanite	23K	7247600	1706800	Lundström et al. (1997)
Granite clast, Ledfat conglomerate, Setmyrliden	PMS	1866±17	Zircon	24I	7265800	1614400	Skiöld (1988)
Granite, Vargliden	PMS	1873^{+18}_{-14}	Zircon	23J	7233890	1691940	Wilson et al. (1987b)
Granite, Granberget	PMS	1873±12	Zircon	23K	7232800	1702340	SGU, unpublished
Monzonite, Bredträskliden, Gallejaur	PMS	1873±10	Zircon	23J	7235500	1676900	Skiöld (1988)
Granite, Avaviken	PMS	1874±4	Zircon	24I	7286960	1630300	Bergström & Triumf (2002)
Gabbro, Gallejaur	PMS	1876±4	Zircon	23J	7233300	1669900	Skiöld et al. (1993)
Arvidsjaur granite, Akkanålke, Arvidsjaur	PMS	1877^{+8}_{-7}	Zircon	24I	7273500	1647550	Skiöld et al. (1993)
Granite, Antakberget	PMS	1879^{+15}_{-12}	Zircon	24J	7254650	1691940	Kathol & Persson (1997)
Felsic volcanic rock, Vithatten	VG	1871±5	Zircon	23J	7238905	1676498	Bergström et al. (2003)
Ignimbritic felsic volcanic rock, Gallejaur power station	VG	1874.9±3.7	Zircon	23J	7229200	1670050	Billström & Weihed (1996)
Felsic volcanic rock, Heden, Bure	AG	1860±7	Zircon	24H	7274200	1589800	Skiöld et al. (1993)
Volcanic matrix, conglomerate-like rock, Fagervik	AG	1871±2	Zircon	24L	7273350	1784250	Lundqvist et al. (2000)
Gneissic mafic volcanic rock, Brännbergsliden	AG	1872±7	Zircon	23K	7242190	1706020	Lundström & Persson (1999)
Dacitic dyke, Fågelberget, Abborrträsk	AG	1877±9	Zircon	24K	7263800	1680590	Kathol & Triumf (2004)
Felsic volcanic rock, Skyberget and Gråberget	AG	1878±2	Zircon	24J	7256150	1693450	Skiöld et al. (1993)
Granodiorite, Sikträsk	ESC	1854±9	Zircon	22J	7199200	1687300	Billström & Weihed (1996)
Orthogneiss, Sikträsk	ESC	1859±3	Zircon	22J	7196000	1692600	Weihed & Vaasjoki (1993)
Granodiorite, Riskölen	ESC	1861±19	Zircon	24L	7293300	1763400	Mellqvist et al. (2003)
Tonalite porphyry dyke in Pite conglomerate, Degerberget, Piteå	ESC	1865^{+24}_{-10}	Zircon	24L	7256000	1771250	Persson & Lundqvist (1997)
Intermediate dyke, Hemberget, Knaften	ESC	1866±11	Zircon	22I	7159600	1641160	Billström et al. (2002)
Granodiorite, Karlberg, Piteå	ESC	1867±11	Zircon	24L	7264550	1760400	Wikström & Persson (1997a)
Granodiorite clast, Pite conglomerate, Degerberget, Piteå	ESC	1868±13	Zircon	24L	7256000	1771350	Persson & Lundqvist (1997)
Granite, Dobblon	ESC	1869±19	Zircon	24H	7275800	1562300	Skiöld (1988)
Granodiorite, Jörn	ESC	1874^{+45}_{-26}	Zircon	23K	7222590	1700400	Wilson et al. (1987b)
Diorite, Yttre Brandbergen, Stavaträsk	ESC	1877±2	Zircon	23K	7226380	1721900	Lundström et al. (1997)
Tonalite fragment, Bälingsberget breccia, Måttsundsberget	ESC	1879±4	Zircon	24L	7286700	1782600	Wikström et al. (1996a)
Quartz monzodiorite, Barsele	ESC	1880±4	Zircon	23H	7216450	1579220	Eliasson et al. (2001)
Quartz-feldspar prophyritic rock, Tallberg	ESC	1886^{+15}_{-9}	Zircon	23J	7221000	1693000	Weihed & Schöberg (1991)
Granodiorite clast in conglomerate, Blåviksjön	ESC	1890±7	Zircon	22I	7191250	1602250	Welin et al. (1993)
Granodiorite, Sjulsmark	ESC	1892±14	Zircon	24L	7275000	1762300	Öhlander et al. (1987)
Granodiorite clast in Urikberget conglomerate, Hej	ESC	1893±4	Zircon	24K	7256830	1694640	Kathol & Triumf (2004)

Table 1a. continued

Object	Unit	Age (Ma)	Mineral	Map	N-coord	E-coord	Reference
Granodiorite, Kvarnberget	ESC	1895^{+14}_{-12}	Zircon	22K	7164300	1732300	Weihed et al. (2002a)
Tonalite, Hålmyrtjärnen	ESC	1898±11	Zircon	23J	7226872	1682720	Bergström et al. (2003)
Tonalite, Blåviksjön	ESC	1902±2	Zircon	22H	7191600	1606200	Björk & Kero (1996)
Tonalite clast, conglomerate-like rock, Fagervik	ESC	1903±5	Zircon + titanite	24L	7273350	1784250	Lundqvist et al. (2000)
Tonalite, Norra Svanaberget, Kristineberg	ESC	1907±13	Zircon	23I	7216930	1634140	Bergström et al. (1999)
Quartz-feldspar porphyritic dyke, Knaften	ESC	1940±14	Zircon	22I	7155730	1642200	Wasström (1996)
Granite, Knaften	ESC	1954±6	Zircon	22I	7157120	1634980	Wasström (1993)
Rhyolitic mass flow, Lillträsk, Petikträsk	SG	1847.1±2.8	Zircon	23J	7225200	1681250	Billström & Weihed (1996)
Felsisc subvolcanic rock, Röjnoret	SG	1875±13	Zircon + titanite	22K	7189300	1713440	Weihed (2002a)
Felsic volcanic rock, Rakkejaurheden	SG	1881±6	Zircon	23J	7233920	1657610	SGU, unpublished
Felsic volcanic rock, Vargforsdammen, Nicknoret	SG	1882±8	Zircon	23J	7221760	1680050	Welin (1987)
Quartz-feldspar porphyritic subvolcanic rhyodacite, Bjurvattnet	SG	1884.1±5.5	Zircon	23K	7202590	1708540	Billström & Weihed (1996)
Volcaniclastic rhyolite, Fågelberget, Abborrträsk	SG	1886±13	Zircon	24K	7263720	1680550	Kathol & Triumf (2004)
Quartz porphyritic metavolcanic rock, Melestjärn, Bjurträsk	SG	1888.8±4.2	Zircon	23J	7213410	1685530	Billström & Weihed (1996)
Paragneiss, Långtjärnberget	BSG	1867±10	Monazite	24K	7281534	1710117	SGU, unpublished
Metadacite, Barsele	BSG	1959±14	Zircon	23H	7217750	1579250	Eliasson et al. (2001)
Granitoid clast, Bälingsberg breccia, Bälingsberget, Luleå	ARC	2638±19	Zircon	24L	7292350	1780350	Wikström et al. (1996a)
Granodiorite clast, magmatic breccia, Mittihedsberget, Vallen	ARC	2655±7	Zircon	24L	7275450	1784600	Lundqvist et al. (2000)
Tonalite, Alhamn	ARC	2704±3	Zircon	24L	7272050	1786700	Lundqvist et al. (2000)
Tonalite clast, conglomerate-like rock, Fagervik	ARC	2706±6	Zircon + titanite	24L	7273350	1784250	Lundqvist et al. (2000)
Pegmatite, Varuträsk	Pg	1775±11	Columbite	22K	7198000	1733000	Romer & Wright (1992)
Pegmatite, Ytterboliden	Pg	1782±9	Columbite	24K	7297000	1735100	Romer & Smeds (1997)
Pegmatitic granite, Sillhällarna	Pg	1861.8±6.8	Zircon + monazite	22L	7163200	1778500	Rutland et al. (2001b)
Granitic dyke, Rävelsberget	Dy	1859±6	Zircon + monazite	22L	7160150	1763700	Rutland et al. (2001b)
Greisen dykes in Revsund granite, Joran dome	Dy	1775-1782	Zircon	22H	7200000	1576200	Billström & Öhlander (1989)
Trondhjemitic dyke, Pultarliden	Dy	1874±3	Zircon + monazite	23K	7223500	1715820	Lundström et al. (1999)
Felsic dyke, Trehörningen	Dy	1874.5±3.2	Zircon + monazite	22L	7160950	1751700	Rutland et al. (2001b)

Table 1b. Sm-Nd data from rocks in the project area. The table includes only data obtained by the Geological Survey of Sweden.
Sm-Nd-data för bergarter i projektområdet. Tabellen innehåller enbart data från Sveriges geologiska undersökning.

Sample	N-coord	E-coord	Rock type	$^{143}Nd/^{144}Nd$ corr.	2σ mean	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	ε_{Nd}	t-DM (Ga)	Age (Ma)
HCA950012A	7228000	1744400	paragneiss	0.511509	6	5.7	30.8	0.1123	–1.45	2.32	1900
HCA930022A	7210880	1724080	greywacke	0.511807	6	3.3	15.8	0.1266	0.89	2.17	1900
OIL930091	7201200	1718250	siltstone	0.511572	7	4.5	23.0	0.1179	–1.57	2.35	1900
HCA950210	7249070	1747360	migmatite	0.511542	6	7.6	40.4	0.1142	–1.27	2.31	1900
OIL920027A	7214200	1728900	arenite	0.511525	8	6.3	32.9	0.1156	–1.93	2.37	1900
HCA920267	7212240	1735530	paragneiss	0.511431	6	4.4	23.8	0.1112	–2.69	2.41	1900
24LOM372-1	7255345	1786415	basalt	0.511933	13	4.27	20.07	0.1286	2.78	1.99	1890
24LOM372-2	7255325	1786395	basalt	0.512922	7	2.51	7.41	0.2049	3.57	2.05	1890
24LOM372-3	7255300	1786370	basalt	0.511874	5	3.04	9.13	0.2011	3.56	2.01	1890
LRI950083	7297400	1792450	trondhjemite	0.510491	5	6.10	51.98	0.0710	–11.4	2.75	1890
CM940821	7275600	1784500	trondhjemite	0.511168	11	9.4	1.87	0.1202	–2.12	3.10	2700
CM940822	7275500	1785050	trondhjemite	0.510146	10	6.63	0.64	0.0586	–0.61	2.87	2700
JPN950031	7216450	1579220	granitoid	0.511675	12	8.4	47.6	0.1069	3.1	1.95	1900
JPN940274	7216450	1579220	dacite	0.512120	6	4.9	21.1	0.1402	3.70	1.91	1900
TEN940071	7200440	1570000	granite	0.511511	9	14.2	87.6	0.0984	0.73	2.03	1800
JPN940216	7219930	1578460	quartz diorite	0.511684	7	4.65	25.93	0.1085	3.04	1.97	1910
TEN940072	7245220	1567730	granite	0.511461	6	3.82	24.01	0.0961	0.27	2.05	1800
TEN930191	7207780	1567310	basalt	0.512623	9	3.60	12.04	0.1807	3.76	not defined	1960

Table 1b. continued

Sample	N-coord	E-coord	Rock type	$^{143}Nd/^{144}Nd$ corr.	2σ mean	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	ε_{Nd}	t-DM (Ga)	Age (Ma)
TNT940095	7247580	1571080	basalt	0.512790	22	7.98	24.95	0.1933	3.83	not defined	1960
TEN960101	7217170	1581840	basalt	0.513086	9	2.18	6.15	0.2144	4.30	3.26	1960
DWE950001	7229030	1560260	granite	0.511733	7	6.59	32.85	0.1213	−0.25	2.17	1800
GSO950167	7231680	1565170	granite	0.511711	3	2.90	14.58	0.1204	−0.46	2.18	1800
DWE950109	7224700	1563570	granite	0.512228	5	2.96	10.86	0.1648	−0.63	2.57	1800
BJA930372	7196250	1615100	granite	0.511606	4	6.21	38.50	0.0977	3.90	1.89	1890
BJA930134	7197200	1619900	granite	0.511564	4	1.92	12.44	0.0932	4.19	1.87	1890
JPN940061	7216700	1571700	sandstone	0.511522	7	5.5	27.98	0.1189	−2.81	2.46	1900
JPN930061	7216700	1571700	siltstone	0.511496	8	8.22	43.35	0.1147	−2.28	2.39	1900
GSO950203	7230570	1568570	sandstone	0.511505	6	6.23	32.86	0.1149	−2.15	2.38	1900
GSO950203	7230570	1568570	siltstone	0.511404	37	9.54	55.32	0.1046	−1.9	2.32	1900
GSO940138	7208170	1591680	sandstone	0.511543	6	5.91	30.68	0.1165	−1.8	2.36	1900
GSO940138	7208170	1591680	siltstone	0.51157	4	5.83	28.21	0.1250	−3.37	2.55	1900
MGN930258	7216930	1634140	tonalite	0.511729	5	4.32	23.79	0.1097	3.51	1.93	1900
MGN930285	7213360	1637610	basalt	0.512139	5	7.29	50.18	0.1453	2.69	2.01	1880
UJB930017	7226150	1624140	rhyolite	0.511685	10	5.6	32.4	0.1044	3.82	1.89	1890
AFT940080	7222300	1612660	sill	0.512001	4	1.55	7.27	0.1286	3.93	1.87	1870
MGN940342A	7233040	1639590	pillowlava	0.512769	11	3.1	15.99	0.1933	3.39	2.03	1880
MGN940342B	7233040	1639590	rhyolite	0.512067	8	3.77	16.75	0.136	3.45	1.91	1870
UJB930036	7227750	1628510	granite	0.512192	21	5.53	22.1	0.1513	1.8	2.08	1800
FRJ950014	7257600	1630070	basalt	0.512183	7	2.1	8.7	0.146	3.37	1.93	1880
UJB950124	7229650	1618020	sedimentary rock	0.511566	4	4.17	22.31	0.1131	−0.52	2.24	1900
952005	Borr-kärna	Vinliden	sedimentary rock	0.51148	5	4.54	24.23	0.1133	−1.28	2.31	1900
95025	7210700	1729200	quartz monzodiorite	0.511494	6	9.51	60.69	0.0948	2.62	1.99	1900
91018	7222550	1615800	diorite	0.511842	11	6.91	35.4	0.1188	3.18	1.93	1880
96016	7224450	1732500	gabbro	0.512122	8	3.72	14.33	0.157	−0.48	2.49	1880

Table 1c. Lead isotope data of minerals, related to ore deposits in the Skellefte District.
Blyisotopdata från mineral associerade med malmförekomster i Skellefteфältet.

Locality	Sample no	Phase	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Reference
Pålsträsk	dh 85001,18.0	galena	22.751	16.162	40.496	Billström et al. (1997b)
Adak	sample OM	galena	22.739	16.135	40.849	Billström et al. (1997b)
Långdal	central A-ore	galena	15.153	15.126	34.947	Billström et al. (1997b)
Långdal	dh534,40.25 m	galena	15.126	15.083	34.818	Billström et al. (1997b)
Långdal	dh629,61.60 m	galena	15.105	15.061	34.746	Billström et al. (1997b)
Kristineberg	Sk89-2	galena	15.182	15.077	34.795	Billström & Vivallo (1994)
Kristineberg	G356	galena	15.183	15.067	34.724	Billström & Vivallo (1994)
Kristineberg	G357	galena	15.207	15.101	34.821	Billström & Vivallo (1994)
Kristineberg	G358	galena	15.217	15.128	34.886	Billström & Vivallo (1994)
Kristineberg	G359	galena	15.192	15.078	34.757	Billström & Vivallo (1994)
Kristineberg	LIG-Kri-2	galena	15.208	15.092	34.834	Billström & Vivallo (1994)
Kristineberg	G373B po	galena	15.280	15.087	34.817	Billström & Vivallo (1994)
Kristineberg	G373c-1 su	galena	15.190	15.072	34.759	Billström & Vivallo (1994)
Kristineberg	G373c-2 su	galena	15.201	15.080	34.765	Billström & Vivallo (1994)
Kristineberg	G373c-3 su	galena	15.193	15.065	34.727	Billström & Vivallo (1994)
Kristineberg	G373D sp	galena	15.187	15.078	34.796	Billström & Vivallo (1994)
Rävliden	Sk89-4	galena	15.176	15.078	34.810	Billström & Vivallo (1994)
Rävliden	Sk89-5	galena	15.180	15.073	34.786	Billström & Vivallo (1994)
Rävliden	G360	galena	15.106	15.005	34.483	Billström & Vivallo (1994)
Rävliden	G361	galena	15.121	15.014	34.585	Billström & Vivallo (1994)
Rävliden	LIG-Rl1a	galena	15.212	15.116	34.910	Billström & Vivallo (1994)
Rävliden	LIG-Rl4	galena	15.231	15.091	34.863	Billström & Vivallo (1994)
Hornträsk	LIG-Ht1	galena	15.252	15.179	35.109	Billström & Vivallo (1994)
Hornträsk	LIG-Ht9	galena	15.180	15.066	34.643	Billström & Vivallo (1994)

Table 1c. continued

Locality	Sample no	Phase	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Reference
Vindelgransele	Sk-Sundblad	galena	15.268	15.086	34.816	Billström & Vivallo (1994)
Rakkejaur	Sk89-6 sp	galena	15.395	15.195	34.984	Billström & Vivallo (1994)
Rakkejaur	Sk89-7	galena	15.383	15.185	34.963	Billström & Vivallo (1994)
Rakkejaur	Sk89-8 su	galena	15.377	15.180	34.931	Billström & Vivallo (1994)
Rakkejaur	Sk89-9 sp	galena	15.401	15.195	34.984	Billström & Vivallo (1994)
Rakkejaur	Sk89-10 su	galena	15.381	15.188	34.966	Billström & Vivallo (1994)
Mensträsk	Sk89-12	galena	15.412	15.214	35.017	Billström & Vivallo (1994)
Mensträsk	Sk89-13 su	galena	15.398	15.191	34.950	Billström & Vivallo (1994)
Mensträsk	Sk89-14 su	galena	15.397	15.195	34.942	Billström & Vivallo (1994)
Mensträsk	Sk89-15 su	galena	15.421	15.205	34.978	Billström & Vivallo (1994)
Maurliden	Sk89-26	galena	15.363	15.182	34.962	Billström & Vivallo (1994)
Maurliden	Sk89-27 su	galena	15.350	15.177	34.942	Billström & Vivallo (1994)
Maurliden	Sk89-28 su	galena	15.369	15.183	34.959	Billström & Vivallo (1994)
Maurliden	Sk89-29 su	galena	15.360	15.184	34.966	Billström & Vivallo (1994)
Bjurfors M.	Sk89-16 sp	galena	15.112	15.059	34.780	Billström & Vivallo (1994)
Bjurfors M.	Sk89-17 py	galena	15.130	15.058	34.778	Billström & Vivallo (1994)
Bjurliden	Sk89-19	galena	15.119	15.067	34.794	Billström & Vivallo (1994)
Bjurliden	Sk89-20	galena	15.106	15.060	34.773	Billström & Vivallo (1994)
Bjurliden	Sk89-22	galena	15.094	15.050	34.745	Billström & Vivallo (1994)
Bjurliden	Sk89-23 su	galena	15.109	15.061	34.787	Billström & Vivallo (1994)
Norrliden	Sk89-30 su	galena	15.147	15.072	34.783	Billström & Vivallo (1994)
Norrliden	Sk89-32 su	galena	15.164	15.087	34.833	Billström & Vivallo (1994)
Udden	Sk89-33	galena	15.131	15.073	34.788	Billström & Vivallo (1994)
Udden	Sk89-34	galena	15.131	15.071	34.792	Billström & Vivallo (1994)
Udden	Sk89-36	galena	15.133	15.072	34.791	Billström & Vivallo (1994)
Udden	Sk89-37	galena	15.135	15.074	34.796	Billström & Vivallo (1994)
Udden	Sk89-39	galena	15.129	15.075	34.796	Billström & Vivallo (1994)
Udden	Sk89-43	galena	15.127	15.066	34.769	Billström & Vivallo (1994)
Udden	Sk89-44	galena	15.134	15.071	34.787	Billström & Vivallo (1994)
Udden	Sk89-45	galena	15.171	15.096	34.831	Billström & Vivallo (1994)
Udden	LIG-Ud9	galena	15.152	15.062	34.774	Billström & Vivallo (1994)
Udden	LIG-Ud11	galena	15.158	15.109	34.913	Billström & Vivallo (1994)
Svansele	Sk89-46	galena	15.119	15.067	34.795	Billström & Vivallo (1994)
Svansele	Sk89-47 su	galena	15.118	15.067	34.788	Billström & Vivallo (1994)
Svansele	Sk89-48	galena	15.106	15.054	34.762	Billström & Vivallo (1994)
Svansele	Sk89-49 su	galena	15.119	15.066	34.772	Billström & Vivallo (1994)
Svansele	Sk89-50	galena	15.112	15.067	34.772	Billström & Vivallo (1994)
Svansele	Sk89-52	galena	15.113	15.059	34.771	Billström & Vivallo (1994)
Kedträsk	Sk89-53	galena	15.230	15.074	34.867	Billström & Vivallo (1994)
Kedträsk	Sk89-54	galena	15.118	15.062	34.775	Billström & Vivallo (1994)
Kedträsk	Sk89-55	galena	15.128	15.066	34.788	Billström & Vivallo (1994)
Kedträsk	Sk89-56	galena	15.123	15.073	34.796	Billström & Vivallo (1994)
Kedträsk	Sk89-58	galena	15.120	15.063	34.775	Billström & Vivallo (1994)
Åsen	Sk89-60	galena	15.145	15.058	34.770	Billström & Vivallo (1994)
Åsen	Sk89-61	galena	15.153	15.065	34.800	Billström & Vivallo (1994)
Åsen	Sk89-62	galena	15.164	15.062	34.779	Billström & Vivallo (1994)
Petiknäs	Sk89-63	galena	15.245	15.131	34.879	Billström & Vivallo (1994)
Petiknäs	Sk89-64	galena	15.237	15.122	34.859	Billström & Vivallo (1994)
Petiknäs	Sk89-65	galena	15.256	15.139	34.901	Billström & Vivallo (1994)
Renström	Sk89-68 su	galena	15.134	15.081	34.808	Billström & Vivallo (1994)
Renström	G366	galena	15.114	15.075	34.747	Billström & Vivallo (1994)
Renström	G375A su	galena	15.127	15.095	34.778	Billström & Vivallo (1994)
Renström	G375B su	galena	15.157	15.108	34.878	Billström & Vivallo (1994)
Kankberg	Sk89-68 su	galena	15.190	15.128	34.877	Billström & Vivallo (1994)
Kankberg	Sk89-69 su	galena	15.191	15.125	34.893	Billström & Vivallo (1994)
Kankberg	Sk89-70 su	galena	15.439	15.175	35.083	Billström & Vivallo (1994)
Boliden	LIG-Bol183	galena	15.240	15.118	34.840	Billström & Vivallo (1994)
Boliden	LIG-Bol206	galena	15.262	15.191	35.053	Billström & Vivallo (1994)

Table 1c. continued

Locality	Sample no	Phase	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	Reference
Boliden	LIG-Bol233	galena	15.224	15.143	34.919	Billström & Vivallo (1994)
Boliden	LIG-Bol406	galena	15.239	15.166	34.988	Billström & Vivallo (1994)
Boliden	LIG-Bol441	galena	15.258	15.159	34.964	Billström & Vivallo (1994)
Boliden	LIG-Bol550	galena	15.262	15.202	35.086	Billström & Vivallo (1994)
Boliden	LIG-Bol761	galena	15.231	15.166	34.983	Billström & Vivallo (1994)
Boliden	LIG-Bol1081	galena	15.219	15.158	34.968	Billström & Vivallo (1994)
Långsele	LIG-Ls37	galena	15.195	15.113	34.908	Billström & Vivallo (1994)
Långsele	LIG-Ls54	galena	15.175	15.186	35.114	Billström & Vivallo (1994)
Långsele	LIG-Ls140	galena	15.099	15.079	34.795	Billström & Vivallo (1994)
Långsele	LIG-Ls141	galena	15.125	15.116	34.895	Billström & Vivallo (1994)
Långsele	LIG-Ls161	galena	15.131	15.135	34.966	Billström & Vivallo (1994)
Långdal	G363	galena	15.079	15.074	34.677	Billström & Vivallo (1994)
Långdal	G364	galena	15.078	15.065	34.684	Billström & Vivallo (1994)
Långdal	G365	galena	15.093	15.074	34.723	Billström & Vivallo (1994)
Långdal	LIG-Ld56	galena	15.122	15.071	34.778	Billström & Vivallo (1994)
Långdal	LIG-Ld56	galena	15.113	15.068	34.775	Billström & Vivallo (1994)
Långdal	LIG-Ld56	galena	15.139	15.105	34.882	Billström & Vivallo (1994)
Långdal	LIG-Ld56	galena	15.135	15.102	34.872	Billström & Vivallo (1994)
Middagsberget	Lillholmsberget	galena	15.285	15.108	34.847	Sundblad et al. (1993)
Middagsberget	Dh 84002, 220.60	galena	15.362	15.149	34.933	Sundblad et al. (1993)
Middagsberget	Dh 84002, 203.64	galena	15.358	15.139	34.903	Sundblad et al. (1993)
Middagsberget	Fäbodliden A/B	galena	15.426	15.192	35.011	Sundblad et al. (1993)
Middagsberget	Fäbodliden B-1	galena	15.422	15.191	34.998	Sundblad et al. (1993)
Middagsberget	Fäbodliden, B-2	galena	15.432	15.190	35.034	Sundblad et al. (1993)
Vindelgransele	VMS	galena	15.268	15.086	34.816	Sundblad et al. (1993)
Tallberg	Tallberg 86861 H	galena	15.448	15.181	34.944	Sundblad et al. (1993)
Tallberg	Tallberg 86861 H	galena	15.437	15.208	35.028	Sundblad et al. (1993)
Älgträsk	Älgträsk Dh 7, 55m	galena	15.827	15.236	35.420	Sundblad et al. (1993)
Älgträsk	Älgträsk Dh 7, 55m	galena	15.412	15.179	34.959	Sundblad et al. (1993)
Björkdal	Au, TURM 1	tourmaline	15.516	15.116	35.328	Bergman Weihed et al. (1998)
Björkdal	Au, PURE	Au(s)	15.276	14.950	34.807	Bergman Weihed et al. (1998)
Björkdal	Au. Stuff	Au(s)	15.239	15.125	35.088	Bergman Weihed et al. (1998)
Björkdal	Au, TURM 2	tourmaline	15.498	15.138	35.347	Bergman Weihed et al. (1998)
Björkdal	scheelit, 306	scheelite	15.244	15.122	35.034	Bergman Weihed et al. (1998)
Björkdal	scheelit, 108	scheelite	15.189	15.136	35.381	Bergman Weihed et al. (1998)
Björkdal	scheelit, EJ+303	scheelite	17.371	15.366	35.209	Bergman Weihed et al. (1998)
Björkdal	pyrit, 104	pyrite	16.752	15.367	37.249	Bergman Weihed et al. (1998)
Björkdal	kalcit, 306-92	calcite	64.687	20.615	42.392	Bergman Weihed et al. (1998)
Björkdal	kalcit, 307-92	calcite	22.30	15.72	42.51	Bergman Weihed et al. (1998)
Björkdal	kalcit, Bd-2	calcite	16.529	15.367	35.329	Bergman Weihed et al. (1998)
Björkdal	kalcit, 301-92	calcite	21.910	16.033	42.263	Bergman Weihed et al. (1998)
Björkdal	kalcit, 313-92	calcite	17.460	15.415	37.150	Bergman Weihed et al. (1998)
Björkdal	kalcit, 313-90	calcite	15.594	15.184	35.380	Bergman Weihed et al. (1998)
Björkdal	kalcit, 302	calcite	18.777	15.633	39.076	Bergman Weihed et al. (1998)
Björkdal	Bd 323-92A1	galena	15.105	15.121	35.018	Billström et al. (1997)
Björkdal	bJÖRK 5	galena	18.716	15.603	39.008	Billström et al. (1997)
Björkdal	Bdal-Pb1	galena	22.850	16.152	42.891	Billström et al. (1997)
Björkdal	Bdal-Pb2	galena	17.528	15.459	37.767	Billström et al. (1997)
Björkdal	Bd 323-92 (B)	galena	15.093	15.091	34.948	Billström et al. (1997)
Björkdal	Bd 323-92A2	galena	15.098	15.099	34.972	Billström et al. (1997)
Björkdal	Bd-Alb	galena	23.50	16.30	42.87	Billström et al. (1997)
Barsele	jam	jamesonite	15.600	15.274	35.151	Billström & Grensman (1993)
Barsele	apy	arsenopyrite	15.041	15.029	34.722	Billström & Grensman (1993)

Pb-Pb analyses

Common lead samples from the Björkdal gold deposit (cf. Bergman Weihed et al. 1998) were analysed (results reported in Table 1c). These samples include galenas, calcites, scheelites and also tourmaline and pure gold samples. In principle, the HBr ion exchange method was used to extract lead from all phases except for galenas, which went through an electrodeposition step. All samples were analysed on the Finnigan MAT 261 spectrometer.

DRILL HOLES

Figure 6 shows the locations of drill holes in the Skellefte District and surrounding areas for which the coordinates are now known (2002-05-21) in the Swedish national grid (RT90). The number of drill holes known

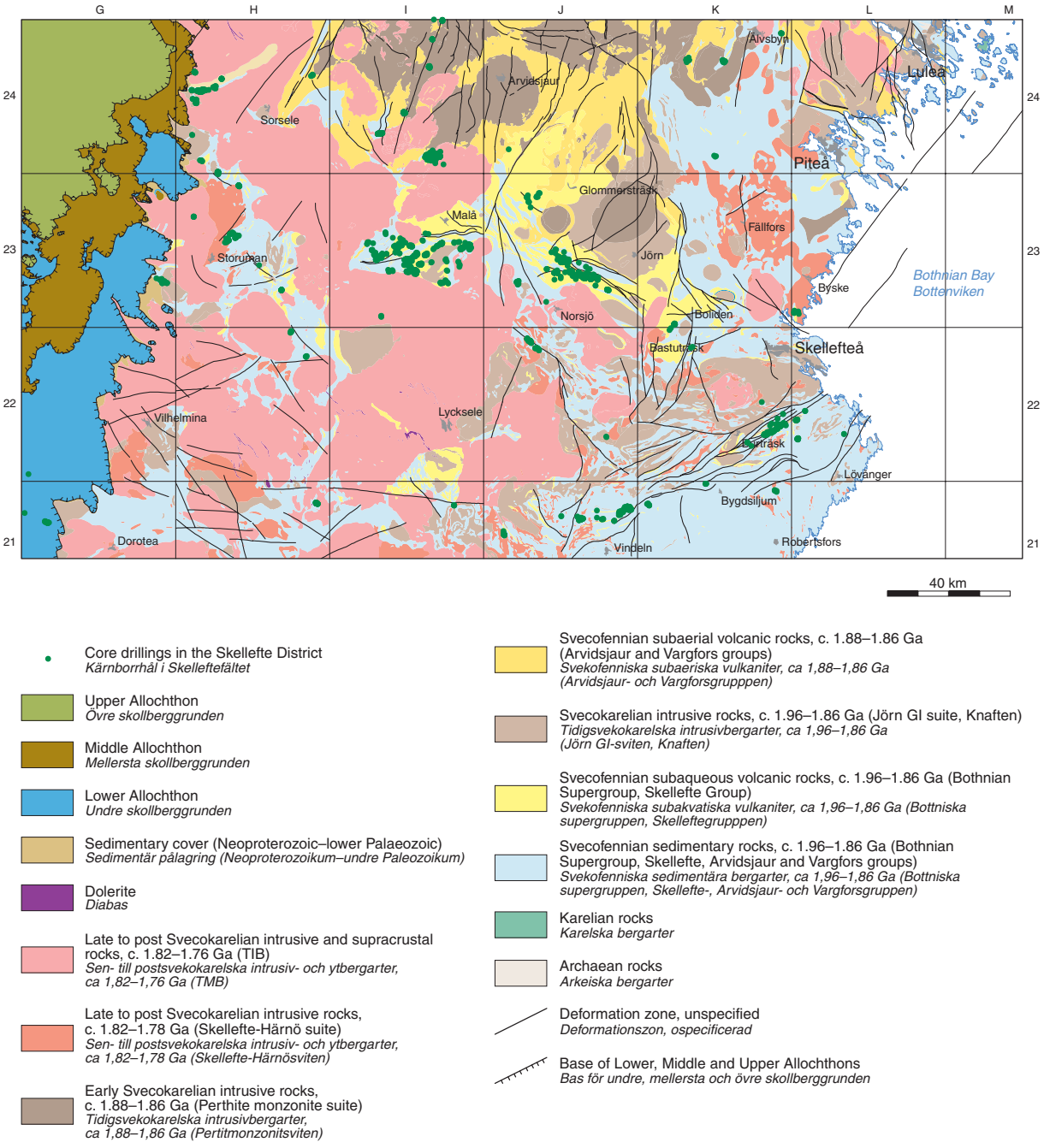


Fig. 6. Simplified bedrock map of the Skellefte District and surrounding areas showing locations of drill holes. The drill hole data (core or cuttings) are stored in the drill hole database at SGU.

Förenklad berggrundskarta över Skelleftefältet med omnejd med lägen för diamantborrhål. Borrhålsinformationen är lagrad i SGUs borrhålsdatabas.

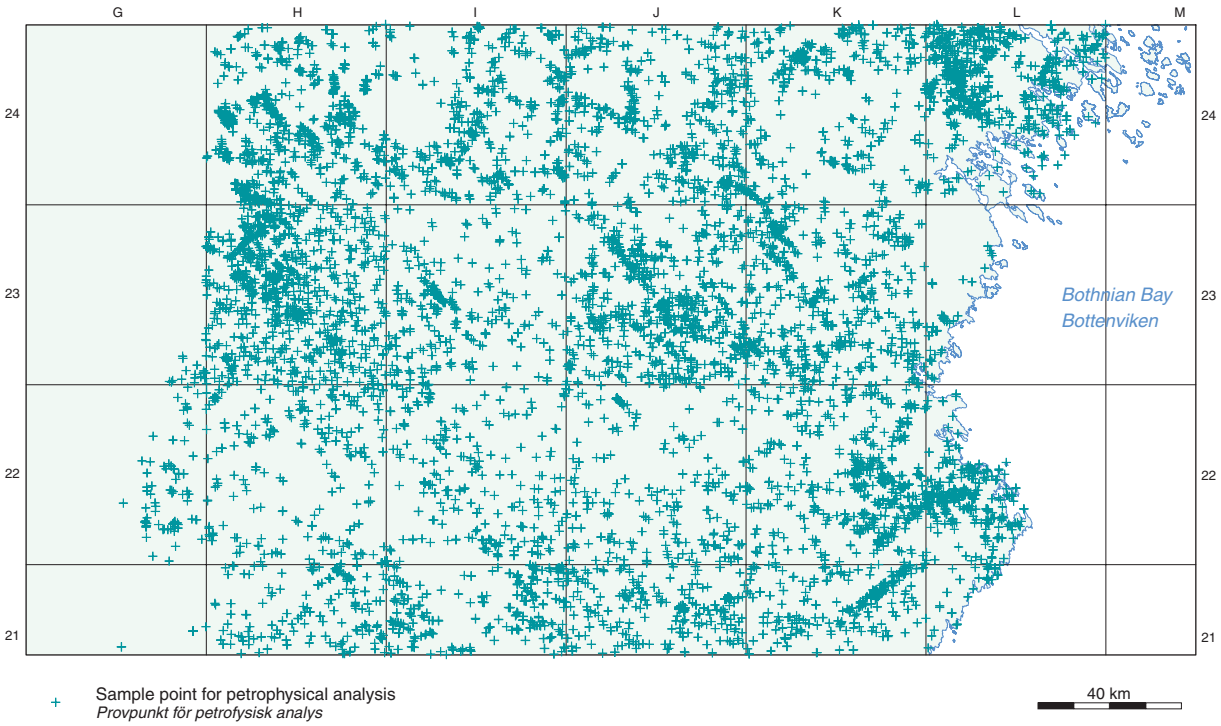


Fig. 7. Map of sample points for petrophysical analyses in the project area.
Karta över provpunkter för petrofysiska analyser i projektområdet.

in the district is 3150 and cores are available for 2163 of these. The core diameter is 38 mm in most cases. There are 2301 drill logs and 1828 measure logs. For 1879 drill cores, complementary lithochemical data are available. The drillings in the map area were carried out by the Swedish Geological Company (SGAB), the State Mining Property Commission (NSG), the Geological Survey of Sweden (SGU), the Swedish Nuclear Fuel and Waste Management Co (SKB), Boliden Mineral AB, Cogema, and Outokumpu Oy.

PETROPHYSICAL AND SPECTROMETRY DATA

Rock samples for determination of density and magnetic properties have been collected from outcrops and boulders within the Skellefte District and surrounding areas for more than twenty years (Fig. 7). The quality of documentation regarding coordinates, rock type, source etc. is not uniform. In practice, this means that the statistical treatment of petrophysical data is uncertain due to the presence of some erroneous values. However, as these data are sporadic, the authors considered the negative influence to be negligible.

Before regular gamma ray spectrometry was employed in bedrock mapping programmes of the Geological Survey of Sweden (SGU) only sporadic campaigns including spectrometry were carried out, and then mainly in connection with uranium exploration. The database for gamma spectrometry is still under construction. Classification of measuring points was carried out by correlating geographical locations of measuring points to corresponding digitized geological units. As the digitization of the geological map was carried out in order to suit a printed scale of 1:250,000, minor geological units were disregarded. Thus, the classification presented here must be considered to include some errors.

LITERATURE

In the reference list, only those publications that are cited in the text are included. For additional references, concerning the Skellefte District and surrounding areas, the reader is referred to the database Georegister, which can be found at http://www.sgu.se.

Historical overview of the Skellefte District

The name Skellefteåfältet stems from A.G. Högbom (1899) who, in a note for the Geological Society of Sweden, described his expeditions to the interior of northern Västerbotten and southern Norrbotten. His definition of "Skellefteåfältet" was (translated from Swedish): "a complex of rocks, sedimentary and eruptive, encompassing a larger area between Arvidsjaur and Skellefteå". This name has since been amended to Skelleftefältet in Swedish, translated either to Skellefte field or Skellefte District in the English literature. The first real description of the Skellefte District was published by Eklund (1923) and J. Eklund in Tegengren & Johansson (1924). Both these descriptions were published immediately before the Boliden discovery was announced (see below) and hence before the real mining boom started.

The next major work on the Skellefte District was published by Högbom (1937): "The Skellefte District with adjacent parts of Westerbotten and Norrbotten. A review of the geology and ore deposits (translation by editors)", printed in Swedish with an English summary. At this stage, mining had commenced and most of the volcanic massive sulphide (VMS) deposits had been discovered. During the next two decades the following papers were published, emphasizing the geology of ore deposits in the district: Du Rietz (1953), Gavelin (1939, 1948, 1955), Gavelin & Grip (1946), Grip (1935, 1941, 1942, 1946), and Ödman (1941).

The description to the county map of Västerbotten (Gavelin 1955) was the first thorough geological description of the entire county (most of which is covered by this project), but the stratigraphic thinking did not really change until the two papers by Kautsky (1957, 1959) were published and modern stratigraphic ideas, emphasizing both lateral and vertical facies changes, were introduced (see below). At the same time, Offerberg (1959) published the only comprehensive work on the Ledfat area (7268200/1617410).

In the 1960s, the geology of the Kristineberg area was summarized by Edelman (1963) and the hydrothermal alteration and exploitation history of the Boliden deposit was described by Nilsson (1968) and Grip & Wirstam (1970) respectively. Helfrich (1971) further developed the stratigraphic concepts of the formation of the Skellefte District. Rickard & Zweifel (1975) compared the volcanogenic massive sulphide (VMS) deposits of the Skellefte District with the Kuroko ores of Japan and initiated the era of modern ore genetic work in the district. The ideas assembled during the 1970s by SGU geologists active in the area were summarized by Lundberg (1980).

The last two decades have seen numerous papers published on a variety of aspects of the geology of the Skellefte District and surrounding areas and the list is too long to be cited here. Most work is referred to in other sections of this publication.

MINERAL DEPOSIT DISCOVERY HISTORY

The record of mineral exploration dates back to the early eighteenth century. The brief historical outline of pre-modern mining below is based largely on the summary presented in Tegengren & Johansson (1924). The first record of mining is from 1704 when copper ore was mined in the north-eastern part of the Skellefte District at Storkågeträsk (7215730/1727370, Hermelin 1804). Sporadic short-lived trial mining seems to have prevailed throughout the eighteenth century. Around 1850 attempts were made to mine silver in Skellefteå (Moröns silvergruva). In early 1900 gold was discovered at Krångfors (7191300/1722320) and this resulted in intensified exploration in the area. Several minor gold-arsenic mineralizations were discovered as well as iron-copper sulphide mineralizations. However, none of the mineralizations were found to be economically worthwhile and in 1908, only the Krångfors claim was still held.

The modern history of the Skellefte District began after World War I when the Kristineberg ore was discovered in 1918. At this time, exploration was carried out in the area by Centralgruppens Emmissionsbolag (predecessor to Boliden AB) and the Geological Survey of Sweden (SGU). The improvements made to electrical and electromagnetic geophysical exploration methods by Lundberg and Nathorst were a huge success and led to the discovery of several base metal sulphide ores in 1920–1922. Sjömalmerna at Mensträsk (7223870/1669270), Näsliden (7225900/1654950), Rakkejaur (7230700/1657250), and Bjurfors (7216800/1679560) were the major discoveries. In 1921 Centralgruppens Emmissionsbolag investigated an area where ore boulders had been found and trenches dug near Svanfors (7203530/1721450). They used the new electrical methods and found some interesting anomalies 2.5 km north of Bjurliden (7201710/1716740, misnamed Boliden on topographical maps). They decided to drill these anomalies and intersected auriferous arsenic-copper ore on December 10th 1924. They had discovered the Boliden ore. Because the name Boliden occurred on the topographical maps the name persisted and the Centralgruppens Emmissionsbolag became the Boliden Mining Company, now Boliden Mineral AB.

Another discovery of auriferous base-metal ore in Holmtjärn (7228630/1677070) was made during the 1920s in the central part of the district, but the Boliden ore was the only to be mined continuously until the Rävliden mine in the west opened in 1936.

With the major discovery of the Boliden ore, intensive mining activities were initiated in the Skellefte District. A concentrator was built at Boliden and a smelter at Rönnskär (7185210/1760470) on the coast about 50 km east of Boliden. After a period of limited mining activities, a number of mining operations started in the late 1930s and during World War II: Kristineberg (1940), Adak (1940), the nickel mine Lainijaur (1941) and others. A new concentrator was built in Kristineberg, and an approximately 100 km long cableway connected the two mining camps of Kristineberg and Boliden. Apart from the Boliden Company, SGU also undertook exploration in the Skellefte District. Economic prospects were handed over to the Boliden Company for development and mining.

The Boliden mine was closed in 1967, and the Adak camp (four mines) closed in 1976. New economic deposits such as Renström (found in the mid-1920s and still in production), Näsliden (in production 1953–1989), Udden (in production 1960–1991), Långdal (discovered in the 1930s and in production 1967–1997), Långsele (discovered mid-1920s, in production 1957–1990), Åsen ÖM (discovered 1960s, in production 1970, 1988–1993), Kankberg (discovered early 1940s, in production 1966–1969, 1989–1997), and Kedträsk (discovered 1920s, in production 1969–1971, 1989–1991, 1998–2000), compensated for the exhaustion of the older mines.

In the 1980s, ore reserves in most of the existing mines were rapidly depleted and exhaustion was predicted within a decade for many mines. The Kristineberg concentrator was closed in 1991 partly because the Rävliden, Rävlidmyran, and Hornträskviken M mines were exhausted, and the ore from Kristineberg mine, which even today has considerable reserves, is currently trucked to the Boliden plant. In the 1980s, the Boliden exploration strategy changed into more aggressive deep drilling within the ore-bearing sections of the district and regional programmes were directed towards gold. The gold exploration led to the discovery of gold ore at Åkerberg (7224550/1732500) which was put into production in 1989. The deep drilling exploration resulted in two new discoveries during the early 1990s: Petiknäs Norra and Petiknäs Södra only a few kilometres west of the Renström mine. These two deposits are currently being mined. In 1998 the exploration company NAN (North Atlantic Natural Resources) announced a new discovery at Storliden (7238900/1644600) 8 km north of Malå. The Storliden mine came into production in 2002 and is the most recent new discovery. At the same time as the Storliden discovery, Boliden AB announced that they would undertake a feasibility study of the Maurliden deposit, known since the 1950s but considered uneconomic. This study led to the opening of the Maurliden Västra mine in 2002. During the new millenium, more ore has been proved in the Kristineberg and Renström mines, but the ore reserves at the time of writing are at their lowest ever, with only 4–5 years proven production.

SGU exploration was directed towards nickel in the south-eastern part of the Skellefte District and surrounding areas, uranium north-west of the district and tin-tungsten south-west of the district during the 1970s and the 1980s. No economically viable deposits were found, but a large number of subeconomic mineralizations and prospects. The state-run exploration ended in 1992; legislation was altered so that foreign exploration companies were able to commence exploration in Sweden. Swedish junior companies had been active for some time and Terra Mining AB announced the discovery of the large Björkdal gold deposit, about 20 km north-east of Boliden, in 1985. This is one of the largest gold deposits in Western Europe, and was in production from 1987 to 1998. Production was recommenced in 2001 by Björkdalsgruvan AB and has been fully owned by MinMet since 2003. In 2004, Dragon Mining NL announced the opening of the Svartliden mine which is the first operating mine in the so-called "gold line" south-west of the Skellefte District.

DEVELOPMENT OF STRATIGRAPHIC SCHEMES

In Figure 8 the development of stratigraphic ideas over the years is shown. The early concepts are illustrated by the stratigraphic schemes of Högbom (1937) and Gavelin (1955). Bearing in mind that no radiometric geochronological methods were available to the geologists at that time, the very early debate on the stratigraphic position of the well preserved rocks of the Skellefte District even involved the possibility that the rocks could be correlated with the overthrusted rocks of the Caledonian orogen. This was however never really accepted and the rocks were thought to belong to the Precambrian basement complex and designated Archaean.

In the early works, the Jörn type intrusions (see below) were considered to constitute a basement to the metavolcanic and metasedimentary rocks of the Skellefte Group. This concept was challenged by Eklund (1923) who considered the Jörn metagranitoids to be younger than the supracrustal rocks of the Skellefte Group, but older than the Vargfors formation. Eklund

considered the Vargfors formation to be older than the Revsund granite. Högbom (1937) and Gavelin (1955) on the other hand regarded the Revsund granite as older than the Vargfors formation, based on observations that the Sorsele granite was younger than the Vargfors formation in the Sorsele area. Kautsky (1957) challenged this and put the Revsund granite as younger than the Vargfors formation which in turn was regarded as coeval with a younger series of fine-grained sedimentary units called the Elvaberg slates.

Kautsky was the first to take this approach and he also subdivided the sedimentary units into older sedimentary rocks (the Maurliden and Petikträsk slates) belonging to the Maurliden series and the younger Elvaberg series (the Vargfors and Mensträsk conglomerates and the Elvaberg slates).

A similar but more dynamic approach was adopted by Helfrich (1971), see Figure 8. The stratigraphy presented by Kautsky (1959) was further developed by Lundberg (1980) who also included the Arvidsjaur and Dobblon Groups in this stratigraphic scheme (see Fig. 8). Lundberg concluded, as was also previously suggested, that the Arvidsjaur Group largely overlies the Skellefte Group and placed the Dobblon Group as a separate unit between the Revsund and Sorsele granitoids. At this stage, radiometric age determinations had been obtained from some intrusive rocks which also made it possible to better constrain the emplacement ages of the different rocks.

Weihed et al. (1992) suggested that the Vargfors Group was not separated from the Skellefte Group by a major unconformity but rather was conformable to disconformable with the older unit and, importantly, had experienced the same deformation (see Fig. 8). In their stratigraphic scheme (Weihed et al. 1992), the absolute age of the different units was also better constrained by modern U-Pb zircon ages of most rock units. The idea of Weihed et al. (1992) was further developed by Allen et al. (1996), see Figure 8, which is the basis of current thinking on the generalized stratigraphy of the Skellefte District and surrounding areas within this project.

In Figure 9, stratigraphic columns from different areas in and around the Skellefte District also emphasize both the spatial and temporal geological evolution of the area. Thus it can be concluded that in detail the stratigraphy of any area is extremely complex and no laterally extensive units actually exist in the area.

Explanation to the Bedrock Map

The bedrock in Västerbotten and Norrbotten Counties can, according to the age and the geological history of the rock sequences, be divided and assigned to three major geological units. These are the Fennoscandian Shield, the Neoproterozoic to Early Palaeozoic sedimentary cover sequence, and the Caledonides. Rocks of these three units occur to a differing extent within the map area, i.e. the Skellefte District and surrounding areas (Fig. 10).

The bedrock of the Fennoscandian Shield in northern Sweden and in northern Finland has been affected by the Svecokarelian orogeny, which lasted from c. 1.96 to 1.75 Ga. This time interval includes subduction-related processes, collision, and extension-related collapse of the thickened crust. The peak of Svecokarelian deformation and metamorphism occurred between 1.85 and 1.80 Ga (Stephens et al. 1997). The Svecokarelian orogen comprises Svecokarelian intrusive rocks, formed by orogenic processes, and Svecofennian supracrustal rocks, i.e. early orogenic sedimentary and volcanic rocks. Rocks that have been affected by the Svecokarelian orogeny are denoted with the prefix "meta" in the following description. However, this prefix is omitted for rocks of the low-grade Arvidsjaur and Vargfors Groups and the Perthite monzonite suite, in order to emphasize the good preservation with occurrences of primary textures and structures within these rocks.

Mainly Svecokarelian rocks, including the Transscandinavian Igneous Belt (TIB), Svecofennian rocks and subordinate Archaean rocks of the Fennoscandian Shield build up the major part of the bedrock within the map area and are the substantial subjects for this project. In view of the intention of the project, less attention has been paid to the allochthonous nappe sequences of the Caledonides and the underlying autochthonous cover rocks.

The following description of the bedrock in the map area is based mainly on the descriptions to the geological maps on a scale of 1:50,000, prepared by the Geological Survey of Sweden (SGU). Further references cited in this chapter are given directly in the text.

THE FENNOSCANDIAN SHIELD

Archaean rocks

Archaean (c. 2700 Ma) rocks occur within the Luleå region in the north-easternmost part of the map area,

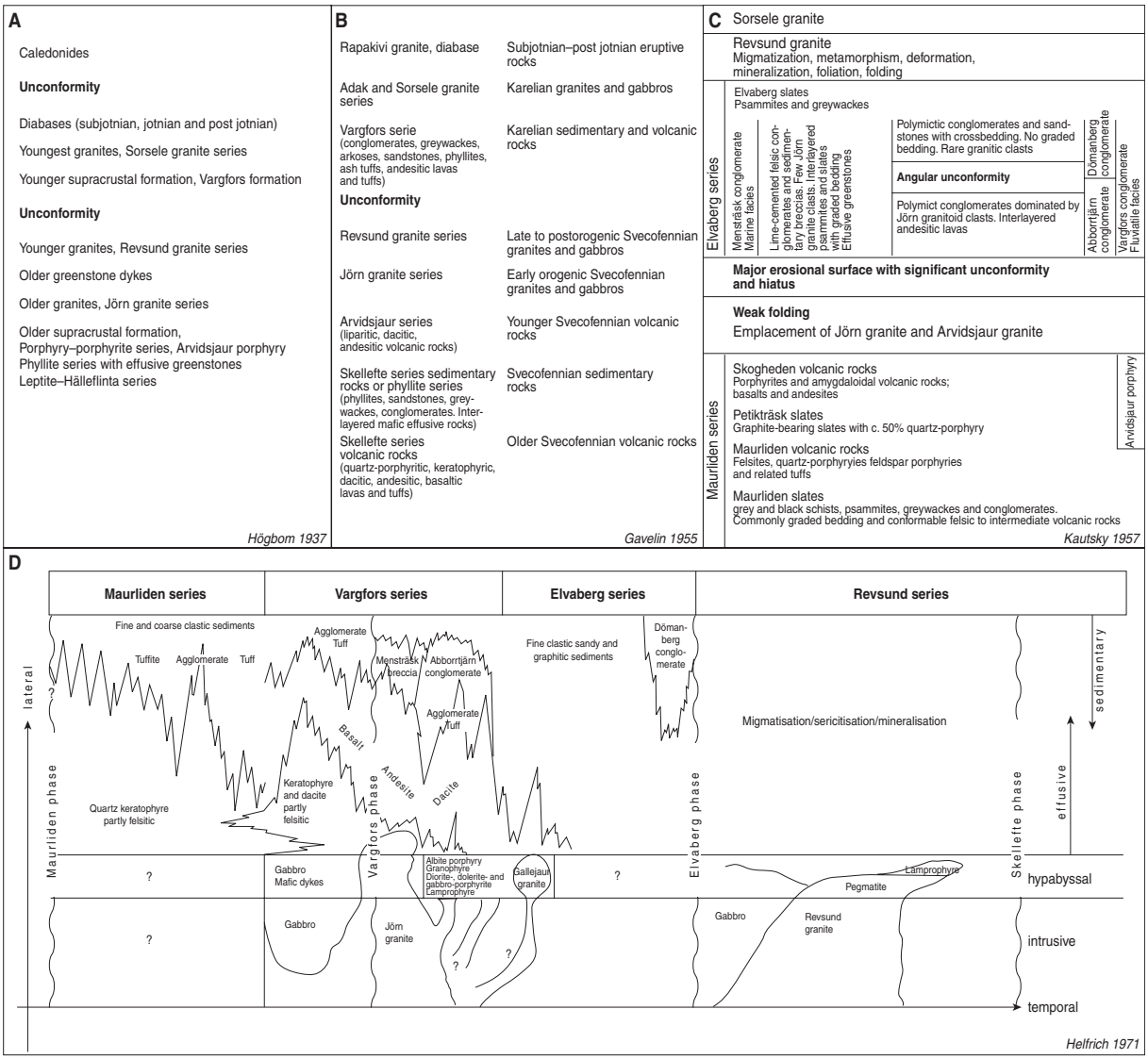


Fig. 8. The development of stratigraphic interpretations as shown by different stratigraphic schemes and generalized cross-sections. **A**. from Högbom (1937), **B**. from Gavelin (1955), **C**. from Kautsky (1957), **D**. from Helfrich (1971), **E**. from Lundberg (1980), **F**. from Weihed et al. (1992), **G**. from Allen et al. (1996), PMS: Perthite monzonite suite. Translation from Swedish and German by the editors. In this description, the stratigraphic scheme of Allen et al. (1996) is used.

*Utveckling av stratigrafiska tolkningar illustrerad med olika stratigrafiska scheman och förenklade profiler. **A**. från Högbom (1937), **B**. från Gavelin (1955), **C**. från Kautsky (1957), **D**. från Helfrich (1971), **E**. från Lundberg (1980), **F**. från Weihed m.fl. (1992), **G**. från Allen m.fl. (1996), PMS: Pertitmonzonitsviten. Översättning från svenska och tyska av redaktörerna. I den här beskrivningen används det stratigrafiska schemat av Allen m.fl. (1996).*

where they are exposed in small areas to the north and west of Luleå and in the Vallen-Alhamn area (7273640/1784630) at the coast between Luleå and Piteå (Lundqvist et al. 1996b, 2000). The Archaean bedrock of these areas consists of tonalitic to trondhjemitic gneisses, porphyritic metagranodiorites and subordinate metagabbros (Fig. 11). Within the Luleå area, the Archaean rocks form the basement to the Palaeoproterozoic Svecokarelian and Svecofennian units. All other parts of the map area lack any indication of the existence of a continental basement.

Palaeoproterozoic rocks

The Skellefte District in a wide sense is situated in the transition area between the Bothnian Basin (Hietanen 1975) in the south, and areas consisting mainly of marine and subaerial volcanic arc assemblages in the north. The marine, mainly epiclastic supracrustal rocks of the basin are here grouped under the name Bothnian Supergroup, whereas the volcanic arc assemblages are divided into the Skellefte, Vargfors, and Arvidsjaur Groups. Within the volcanic arc–Bothnian Basin transition zone, epiclastic,

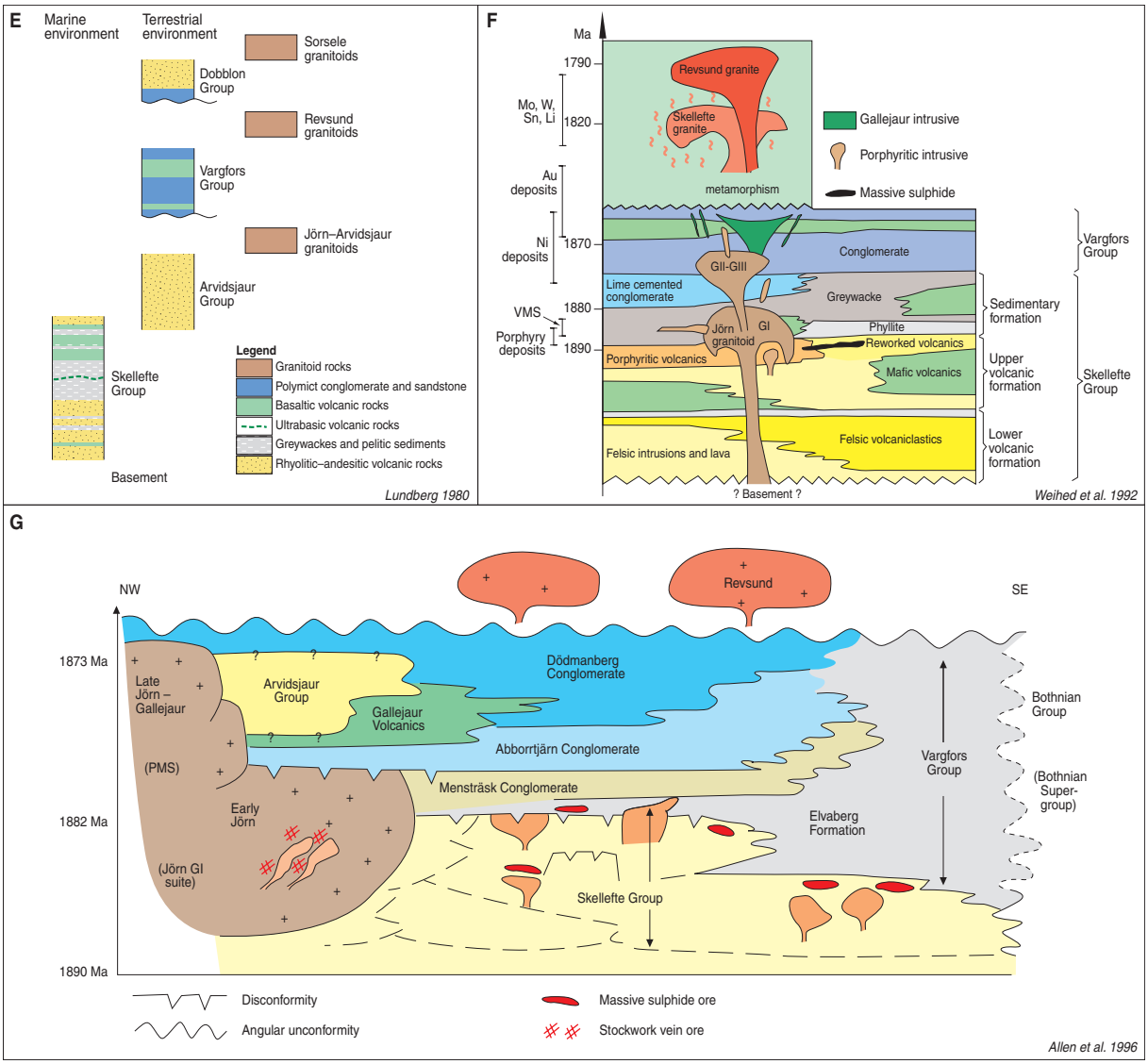


Fig. 8. Continued.

commonly turbiditic sedimentary rocks are interpreted to interfinger with subaqueous volcanic rocks and sedimentary rocks of the Skellefte and Vargfors Groups. Upwards and laterally to the north, the Skellefte Group rocks pass into mainly subaerial volcanic sequences of the Arvidsjaur Group. The marine equivalent of the Arvidsjaur Group is the Vargfors Group, which consists mainly of coarse clastic and turbiditic sedimentary rocks and mafic volcanic rocks, deposited on the rocks of the Skellefte and Bothnian Groups or the lower parts of the Arvidsjaur Group.

Differences between the Skellefte, Vargfors, and Bothnian Groups are indicated by different geochemical affinities of basic volcanic rocks. However, as these rocks occur only sparsely, especially within the Bothnian Supergroup, the boundary between the Skellefte and Vargfors Groups on the one hand and the Bothnian Supergroup on the other is drawn somewhat arbitrarily on the map. It runs from lake Dobblon (7275960/1557000), south of river Vindelälven and south of Kristineberg to Norsjö and Bastuträsk, from where it turns north. This artificial line is generally interpreted as a lateral transition from one group to the other. Rocks of the Skellefte and Vargfors Groups have their coeval counterparts within the Bothnian Supergroup. In places, the Skellefte/Bothnian Groups or Vargfors/Bothnian Groups contain laterally equivalent rock associations. In terms of sequence stratigraphy these associations should be considered as one unit, which probably consists of several, individual sequences.

At different stages and at different levels throughout the sedimentary and volcanic evolution within the map area, the supracrustal rocks have been intruded

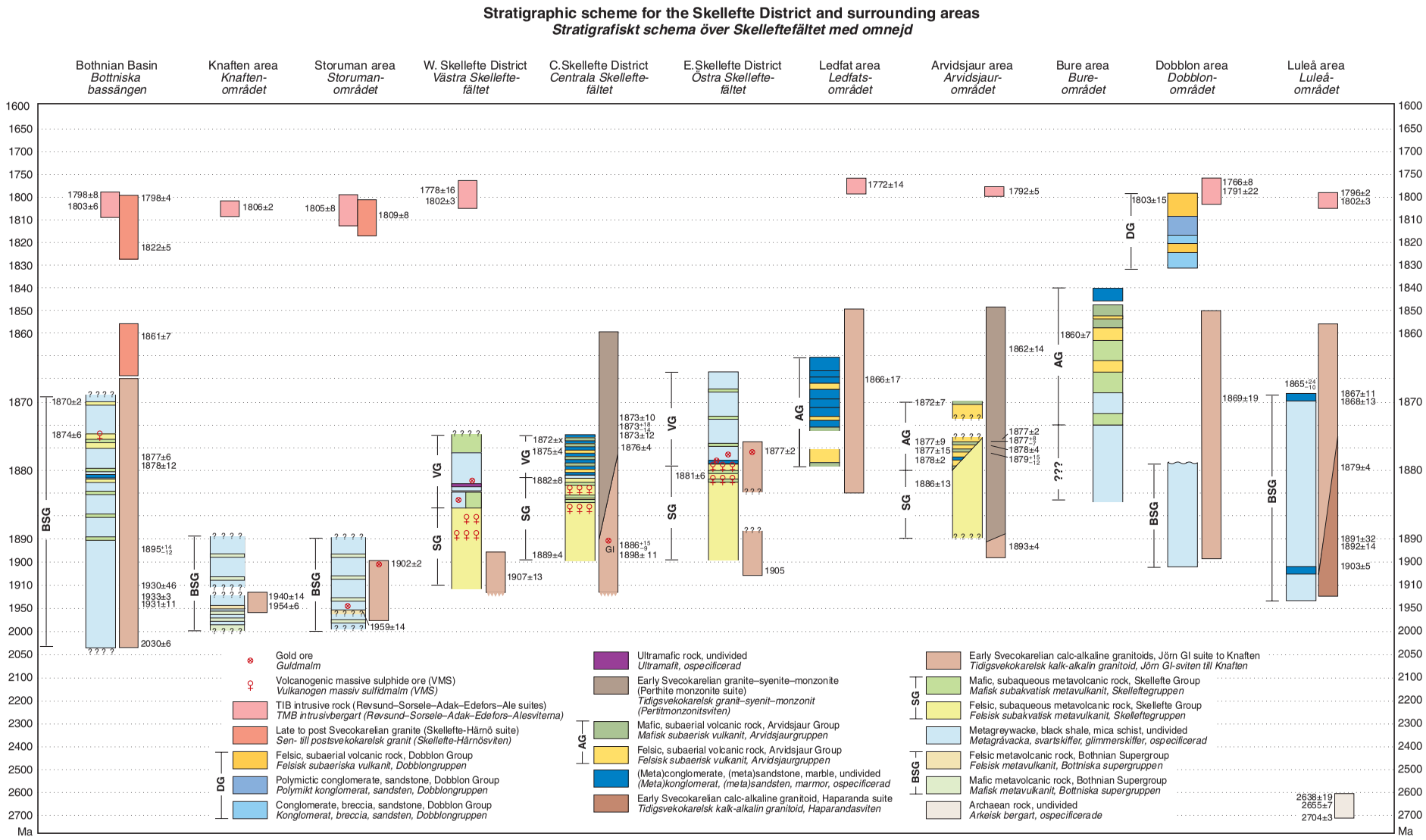
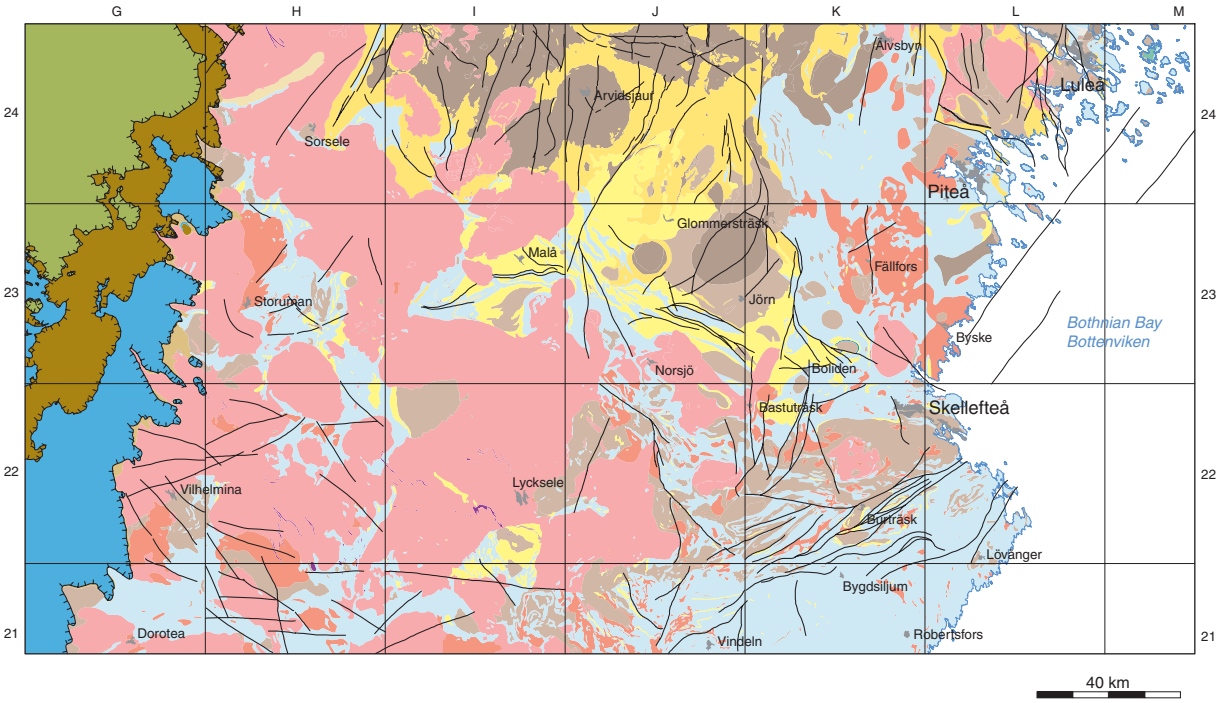


Fig. 9. Stratigraphic columns for various parts of the project area, based on available age determinations (U-Pb) of different igneous rocks (ages in million years). The geographical position of individual areas is not strictly defined. Note that the time scale is not linear. Abbreviations: BSG: Bothnian Supergroup, SG: Skellefte Group, VG: Vargfors Group, AG: Arvidsjaur Group, DG: Dobblon Group. References to ages are found in Table 1a.

Stratigrafiska kolumner för olika delar av projektområdet baserade på tillgängliga åldersdata (U-Pb) från olika magmatiska bergarter. Åldrar i miljoner år. Den geografiska utbredningen av de enskilda områdena är inte strikt definierad. Observera att tidsskalan inte är linjär. Förkortningar: BSG: Bottniska supergruppen, SG: Skelleftegruppen, VG: Vargforsgruppen, AG: Arvidsjaurgruppen, DG: Dobblongruppen. Referens till åldrarna ges i tabell 1a.



Upper Allochthon
Övre skollberggrunden

Middle Allochthon
Mellersta skollberggrunden

Lower Allochthon
Undre skollberggrunden

Sedimentary cover (Neoproterozoic–lower Palaeozoic)
Sedimentär pålagring (Neoproterozoikum–undre Paleozoikum)

Dolerite
Diabas

Late to post Svecokarelian intrusive and supracrustal rocks, c. 1.82–1.76 Ga (TIB)
Sen- till postsvekokarelska intrusiv- och ytbergarter, ca 1,82–1,76 Ga (TMB)

Late to post Svecokarelian intrusive rocks, c. 1.82–1.78 Ga (Skellefte-Härnö suite)
Sen- till postsvekokarelska intrusiv- och ytbergarter, ca 1,82–1,78 Ga (Skellefte-Härnösviten)

Early Svecokarelian intrusive rocks, c. 1.88–1.86 Ga (Perthite monzonite suite)
Tidigsvekokarelska intrusivbergarter, ca 1,88–1,86 Ga (Pertitmonzonitsviten)

Svecofennian subaerial volcanic rocks, c. 1.88–1.86 Ga (Arvidsjaur and Vargfors groups)
Svekofenniska subaeriska vulkaniter, ca 1,88–1,86 Ga (Arvidsjaur- och Vargforsgrupppen)

Svecokarelian intrusive rocks, c. 1.96–1.86 Ga (Jörn GI suite, Knaften)
Tidigsvekokarelska intrusivbergarter, ca 1,96–1,86 Ga (Jörn GI-sviten, Knaften)

Svecofennian subaqueous volcanic rocks, c. 1.96–1.86 Ga (Bothnian Supergroup, Skellefte Group)
Svekofenniska subakvatiska vulkaniter, ca 1,96–1,86 Ga (Bottniska supergruppen, Skelleftegrupppen)

Svecofennian sedimentary rocks, c. 1.96–1.86 Ga (Bothnian Supergroup, Skellefte, Arvidsjaur and Vargfors groups)
Svekofenniska sedimentära bergarter, ca 1,96–1,86 Ga (Bottniska supergruppen, Skellefte-, Arvidsjaur- och Vargforsgruppen)

Karelian rocks
Karelska bergarter

Archaean rocks
Arkeiska bergarter

Deformation zone, unspecified
Deformationszon, ospecificerad

Base of Lower, Middle and Upper Allochthons
Bas för undre, mellersta och övre skollberggrunden

Fig. 10. Simplified bedrock map of the Skellefte District and surrounding areas.
Förenklad berggrundskarta över Skelleftefältet med omnejd.

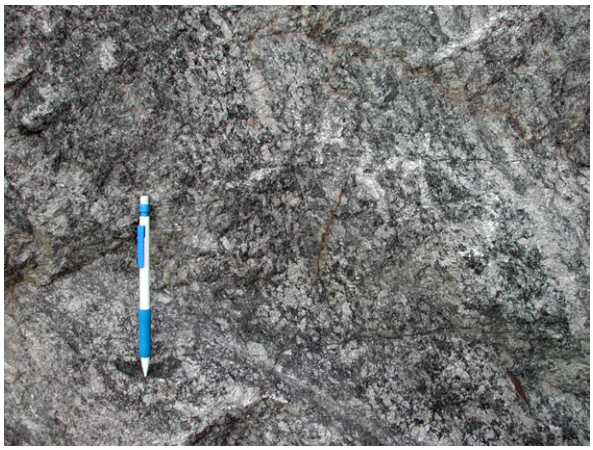


Fig. 11. Porphyritic Archaean metagranodiorite. Quarry at Näverberget hill, about 10 km west-southwest of Luleå (7288210/1783520). Photo Claes Mellqvist.
Porfyrisk arkeisk granodiorit. Stenbrott vid Näverberget, ca 10 km västsydväst om Luleå.

by voluminous amounts of plutonic rock. On the one hand, these plutonites enable dating of the sedimentary record; on the other hand they obscure primary relationships between different supracrustal units.

Svecofennian supracrustal rocks: Bothnian Supergroup

The Bothnian Supergroup comprises sedimentary successions of the Härnö Group (Kousa & Lundqvist 2000) in the south, Karelian sedimentary rocks in the north-east, and supracrustal rocks of uncertain affinity between these units. Scattered occurrences of metavolcanic rocks are included within the group.

Rocks of the Bothnian Supergroup form the bedrock in vast areas of the south-eastern and eastern parts of the map area. The rocks of the south-eastern area belong to the sedimentary successions of the Bothnian Basin (Hietanen 1975), which are correlated across the Baltic Sea with the Pohjanmaa or Bothnian schist belt in Finland (Kousa & Lundqvist 2000). To the west and south-west of the Skellefte District, the supracrustal rocks of the Bothnian Supergroup occur as irregularly shaped relics between the different intrusions of the Transscandinavian Igneous Belt (TIB) and older Svecokarelian intrusive suites.

In general, the Bothnian Supergroup consists of volcanogenic turbiditic greywackes and argillites, debrites and other conglomeratic rocks, interlayered by mafic and subordinate felsic volcanic rocks. Apart from the Knaften (7152660/1636300) and Gunnarn areas, volcanic assemblages are rare within the Bothnian Supergroup. The rocks of the Bothnian Supergroup display evidence of two or more periods of folding. In places, intercalated horizons of black shales, commonly associated with graphite and pyrrhotite, give a distinct magnetic anomaly pattern, which explains the structural framework of the group. The metamorphic grade varies considerably, from greenschist to upper amphibolite facies with veining, migmatization and generation of migmatite granites.

The sedimentary evolution of the Bothnian Supergroup started before 1954 Ma in the map area and probably even earlier in the central parts of the Bothnian Basin south of the map area. Lundqvist (1987) estimates the maximum thickness of the supracrustal sequence to c. 10 km for the central part of the Bothnian Basin. Metagreywackes of the central Bothnian Basin with negative ε_{Nd}-values (–2.4 to –3.1) indicate influx of older (>1900 Ma) detrital crustal material (Claesson 1987). Metasedimentary rocks of the Storuman area and of the area north of Boliden show ε_{Nd}-values between –1 and –2, suggesting Archaean influence even in those sediments. Detrital zircons from low-grade greywackes range in age from 1880 to 2020 Ma (Lundqvist et al. 1998). The sedimentation lasted more than 80 Ma and continued up to at least 1870 Ma (Lundqvist et al. 1998).

The Bothnian Supergroup was intruded by several generations (c. 1950 to 1890 Ma) of early Svecokarelian granitoids and late to post Svecokarelian granites and associated rocks of the Skellefte-Härnö suite and the Transscandinavian Igneous Belt (TIB; see below). These rocks geographically divide the metasedimentary bedrock into several subareas. In the following description of the metasedimentary rocks of the Bothnian Supergroup, six subareas (1–6) have been distinguished.

The metasedimentary rocks of the south-eastern area between Skellefteå, Vindeln, and Robertsfors, hosting the Nickel-zone (*subarea 1*), consist mainly of metagreywackes and meta-argillites. These rocks were originally impure sand and clay which had been deposited mainly by turbidity currents in a marine basin environment and then lithified to greywackes and shale.

During Svecokarelian deformation and metamorphism, the rocks were transformed to paragneisses or veined gneisses. Within the latter, dark, biotite-rich and light, quartz-feldspar dominated layers are alternating in mm to cm scale (Fig. 12a). Increased metamorphism led to the formation of migmatites with partial melting of the metasedimentary rocks, i.e. the generation of granitic to granodioritic melts, which occur both parallel with the gneissic foliation and truncating it. Relics of gneissic foliation and schlieren or xenoliths of metasedimentary rocks are common within these migmatites.

Intercalation of graphite- and pyrrhotite-bearing horizons is a characteristic feature within the metasedimentary sequence. The graphite is confined to thin horizons, commonly along the schistosity surfaces. Pyrrhotite occurs as dissemination but also as breccias with massive pyrrhotite. Where exposed, these horizons are 1–10 m thick, but thicknesses of several hundred metres are indicated by geophysical ground measurements. The graphite- and pyrrhotite-bearing horizons cause distinct anomalies on the magnetic anomaly and electromagnetic maps, which demonstrate excellently the diversity of deformation patterns in different areas.

The predominant minerals within the metasedimentary sequence are biotite, quartz, and feldspar (oligoclase). Sillimanite and garnet occur within the veined gneisses, whereas cordierite has only been found within the migmatites. A lens of quartz-rich, light grey or bluish grey, foliated rocks, denoted as chert on the map, contains amphibole and disseminated magnetite. This rock is interpreted as a probable product of exhalative precipitation in connection with volcanic activity with-

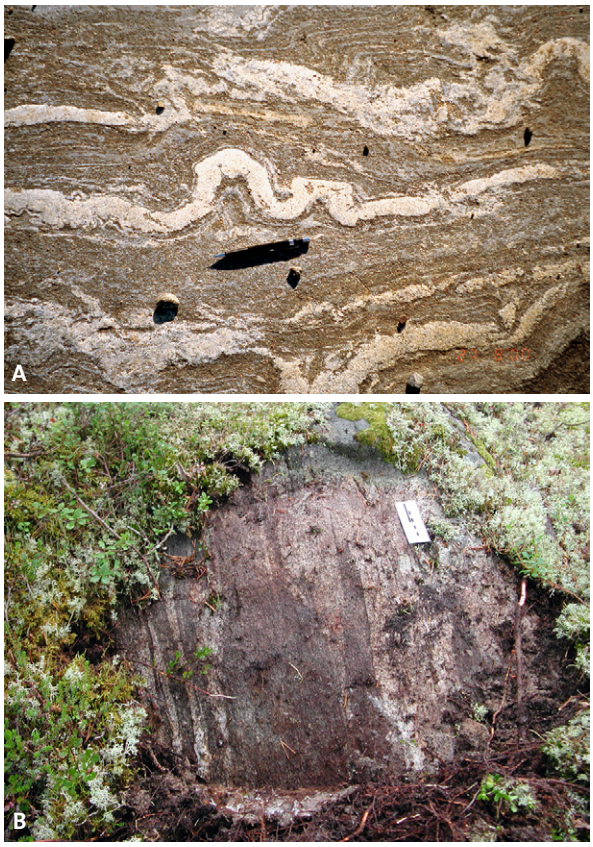


Fig. 12. **A**. Migmatitic veined gneiss, Bothnian Supergroup. Fagerliden, about 3 km north of Robertsfors (7133750/1744600). **B**. Migmatized greywacke with deformed neosome, Bothnian Supergroup. Klubbälven, about 12 km south-east of Långträsk (7252347/1719627). Photo Benno Kathol.

***A**. Migmatitisk sedimentådergnejs, Bottniska supergruppen. Fagerliden, ca 3 km norr om Robertsfors. **B**. Migmatitiserad gråvacka med deformerat neosom, Bottniska supergruppen. Klubbälven, ca 12 km sydost om Långträsk.*

in the area. Minor lenses or layers of crystalline carbonate rocks are associated with amphibolites of volcanic origin. Most of the carbonate rocks are intersected by pegmatites.

Carbonates from original carbonate cementation within the greywackes are now altered to calc-silicate (skarn) lenses or nodules. These calc-silicates are common within the less metamorphosed parts of the Bothnian Supergroup and are still preserved within the veined gneisses and migmatites. Elongated lenses of garnet-bearing skarn contain several cm-sized magnetite crystals and some fluorite. Quartz-impregnated calc-silicate rocks (skarn) or quartz-breccias are related to tonalitic intrusions and occur along the contacts or within these tonalite bodies.

Another area with rocks of the Bothnian Supergroup (*subarea 2*) is located to the north of Skellefteå and Boliden, confined by the Jörn granitoid complex (Wilson et al. 1987b) and the Arvidsjaur volcanic rocks in the west, Älvsbyn and Piteå in the north and the coastline in the east. The Svecofennian sedimentary rocks of this area consist mainly of metagreywackes with varying degrees of deformation and metamorphism in different areas. In general, the metamorphic grade increases from medium-grade conditions in the southern and western parts to high-grade conditions with alteration to veined gneisses and migmatites towards the north-east (Fig. 12b). The bedrock in the migmatite areas is dominated in many places by leucosome, i.e. migmatite granites generated by partial melting. Areas where these granites dominate the bedrock are marked on the map as late to post Svecokarelian granites.

South-east of the composite Jörn granitoid complex, the metasedimentary rocks of the Bothnian Supergroup overlie the supracrustal rocks of the Skellefte Group but, in general, the time interval for deposition of the sediments is unclear. A metagreywacke from the area south-west of Storsund (7283590/1722290) yielded a U-Pb monazite age of 1867±10 Ma. This age is interpreted as representing a metamorphic event, which consequently gives a minimum age for the deposition of the sedimentary sequence.

Kalevian-type phyllites, schists, and greywackes of the Luleå area, resting on an Archaean basement, are gathered under the name Råneå Group on the Mid-Norden map (Lundqvist et al. 1996a, Lukkarinen & Lundqvist 2000). The sedimentary rocks of the Råneå Group are considered as transitional to the greywackes of the Svecofennian Härnö Group in the west and south-west; the border between the two groups is arbitrarily drawn on the Mid-Norden map. In this project, no distinction is made for similar rock types, regardless of whether they are resting on an Archaean basement or on an unknown substratum. Therefore, these transitional rocks are included within the Bothnian Supergroup.

The metagreywackes of subarea 2 consist of arenitic to argillitic beds, which were originally deposited by turbidite currents in a marine basin environment. Their turbiditic origin is proven in areas with well preserved primary structures such as graded bedding, load casts and convolute folds, and also by the general character of the sedimentary sequence. Thin layers of volcaniclastic rocks and pillow lavas indicate volcanic activity during the epiclastic sedimentation. Layers of polymict, commonly matrix-supported conglomerates with rounded to well rounded clasts of quartz, black shales, metagreywackes, and greenstones occur as local intercalations within the metagreywacke sequence. Carbonates from original carbonate cementation, now altered to calc–silicate lenses or nodules are common within the southern parts of the subarea (Fig. 13).



Fig. 13. Epidote-bearing calc-silicates in metagreywackes of the Bothnian Supergroup. Berget near Andersberg, about 14 km south of Boliden (7188550/1716870). Photo Risto Kumpulainen.

Epidotförande kalksilikater i metagråvackor av den Bottniska supergruppen. Berget vid Andersberg, ca 14 km söder om Boliden.

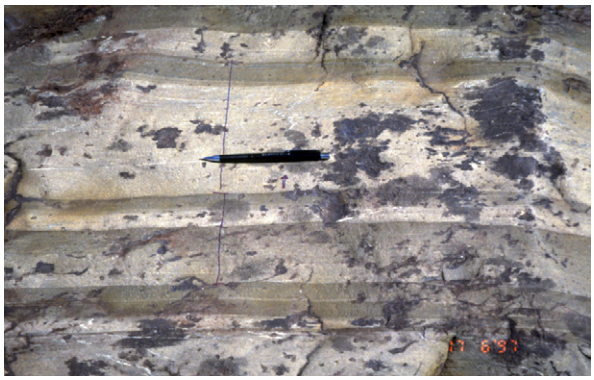


Fig. 14. Turbiditic metagreywacke, Bothnian Supergroup. Haga at river Umeälven, about 13 km east-southeast of Storuman (7216300/1573420). Photo Benno Kathol.

Turbiditisk metagråvacka, Bottniska supergruppen. Haga vid Umeälven, ca 13 km ostsydost om Storuman.

Also in this subarea, horizons of graphite- and pyrrhotite-bearing black shales are common and cause distinct anomalies on the magnetic anomaly and electromagnetic (VLF) maps. In the Åbyälven area, these anomalies have previously been considered to represent continuous amphibolite layers within the metagreywacke sequence (Lundmark 1984, 1985a). However, recent geophysical ground measurements within this project have shown that the anomalies are caused by the above-mentioned black shales and not by amphibolites. Nevertheless, minor lenses of amphibolite do seem to be connected with the black shales. This apparent concentration of volcanic products within these horizons is probably a result of lower sedimentation rates for the black shales, which consequently represent longer time intervals than do beds of equal thickness within the metagreywackes.

The metasedimentary rocks within a north-west–south-east striking zone south of the central part of the Skellefte District, i.e. south of Norsjö and Bastuträsk *(subarea 3)* consist mainly of turbiditic, generally argillitic greywackes. Normally, these rocks are foliated and altered to veined gneisses and migmatites. The metamorphic grade ranges from medium to upper amphibolite facies; index minerals are garnet, andalusite, and cordierite.

The bedrock in the Knaften area *(subarea 4)* consists of a >1.95 Ga old assemblage of supracrustal and intrusive rocks. This assemblage is confined laterally and below by either intrusive rocks of the TIB or, in the south, by a major deformation zone. The Knaften assemblage probably represents an early Svecokarelian megaxenolith in the TIB rocks.

The metagreywackes of the Knaften area represent the oldest parts of the Härnö Group (cf. Lundqvist 2000) in the Mid-Norden map area (Kousa & Lundqvist 2000). This is also valid for the Bothnian Supergroup of the project area, probably with the exception for the Kalevian–Svecofennian transitional metasedimentary rocks of uncertain age in the Luleå area. Minimum ages for the metagreywacke sequences of the Knaften area are given by U-Pb zircon ages of 1954±6 Ma (Wasström 1993) and 1940±14 Ma (Wasström 1996), obtained from intrusive rocks within the metagreywackes.

The metagreywackes are relatively well preserved and consist of an intercalation of cm to dm thick arenitic beds and mm to cm thick argillitic layers. This succession is normally undisturbed, but syngenetic deformation structures such as contortion, folding and fragmentation of particular beds have been observed sporadically. The mineral composition is dominated by quartz, plagioclase, and biotite. Potassium feldspar, muscovite, chlorite, and opaque phases occur in small and varying quantities. Other, subordinate minerals are apatite, graphite, zircon, tourmaline, andalusite, epidote, garnet, and cordierite. Somewhat elongated, cm to dm sized clasts of quartzite, meta-arenite, meta-argillites and metavolcanic rocks are common within the metagreywacke sequence.

The Bothnian Supergroup of the area along the river Umeälven between Åskilje (7202070/1597320) and Storuman and farther to the north to lake Storjuktan *(subarea 5)* is composed of turbiditic metagreywackes, muddy turbidites, coarse clastic rocks and intercalations of felsic and mafic volcanic rocks. In areas where these rocks are well preserved, the turbiditic metagreywackes normally show a distinct cm–dm scale layering of arenitic and argillitic beds; in places, up to 3 m thick arenitic beds have been observed. The ratio of thickness between arenitic and argillitic layers varies, but ranges normally between 2:1 and 3:1 (Fig. 14). Coarser layers contain 2–3 mm sized clasts of quartz, plagioclase,

and rock fragments. The fine-grained matrix contains quartz, plagioclase, biotite, muscovite, chlorite, and opaque phases. Rock fragments are either derived from granitoid sources or from biotite- and chlorite-rich sedimentary rocks. Accessory minerals are zircon, tourmaline, apatite, epidote, chlorite, and secondary calcite. Isotope geochemical analyses indicate that up to half of the sediments are of Archaean origin (Lundström 1998). Primary sedimentary structures such as graded bedding, load casts and slumping breccias are preserved and can in places be used for "way-up" determination. Within the Järvsjö map area, syngenetic slumping (slides) within the turbidite sequence generated breccias with clasts of broken and contorted arenitic layers within an argillitic matrix. Later deformation resulted in flattening of the breccia clasts.

Svecokarelian metamorphism resulted in grain size coarsening, especially within the argillitic layers, and the growth of synkinematic porphyroblasts (<1 cm) of andalusite and cordierite, which in most cases are retrogressed to fine-grained muscovite and feldspar. Quartz veins are common within the metagreywackes, their frequency increasing with increasing metamorphic grade. In areas with amphibolite facies conditions, granitic veins and dykes are common, and the bedrock here is normally very heterogeneous. These veined gneisses, consisting of granitic and biotite-rich bands, are intruded by dykes and minor intrusions of late to post Svecokarelian granites. Alteration to veined gneisses or migmatites occurs south of Blåviksjön (7192780/1606930) and in the Stensele area. The metamorphism in the latter area may have been caused (or at least overprinted) by the major, late to post Svecokarelian granite intrusion north of Storuman.

The volcano-sedimentary succession along river Umeälven, particularly well exposed around Haga (7216300/1573420), about 7–10 km east of Stensele, contains a number of facies types. Due to local high strain and metamorphic grade, reconstruction of the facies relationships is difficult, but interpretation of the general characteristics of the sedimentary basin is still possible. Very thinly to thinly bedded turbidites (C2.3 facies of Pickering et al. 1986), with a mud to sand ratio of about 1:3, dominate this area. Bed thicknesses up to c. 0.5 m are subordinate and beds thicker than 1 m are rare.

Muddy turbidites (D2-type facies of Pickering et al. 1986) are also common and are now represented by black shales with graphite- and pyrrhotite-bearing horizons, which can be clearly distinguished on the magnetic and electromagnetic (VLF) maps. Normally, these black shales are strongly deformed, with well-developed schistosity.

Coarse clastic deposits, both massive debrites (A1.1 facies of Pickering et al. 1986) and stratified conglomerates (A2-type facies of Pickering et al. 1986), occur locally in this fine-grained turbidite succession. Most of the clasts consist of coarse-grained granitoids in the massive debrites, where clast sizes up to 80 cm in diameter have been observed at Björkliden (7210310/1582820), Stor-Orrliden (7224050/1588020) and Blåviksjön (7192780/1606930). Radiometric dating (U-Pb, zircon) of one metagranodiorite clast from the conglomerate at Blåviksjön yielded a U-Pb zircon age of 1890±4 Ma (Welin et al. 1993). The massive debrites at Kovallberget (7208650/1591430) also contain felsic volcanic clasts. The stratified conglomerates at Lisasbergtangen (7199000/1595500, Fig. 15a) and Kovallberget (Fig. 15b) are dominated by felsic volcanic rocks with clasts up to 60 cm in diameter.

Based on these sedimentological features, the character of the sedimentary basin in the area of river Umeälven may be inferred. Deep-water canyons probably crosscut the contemporaneous submarine slope, transporting coarse clastic material to the base of the slope, where the suspension cloud could have turned left or right, trans-



Fig. 15. **A**. Stratified conglomerate, Bothnian Supergroup. Lisasbergtangen, about 16 km south-southeast of Gunnarn (7199000/1595500). **B**. Oligomict conglomerate, dominated by clasts of felsic volcanic rocks, Bothnian Supergroup. Kovallberget, about 5 km south-east of Gunnarn (7208650/1591430). Photo Benno Kathol.

***A**. Stratifierat konglomerat, Bottniska supergruppen. Lisasbergtangen, ca 16 km sydsydost om Gunnarn. **B**. Oligomikt konglomerat, klastmaterialet består till övervägande delen av felsiska vulkaniter, Bottniska supergruppen. Kovallberget, ca 5 km sydost om Gunnarn.*

porting and depositing the fine fractions along the basin, which is commonly the case along active plate margins. In this way, "distal" turbidites can become deposited next to a tectonically active submarine slope. Slope instability, also between the possible canyons, initiates sediment gravity flows at regular or irregular intervals. Depending on the distance of transport, these flows can develop into suspension currents, depositing a turbidite layer, or continue as debris flows and deposit a debrite. This interpretation may be extended to the coarse clastic deposits also in the present area. The high content of quartz in these sedimentary rocks supports the presence of a continental source close to this sedimentary basin. The primitive chemistry of the mafic volcanic rocks in this succession supports the interpretation that these sediments were deposited in a back-arc basin.

The metasedimentary sequence in the south-west between the Knaften area and the Caledonian front *(subarea 6)*, consists of turbiditic metagreywackes with intercalated horizons of graphite- and sulphide-bearing shales.

Within the eastern parts of this area, the metagreywackes are normally well preserved, whereas alteration to paragneisses, veined gneisses or migmatites is common, especially in the south-western parts. Hornfels alteration has been observed in a few localities.

In the areas with well preserved bedrock, the metagreywackes show cm to dm scale alternating layering of arenitic and argillitic beds on a cm to dem scale. Normally, the lighter arenitic beds are thicker than the argillitic layers, and the arenitic components constitute more than half of the rock volume. In places, the succession is predominantly arenitic. Primary structures such as graded bedding are common and "way-up" determinations have been possible in some localities.

Main minerals are quartz, plagioclase, and biotite; potassium feldspar, muscovite, and opaque phases occur in varying amounts. Tourmaline, apatite, zircon, and titanite have been found as accessory minerals. Andalusite, garnet, cordierite and sillimanite occur as index minerals for different metamorphic facies.

A common feature of all metagreywackes of this subarea is the intercalation of meta-argillites and mafic volcanic rocks, which in places dominate the bedrock. Characteristic, calc-silicate (skarn) altered fragments of previously carbonate-rich layers are commonly associated with lenses of mafic volcanic rocks.

In the Fäbodliden area (7170600/1602600), fine-grained meta-arenites with intercalations of dark grey, rusty and in places sulphide-bearing meta-argillites contain metre-sized lenses of greyish white, fine-grained, sulphide-bearing quartzite. Within this area, alternating quartz-rich and magnetite-rich layers cause a distinctive banding of the rocks, which is interpreted as a Banded Iron Formation (BIF, Fig. 16).

The metamorphic grade varies from medium grade in the eastern parts to high grade in the south-western parts of the subarea.

Mostly mafic, metavolcanic rocks of the Bothnian Supergroup occur as rare interbeds and shallow intrusions within the metasedimentary sequence of the areas between lake Storjuktan and Gunnarn and within the Knaften area south of Lycksele. At Knaften (7152660/1636300) a subvolcanic quartz-feldspar porphyritic dyke which cross-cuts a pillow lava has been dated at 1940±14 Ma (Wasström 1996) and a metagranitoid, which is intrusive into the supracrustal rocks, yielded an age of 1954±6 Ma (Wasström 1993). Furthermore, a dacitic to rhyolitic pyroclastic mass flow deposit at Barsele (7216860/1577440) has been dated at 1959±14 Ma (Eliasson & Sträng 1998). Clearly, this unit is much older than the rocks of the Skellefte Group. Wasström (1990) suggests that an even older volcanic episode of MORB affinity preceded the emplacement of the oceanic, tholeiitic Knaften metavolcanic rocks, because they are associated with breccias carrying clasts of older volcanic rock types. At Kovallberget (7208650/1591430) a conglomerate with clasts of felsic volcanic rock also suggests even older volcanism.

The mafic metavolcanic rocks of the Bothnian Supergroup frequently show pillow structures (Fig. 17). In many places, they are associated with hyaloclastic to autoclastic breccias or polymict debris flow deposits. The pillows have amygdaloidal margins in most places, suggesting emplacement in rather shallow water. In the Knaften area, both amygdale-bearing and amygdale-free pillows occur, possibly indicating rapidly changing water depths during emplacement, or variations in gas content.

The stratigraphic position of the supracrustal rocks between Lycksele and the Bothnian Bay is uncertain. They have very rare interbeds of metavolcanic rocks, which are generally too strongly metamorphosed to allow volcanological interpretation. However, Weihed & Antal (1998) report a pillow lava interbedded within volcaniclastic basalts at Rörmyrberget (7150800/1668930).

Felsic metavolcanic rocks are extremely rare within the Bothnian Supergroup. The dated pyroclastic mass flow deposit (see above) at Barsele (7216860/1577440) is an obviously juvenile unit, whereas resedimented felsic tuffites in the Knaften area (7152660/1636300) show cross-bedding, load casts, current ripples, and erosional surfaces (Wasström 1992). These rocks thus represent a more distal facies, apparently deposited in shallow water. Scattered, minor occurrences of more metamorphic, felsic metavolcanic rocks of uncertain



Fig. 16. Banded iron formation (BIF) in metagreywacke, Bothnian Supergroup. Fäbodliden, about 35 km west of Lycksele (7170726/1602616). Photo Benno Kathol.

"Banded iron formation" (BIF) i metagråvacka, Bottniska supergruppen. Fäbodliden, ca 35 km väster om Lycksele.



Fig. 17. Pillow lava, Bothnian Supergroup. Knaften area, about 12 km south-southeast of Lycksele (7156300/1641550). Photo Benno Kathol.

Kuddlava, Bottniska supergruppen. Knaftenområdet, ca 12 km sydsydost om Lycksele.

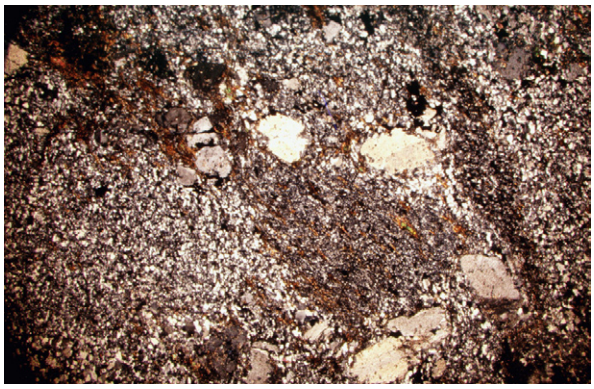


Fig. 18. Angular clasts of quartz, plagioclase, and tubular pumice in pyroclastic mass flow deposit, interbedded within metasedimentary rocks of the Vargfors Group. 1 km south-west of Boliden (23K) (7203060/1715810). Boliden company drill core 678, 318 m. Photo Ingmar Lundström

Kantiga fragment bestående av kvarts, plagioklas och tub-pimpsten i pyroklastisk massflödesavsättning, inlagrad i metasedimentära bergarter i Vargforsgruppen. 1 km sydväst om Boliden. Från Boliden Mineral AB's borrkärna 678, 318 m.

origin occur in the area between Lycksele and the Bothnian Bay.

Within the turbiditic sedimentary rocks east of Boliden, dacitic to rhyolitic volcanic siltstones are common as interbeds. As broken phenocrysts and even pumice fragments can be discerned in the better preserved parts (Fig. 18), Allen et al. (1996) interpreted these siltstones to have formed as post-eruptive mass flow deposits. At Röjnoret (7192770/1705500) east of Bastuträsk, there is a quartz porphyritic apparently subvolcanic intrusive unit. Around and to the south of Skellefteå, scattered lenses of felsic, metavolcanic rocks occur, which are difficult to interpret due to intense metamorphic alteration (medium to high grade) in these areas.

Svecofennian supracrustal rocks: Skellefte Group

The metavolcanic rocks of the Skellefte Group are concentrated along the river Skellefteälven between Jörn, Boliden, Norsjö, and Glommersträsk. Outliers are found in the Malå, Kristineberg, and Vindelgransele (7225010/1617430) areas. They yield radiometric ages around 1.89–1.88 Ga (see Tab. 1a) and were formed as rhyolitic to basaltic, mostly subaqueously emplaced lavas, lava- or cryptodomes, resedimented debris from these, and rather juvenile, pyroclastic mass flow deposits. These units together constitute an extremely variable internal stratigraphy. At least in the central and eastern parts of the area, a characteristic feature of the Skellefte Group metavolcanic rocks is their frequent interbedding with metasedimentary rocks (Fig. 19a).



Fig. 19. **A**. Rip-up clast of planar-bedded siltstone within a volcanic mass flow deposit of the Skellefte Group. Viterberget north-west of Renström mine (7210100/1702200). Photo Ingmar Lundström. **B**. Rhyolitic volcanic mass flow, Skellefte Group. Stora Sandberget, about 12 km west-northwest of Glommersträsk (7250250/1667020). Photo Benno Kathol. **C**. Planar bedded, distal, metavolcanic siltstones. Lillbrännberget, north of Strömfors (7208200/1716700). Photo Ingmar Lundström. **D**. Juvenile, pyroclastic mass flow deposit with partly compacted fiamme, wrapping around lithic clasts. Skellefte Group. Torrberget hill, 4 km north of Kankberg (7214600/1711260). Photo Ingmar Lundström.

***A**. Upprivet fragment av planskiktad siltsten i ett vulkaniskt massflöde inom Skelleftegruppen. Viterberget nordväst om Renströmgruvan. **B**. Ryolitiskt vulkaniskt massflöde, Skelleftegruppen. Stora Sandberget, ca 12 km västnordväst om Glommersträsk. **C**. Planskiktad distal metavulkanisk siltsten. Lillbrännberget norr om Strömfors. **D**. Juvenil, pyroklastisk massflödesavsättning med delvis kompakterade "fiamme" som sveper runt bergartsfragment. Skelleftegruppen, Torrberget 4 km norr om Kankberg.*

In many cases, this indicates that deposition took place in a marine environment below wave base. However, the abundant pumice fragments of the mass flow deposits indicate emplacement from nearby shallow water or subaerial eruptive environments, especially in the northern part of the area. Furthermore, the large amounts of volcaniclastic debris, found within the metasedimentary rocks, indicate a shallow water or subaerial provenance area (Dumas 1986). Consequently, the eruptive and depositional environment must have varied with abrupt changes during the emplacement of the Skellefte Group rocks. The metasedimentary interbeds appear to be more common in the stratigrapically higher levels of the group, which may indicate a gradual change towards the depositional environments prevailing during the deposition of the mainly epiclastic rocks of the Vargfors Group. Carbonate rocks occur sparsely, but most frequently close to the boundary with the overlying Vargfors Group.

The rock compositions variy greatly between different areas (see Fig. 10 in Allen et al. 1996), but the basic or intermediate rocks are generally thought to be more frequent in the upper part of the Skellefte Group.

Other characteristic features within the Skellefte Group are the numerous and locally widespread hydrothermal alterations that have affected the rocks (see chapter "Ores and Mineralizations"). For example, a regional and thorough alteration of phyllic type has affected the Kristineberg area.

The most common felsic metavolcanic rocks are quartz or feldspar porphyritic rhyolitic to dacitic pyroclastic pumiceous mass flow deposits, subvolcanic

intrusions similar to the Jörn GI metagranitoid (see below), lava domes, hyaloclastites, autobreccias, and resedimented rocks derived from these. Proximal volcanic facies (Fig. 19b) are therefore common, but planar bedded, more distally deposited volcanic-derived siltstones also occur (Figs. 19a,c). Although frequently compacted (Fig. 19d), the pumice clasts of the mass flow deposits are mostly unwelded, which demonstrates the subaqueous depositional environment of these deposits. Indications of proximal volcanic depositional environments such as coherent metavolcanic rocks or autoclastic and hyaloclastic breccias are more common in the central and western parts of the area than in the eastern parts, where features indicative of a more distal depositional environment gradually become more frequent (e.g. Fig. 19c). Thus, metasedimentary interbeds are more common, the metavolcanic breccias and conglomerates are more polymict and poorer in pumice and their clasts are more rounded in areas east of Renström (7208310/1703400, Lundström & Antal 2000), where resedimentation and reworking was apparently more common.

Basaltic to andesitic, mostly coherent metavolcanic rocks, interbedded with planar bedded marine metasedimentary rocks occur between Norsjö and Jörn and around Malå. These rocks were called the Skogheden volcanic rocks in the central area by Kautsky (1957) and the Tjamstan metavolcanic rocks in the Malå area by Bergström (1997). Similar rocks are furthermore found on the Sappovare hill (7247030/1652500), about 25 km north-west of the central Skellefte District. Field data are still insufficient to tell if these occurrences are interconnected. The mafic rocks are thought to overlie most of the felsic rocks described above, because a felsic subvolcanic intrusion in felsic Skellefte Group metavolcanic rocks does not penetrate into the overlying mafic Tjamstan metavolcanic rocks at Storliden hill (7237850/1645820) north of Malå. Furthermore, mafic rocks seem to be more frequent in the upper parts of the profiles presented from the central area by Allen et al. (1996). Nevertheless, an interbedded dacitic mass-flow unit on the Tjamstan hill (7233700/1638500) east of Malå has recently yielded a preliminary age of 1895 Ma (SGU, unpublished), which is the oldest age recorded so far among the metavolcanic rocks of the Skellefte Group.

The Tjamstan metavolcanic rocks are plagioclase porphyritic, basaltic to andesitic, locally distinctly pillowed amygdaloidal lavas (Fig. 20a) with frequent hyaloclastic and autobrecciated derivatives as well as interbedded mass flow deposits. From the central area, Kautsky (1957) described the Skogheden metavolcanic rocks as plagioclase porphyritic lavas with quartz-, carbonate-, or chlorite-filled amygdales. At Granbergsliden hill (7226490/1677570), Skogheden type metavolcanic rocks display an interesting pattern of plastically deformed, yet broken pillow clasts (Fig. 20b). The clasts have clearly chilled margins, except along the fractures, which led Allen et al. (1996 and pers. com.) to interpret them as formed by subaqueous basaltic fire fountains (Fig. 20c).

Mafic, possibly metavolcanic rocks also occur among the Skellefte Group metavolcanic rocks north-east of Boliden. Their exact extent is difficult to delineate, however, because they are associated with an extremely pervasive actinolite blastesis that blurs the contact relationships.

The metasedimentary rocks of the Skellefte Group comprise intercalated grey to black mudstones, volcanic-derived siltstones, sandstones, relatively coarse greywackes, breccias, and conglomerates of prevailing volcanic origin, and rare limestone. In places, these rocks are strongly foliated (Fig. 21) and partly sheared. The metamorphic grade varies from greenschist to lower amphibolite facies.

Svecofennian supracrustal rocks: Arvidsjaur Group

An area with supracrustal rocks, almost exclusively of volcanic origin, extends north of the areas occupied by Skellefte and Vargfors group rocks, far into the Norrbotten County. Rocks of this unit, which is called the Arvidsjaur Group, also occur at Bure (7274420/1594550), Ledfat (7268200/1617410), Kamsån (7238710/1712230), and at Vistheden. Arvidsjaur Group rocks have given radiometric ages of 1878±2 Ma (Skiöld et al. 1993), 1879^{+15}_{-12} Ma (Kathol & Persson 1997), and 1877±9 Ma (Kathol SGU, unpublished). This group is therefore of the same age as the more sedimentary Vargfors Group farther south, see below. Field evidence supports this age because Arvidsjaur Group rocks are reported to overlie Skellefte Group metavolcanic rocks at Kuorbevare (7253550/1633510, Grip 1935), at Fågelberget (7263800/1680590), and in the Adak mine (7254940/1631880, Bergström 1997) and occur as clasts in the Dödmanberget (7218960/1686190) conglomerate, belonging to the Vargfors Group. Consequently, they were emplaced after the deposition of the Skellefte Group, but before the end of the deposition of the Vargfors Group. The Arvidsjaur Group rocks were, thus, emplaced laterally to the north and on top of the metavolcanic rocks of the Skellefte Group and can be considered as a lateral facies variety of the Vargfors Group.

The volcanic rocks of the Arvidsjaur Group are rhyolitic to basaltic. The felsic volcanic rocks are considered



Fig. 20. **A**. Pillows with cooled, partly amygdaloidal rinds in lava of Skellefte Group. South-eastern slope of Tjamstan hill, east of Malå (7233050/1639580). Photo Ingmar Lundström. **B**. Pillow lava, Skellefte Group. Granbergsliden, about 20 km north of Norsjö (7226430/1677730). Photo Benno Kathol. **C**. "Fire fountain deposit", Skellefte Group. Granbergsliden, about 20 km north of Norjsö (7226640/1677690). Photo Benno Kathol.

***A**. Kuddar med avkylda, delvis mandelstensförande kanter i lava från Skelleftegruppen. Sydöstra branten på Tjamstanberget, öster om Malå. **B**. Kuddlava, Skelleftegruppen. Granbergsliden, ca 20 km norr om Norsjö. **C**. Eldfontänsavsättningar, Skelleftegruppen. Granbergsliden, ca 20 km norr om Norsjö.*

to be younger than the mafic ones because both Grip (1935) and Bergström & Triumf (1999) reported that the former are superposed on the latter and B. Kathol reports that rhyolitic subvolcanic rocks intrude mafic volcanic rocks.

The characteristic feature of the Arvidsjaur Group rocks is their exclusively subaerial character and the general absence of interbeds of deep-water sedimentary rocks. According to Perdahl & Einarsson (1994), a transition from marine (probably deep water) sedimentary and volcanic rocks of the Vargfors Group to continental sedimentary and volcanic rocks of Arvidsjaur type is recorded by the sequence at Bure (7274420/1594550). Coarse clastic, sedimentary rocks, interbedded with or overlying volcanic rocks of the Arvidsjaur Group occur, for instance, at Bure, Ledfat (Offerberg 1959, 7268200/1617410), and at Hej (7255670/1696180, Rapp 1996, Kathol & Rapp 1996). They are exclusively of shallow water or alluvial type and have a very local extent.

In the Arvidsjaur area, the mafic rocks seem to be dominated by laterally extensive, coherent, coarsely plagioclase porphyritic andesites (Figs. 22a,b), with relatively few volcaniclastic interbeds. These rocks appear to have formed as rather fluid lavas, capable of flowing long distances, or as subvolcanic intrusions. Locally, structures suggesting a pillowed or bulbous, weathered top surface can be seen (Fig. 22c). The plagioclase phenocrysts of the andesites are typically euhedral and elongated and in places form a flow pattern (cf. Fig. 22b). Further petrographic details were published by Grip (1935) and by Offerberg (1959).



Fig. 21. Strongly foliated load casts in metagreywacke, Skellefte Group. Rännträskliden, about 13 km north-northwest of Norsjö (7218000/1668150). Photo Benno Kathol.

Starkt folierade "load casts" i metagråvacka, Skelleftegruppen. Rännträskliden, ca 13 km nordnordväst om Norsjö.

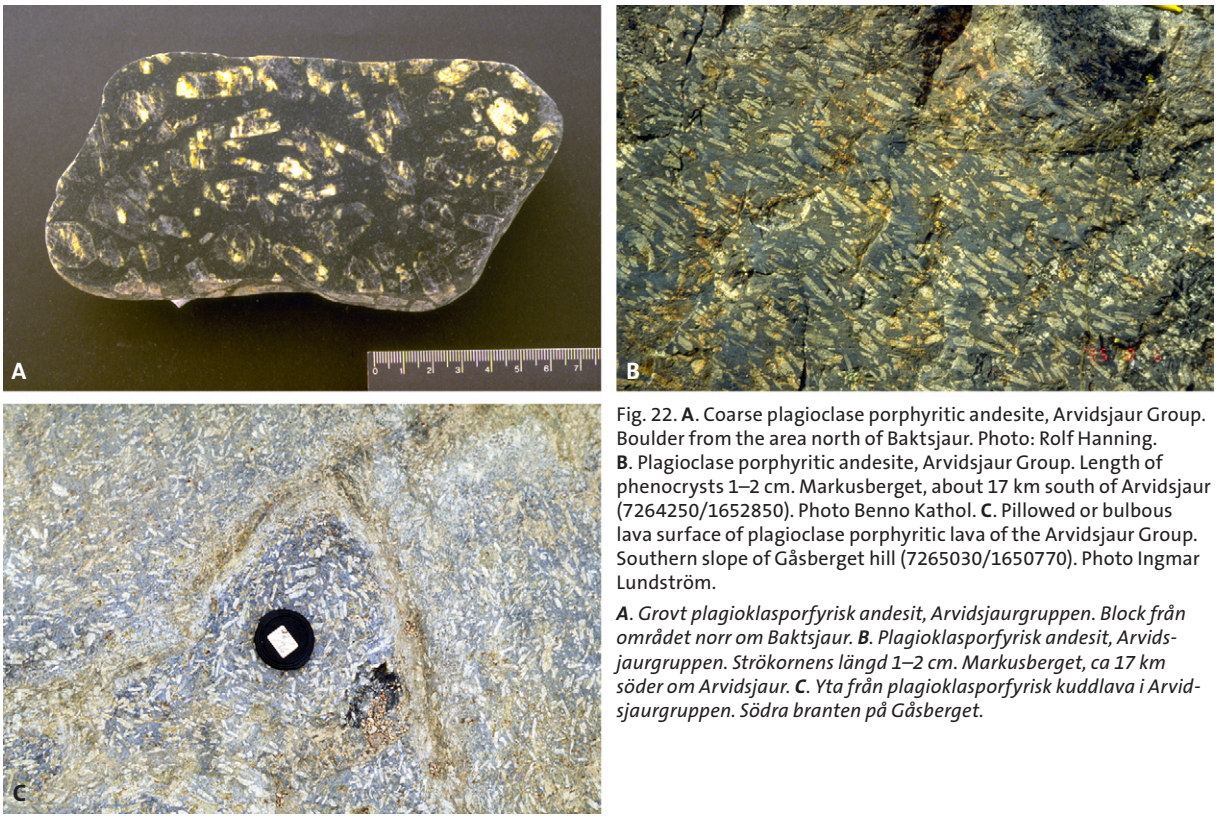


Fig. 22. **A**. Coarse plagioclase porphyritic andesite, Arvidsjaur Group. Boulder from the area north of Baktsjaur. Photo: Rolf Hanning. **B**. Plagioclase porphyritic andesite, Arvidsjaur Group. Length of phenocrysts 1–2 cm. Markusberget, about 17 km south of Arvidsjaur (7264250/1652850). Photo Benno Kathol. **C**. Pillowed or bulbous lava surface of plagioclase porphyritic lava of the Arvidsjaur Group. Southern slope of Gåsberget hill (7265030/1650770). Photo Ingmar Lundström.

***A**. Grovt plagioklasporfyrisk andesit, Arvidsjaurgruppen. Block från området norr om Baktsjaur. **B**. Plagioklasporfyrisk andesit, Arvidsjaurgruppen. Strökornens längd 1–2 cm. Markusberget, ca 17 km söder om Arvidsjaur. **C**. Yta från plagioklasporfyrisk kuddlava i Arvidsjaurgruppen. Södra branten på Gåsberget.*

The felsic volcanic rocks of the Arvidsjaur Group are dominated by subaerial, rhyolitic ash-flow deposits. Pumice clasts are numerous and indicate explosive, shallow water or subaerial eruptions. Furthermore, fiamme, overprinted by lithophysae and spherulites, present evidence of true welding (Figs. 23a,b), which is generally thought to be indicative of subaerial emplacement. Ash-fall tuffs and ignimbritic rhyolites (Fig. 23c) of the Hej area are considered to form a 400–500 m thick compound cooling unit, emplaced in an intracaldera setting (Rapp 1996). Further evidence of subaerial eruptions is presented by accretionary lapilli (Fig. 23d), and for subaerial deposition by impact sags. Minor occurrences of planar-bedded fall tuffs are also known (Fig. 24a). Coherent units are comparatively rare and in places display beautiful flow-banding, enhanced by spherulites (Fig. 24b). Volcanic centres of the Arvidsjaur volcanism are indicated by the occurrence of lag fall breccias at Storljugaren (7264950/1697050, Fig. 24c) or volcanic breccias with phenocryst- or lithophysae-bearing groundmasses in areas north and east of Arvidsjaur.

The more abundant subaerial eruptive and depositional processes and the relative scarcity of proximal volcanic facies of the felsic Arvidsjaur Group rocks presents a clear contrast to the corresponding circumstances of the Skellefte Group. Apparently the felsic Arvidsjaur Group rocks were emplaced by voluminous, explosive volcanic activity, probably related to continental calderas.

Mainly coarse clastic, sedimentary rocks of the Arvidsjaur Group occur within the Bure, Ledfat, and Hej areas at the south-western margin of the volcanic sequences of the Arvidsjaur Group. At least in the Bure and Ledfat areas, they are related to major north-northeast striking deformation zones. According to Kumpulainen (2003), these isolated occurrences are remnants of an extensive cover of late Svecofennian epiclastic rocks in north-western Sweden. The fluviatile, coarse clastic units of the Ledfat and Bure areas can be correlated with the shallow marine Snavva–Sjöfallet Group (cf. Ödman 1957, Witschard & Zachrisson 1995a,b).

In the Bure area, sandstones and polymict conglomerates (Loito Formation of Perdahl & Einarsson 1994) represent the uppermost part of the Arvidsjaur Group. These rocks change in character from intercalated red volcanogenic sandstones and conglomerate horizons to more coarse clastic, mostly matrix-supported units. The clast material consists of felsic and mafic volcanic rocks, granitoids, and metagreywackes. The matrix is phyllonitic and of mafic composition. Due to the occurrence of these sedimentary rocks along or within the Karesuando–Arjeplog deformation zone, the rocks are strongly foliated in places with elongated clasts having length to width ratios of up to 20:1 (Fig. 25).



Fig. 23. **A**. Deformed lithophysae in foliated rhyolite, Arvidsjaur Group. Flyggberget, about 24 km north-west of Långträsk (7281100/1696200). **B**. Compaction structures (fiamme), wrapping around a lithophysae in welded ignimbritic rhyolite, Arvidsjaur Group. North of Annedokkberget, about 14 km north-east of Arvidsjaur (7287640/1668400). **C**. Welded, typically purple, ignimbritic rhyolite, Arvidsjaur Group. Boljerberget, about 19 km north-east of Glommersträsk (7256520/1693830). **D**. Accretionary lapilli in rhyolite, Arvidsjaur Group. Kaltoppen, about 12 km south-west of Långträsk (7255640/1699960). Photo Benno Kathol.

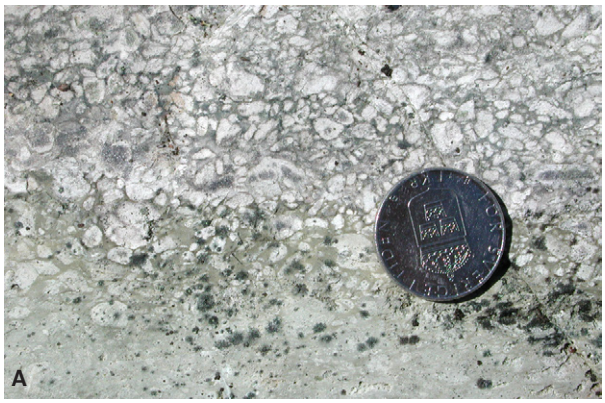
***A**. Deformerade litofyser i folierad ryolit. Arvidsjaurgruppen. Flyggberget, ca 24 km nordväst om Långträsk. **B**. Kompaktionsstrukturer (fiamme) sveper runt en litofys i svetsad ignimbritisk ryolit. Norr om Annedokkberget, ca 14 km nordost om Arvidsjaur. **C**. Svetsade, typiskt violetta, ignimbritiska ryoliter, Arvidsjaurgruppen. Boljerberget, ca, 19 km nordost om Glommersträsk. **D**. Pisolitförande ryolit, Arvidsjaurgruppen. Kaltoppen, ca 12 km sydväst om Långträsk.*

The sedimentary rocks in the area of lake Ledvattnet (Ledfat, 7268200/1617410) in the river Skellefteälven (Ledfat series of Offerberg 1959) overlie the volcanic rocks of the Arvidsjaur Group. Within this project, they are considered to represent the uppermost part of the Arvidsjaur Group and are correlated with the coarse clastic rocks of the Bure area. The Ledfat succession forms an essentially coarsening-upwards sequence, beginning with fine-grained units of distal character which are overlain by successively more proximal deposits in an alluvial setting (Fig. 26). The conglomeratic upper part of the succession has previously been subdivided into two different units (Offerberg 1959). Sedimentologically, this means that two different sources became available for erosion.

Close to the transition zone between the Skellefte and Arvidsjaur Groups south-east of Arvidsjaur, mainly conglomerates and subordinate impure sandstones or volcanic greywackes have been observed as lenses or minor intercalations within the volcanic rocks of the Arvidsjaur Group.

The most extensive conglomerate lens, referred to here as the Urikberget conglomerate, occurs within the volcanic rocks of the Hej area and has a north–south extension of more than 5 km and a thickness of 200–400 m. It is composed of several moderately dipping and westerly younging, unstratified and poorly sorted beds on the one hand, and distinctly layered beds on the other.

The clasts consist of metagranodiorites and metatonalites of the Jörn GI suite and of lavas and lithified





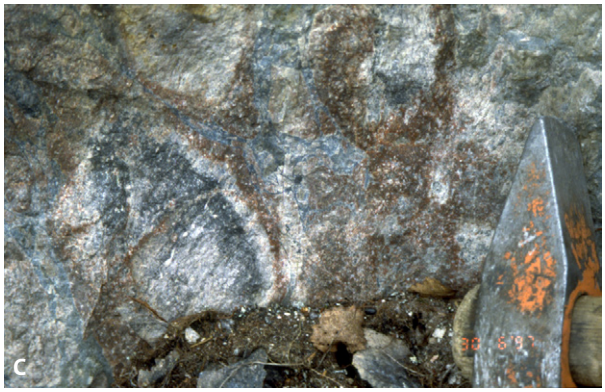


Fig. 24. **A**. Lapilli layer in ash-fall tuffs, Arvidsjaur Group. Boljerberget, about 19 km north-east of Glommersträsk (7256030/1694750). **B**. Flow-banding overprinted by spherulites in coherent volcanic rocks of the Arvidsjaur Group. West of Degervattnet, Kamsån area, about 20 km north-east of Jörn (7236300/1714350). Photo Benno Kathol. **C**. Lag fall breccia in ignimbritic rhyolite, Arvidsjaur Group. Storljugaren, about 14 km west-northwest of Långträsk (7264950/1697050). Photo Benno Kathol.

***A**. Lapilli-lager i "ash-fall"-tuffer, Arvidsjaurgruppen. Boljerberget, ca 19 km nordost om Glommersträsk. **B**. Flödesbandning övervuxen av sfäruliter i koherent vulkanit i Arvidsjaurgruppen. Väster om Degervattnet, Kamsåområdet, ca 20 km nordost om Jörn. **C**. "Lag fall breccia" i ignimbritisk ryolit, Arvidsjaurgruppen. Storljugaren, ca 14 km västnordväst om Långträsk.*



Fig. 25. Sheared conglomerate of the Arvidsjaur Group in the Karesuando–Bure deformation zone. Kallbäckberget, Bure area, about 8 km north-east of Sorsele (7275260/1587480). Photo Benno Kathol.

Skjuvat konglomerat av Arvidsjaurgruppen i Karesuando–Bure-deformationszonen. Kallbäckberget, Bureområdet, ca 8 km nordost om Sorsele.

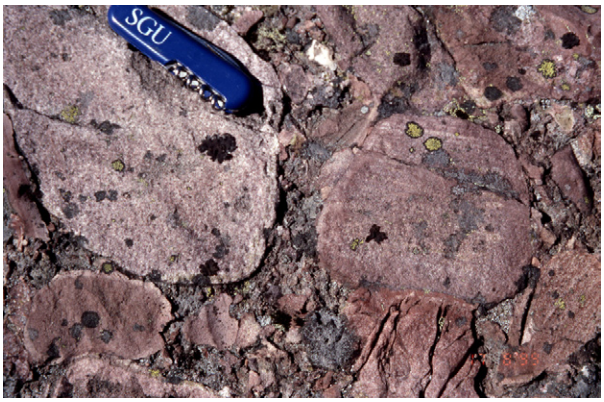


Fig. 26. Conglomerate in the upper part of the Ledfat series with sandstone clasts, derived from lower parts of the series. Setmyrliden, about 20 km north-west of Adak (7265840/1614360). Photo Benno Kathol.

Konglomerat i Ledfatseriens övre del med sandstensklaster från seriens undre delar. Setmyrliden, ca 20 km nordväst om Adak.

volcaniclastic rocks, mainly of the Arvidsjaur Group. The clast material derives from the underlying Arvidsjaur volcanic rocks and the Jörn GI metagranitoids to the east. A metagranodiorite clast of Jörn GI type from the Urikberget conglomerate has been dated at 1893±4 Ma (U-Pb zircon, SGU unpublished). Due to the lack of argillaceous material in the matrix, the occurrence of thick unstratified units, and its inner framework, this conglomerate is considered to be the result of mass flows initiated by slope wasting in alluvial areas with relatively high relief and unweathered volcanic bedrock.

Among the arenitic lenses, both thickly bedded, proximal volcanogenic units with preserved feldspar phenocrysts and thinly bedded, distal varieties with graded bedding occur. Cross-bedding, allowing "way-up" determinations have been observed locally. Drying cracks in a sandstone lens, occurring within volcaniclastic rocks in the vicinity of the Urikberget conglomerate, are indirect evidence of the subaerial environment for the deposition of the Arvidsjaur Group volcanic rocks.

Several isolated occurrences of volcanic rocks of varying metamorphic degree and deformation are not directly connected with the main occurrence of Arvidsjaur Group rocks in the north-central map area. However, due to similar radiometric ages or volcanological character, these rocks are here included in the Arvidsjaur Group.

The geological setting and many of the features of the metavolcanic rocks of the Luleå area seem to differ fundamentally from those found in the other areas. Therefore, the volcanological knowledge gained in the other areas is difficult to apply in the Luleå area. As the Luleå rocks are also partly metamorphosed to medium or high grades and are poorly described in the literature, knowledge of their volcanological nature remains poor. However, several main volcanological themes can be discerned, which are described separately below.

West and south of Luleå, partly extrusive, partly subvolcanic rocks occur in an area near outcrops of Archaean rocks. The subvolcanic rocks consist of a peculiar kind of breccia, which shows clear evidence of magma mixing and mingling. The breccias, including the previously described "Bälinge conglomerate" (Åhman & Ödman 1952), have recently been reinterpreted by Wikström et al. (1996a) to have formed as magmatic, hydraulic breccias. In many places, the matrix of these breccias grades imperceptibly into rhyolitic to andesitic, extrusive, coherent metavolcanic rocks (Wikström & Mellqvist 1997, Wikström et al. 1996a). The matrix also grades into more or less diffuse clasts, interpreted by Wikström et al. (1996b) to have been formed by magma mixing; one clast was dated at 1879±4 Ma, which is thought to date the eruption. The fine-grained, supposedly extrusive parts of these rocks also grade into bedded, clastic varieties, which probably are true conglomerates. These conglomerates (Fig. 27a) carry clasts of infracrustal rocks, one of which yielded a U-Pb zircon-titanite age of 1903±5 Ma and another gave an Archaean age of 2706±6 Ma (Lundqvist et al. 2000). Consequently, Archaean basement was exposed when these conglomerates were deposited about 1900 Ma ago. These rocks therefore show a spatial and relationship to the Archaean rocks.

The extrusive parts also carry more or less irregular, angular fragments of fine-grained, amygdaloidal rocks in many places. They are sometimes diffusely feldspar porphyritic and grade into bedded, banded or flow-banded rocks (Fig. 27b). In the Vallen–Alhamn area (7273640/1784630), this unit also comprises amygdaloidal basalts with a fluidal banding.

Pillow lavas occur both on the mainland west of Piteå (Perdahl 1995) and in the archipelago south and east of Luleå, from which Åhman (1957, 1969)

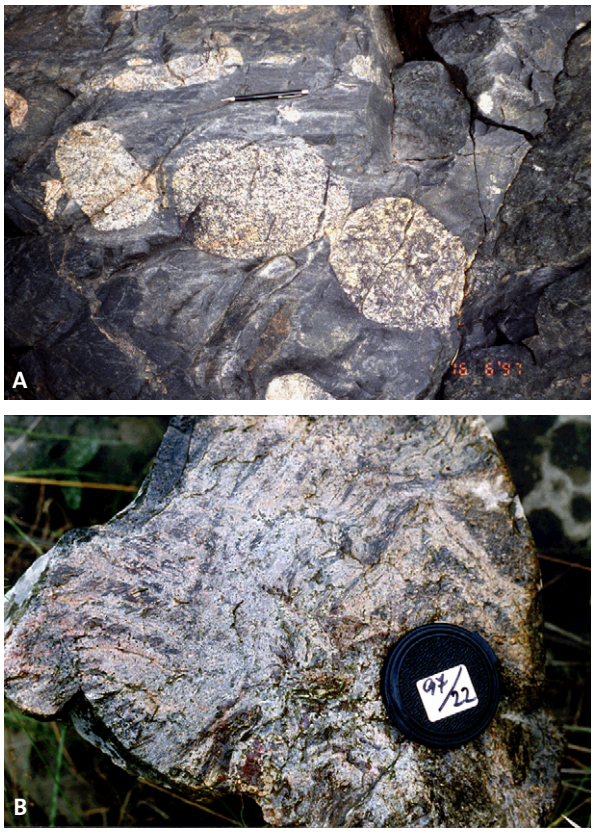


Fig. 27. **A**. Matrix-supported conglomerate with metagranitoid clasts of both Palaeoproterozoic and Archaean ages. Fagervik, about 20 km south-southwest of Luleå (7273250/1784350). Photo Benno Kathol. **B**. Plagioclase porphyritic, diffusely banded rhyolitic metavolcanic rock. West of Vallen (7274950/1782750). Photo Ingmar Lundström.

***A**. Matrixstött konglomerat med klaster med både paleoproterozoiska och arkeiska åldrar. Fagervik, ca 20 km sydsydväst om Luleå. **B**. Plagioklasporfyrisk, diffust bandad ryolitisk metavulkanisk bergart. Väst om Vallen.*

reported sporadic pillow lavas and associated tuffs. They are interbedded with quartzites and carbonate rocks and occur within a metasedimentary environment. The stratigraphic position of these units is unknown, but the overlying conglomerate on the island of Baggen (7260160/1778190) in the Piteå archipelago is very similar to the Degerberget conglomerate (7256030/1771360) south-east of Piteå. This conglomerate carries a granodiorite clast, which has been dated at 1868±13 Ma (Persson & Lundqvist 1997) which is thus the maximum depositional age of the conglomerate. The allegedly associated pillow lavas therefore appear to be among the youngest Svecofennian volcanic rocks in the project area. The authors consider the Degerberget conglomerate to occupy the same stratigraphic position as the conglomerates of the Vargfors Group at lake Vargforsdammen.

North of Norrfjärden, the bedrock consists of mostly mafic, intensely banded, high-grade, mostly migmatized, poorly known metavolcanic rocks. Their stratigraphic position and volcanic facies is unknown, but they may have a field connection with volcanic rocks of the Arvidsjaur Group in the Pålsträsk area (7293730/1749290) to the east of Älvsbyn.

There is a narrow, north-northwest–south-southeast trending belt of fairly well preserved volcanic rocks about 35 km west of Luleå. This was briefly described by Lilljequist (1979, 1980) and it varies in composition between rhyolite and andesite. Felsic ash flow deposits, in many places ignimbritic, are common in the western part of the unit, whereas the central and eastern parts are rich in dacitic to andesitic agglomerates, tuffs, and porphyries.

Svecofennian supracrustal rocks: Vargfors Group

The Vargfors Group, previously defined by Kautsky (1957), was redefined by Allen et al. (1996). According to the latter, the Vargfors Group comprises the Mensträsk conglomerate, argillites and greywackes of the Elvaberg Formation (Elvaberg series of Kautsky 1957), the Abborrtjärn and Dödmanberget conglomerates, and the Gallejaur volcanic rocks with related dykes and sills (see Figs. 8b–g). In this project, we have adopted this new definition.

Sedimentary rocks of the Vargfors Group occur within and south of the central Skellefte District, within the Kristineberg and Bure areas. An indirect age for this sedimentary succession is given by U-Pb zircon ages of 1875±4 Ma (Billström & Weihed 1996) and 1871±5 Ma (Bergström et al. 2003), obtained from volcanic rocks, occurring within the Vargfors sedimentary rocks of the central Skellefte District. These rocks are therefore c. 10 Ma younger than the Skellefte Group rocks and corroborate the stratigraphic relations inferred below. Furthermore, these ages indicate that the Vargfors Group is more or less coeval with the Arvidsjaur Group. At least parts of the Vargfors Group are considered to represent the marine, lateral, southern continuation of the subaerial volcanic rocks of the Arvidsjaur Group.

In the central Skellefte District, the Vargfors Group normally overlies the volcanic sequences of the Skellefte Group and in places rocks of the Bothnian Supergroup. However, gradational and interfingering conformable contact relationships between these groups, especially between the Vargfors and Bothnian Groups, are not excluded. Somewhat different stratigraphical relationships prevail in the Bure area in the western part of the Vargfors Group. Here, the Vargfors Group rests without any visible unconformity on top of the Bothnian Supergroup and is, in its western parts, overlain by volcanic rocks of the Bure Formation (Perdahl & Einarsson 1994), which is included here in the Arvidsjaur Group.

The sedimentary rocks of the Vargfors Group in the central Skellefte District comprise greenschist facies turbiditic greywackes and coarse clastic rocks with well preserved structures and textures. These rocks have their main distribution along river Skellefteälven. South of the central Skellefte District and the Kristineberg area the Vargfors Group is divided into a lower argillitic unit and an overlying unit of arenitic to argillitic, turbiditic greywackes. Also these sequences are generally well preserved, but increased deformation and degree of metamorphism caused alteration to veined gneisses and migmatites within the transition zone between the Vargfors Group and the Bothnian Supergroup in the south.

The Vargfors sedimentary rocks along river Skellefteälven west of Nicknoret are dominated by thickly bedded to laminated, turbiditic greywackes (Fig. 28a) with scattered intercalations of massive sandstones. The greywackes show planar bedding and in places cross-bedding. Grain sizes range from silt to coarse sand (Fig. 28b). The sandstones are very coarse-grained, in places gritty or somewhat conglomeratic, and contain some isolated larger clasts. Transitions from volcaniclastic rocks over massive, gritty conglomeratic rocks to bedded sandstones have been observed in places. Proximal volcanic sources for the sandstones are also indicated by a high content of detritic feldspar grains. Basic to intermediate sills, dykes, and lavas, which occur within this greywacke sequence, are related to the mafic magmatism of the Gallejaur intrusive complex.

Farther to the south-east, in the area around the Vargfors dam (7218320/1682950), the Vargfors Group

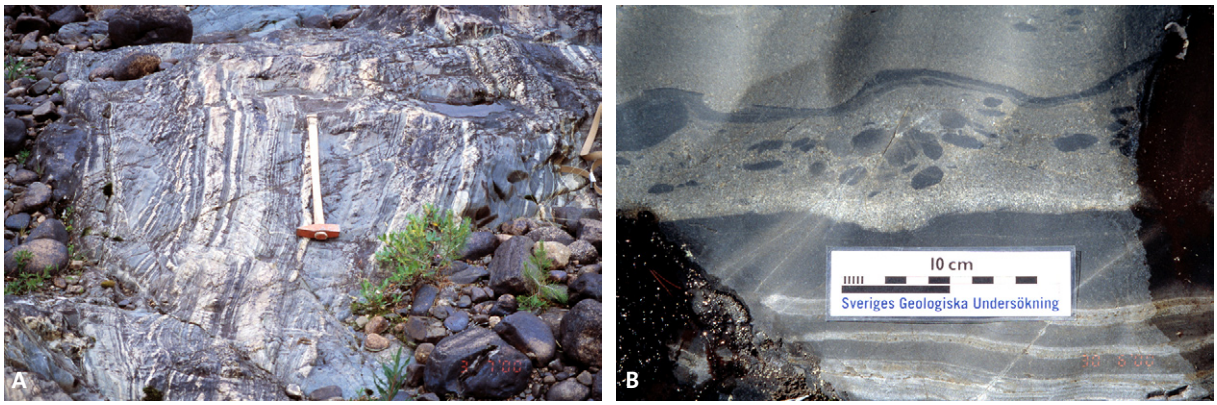
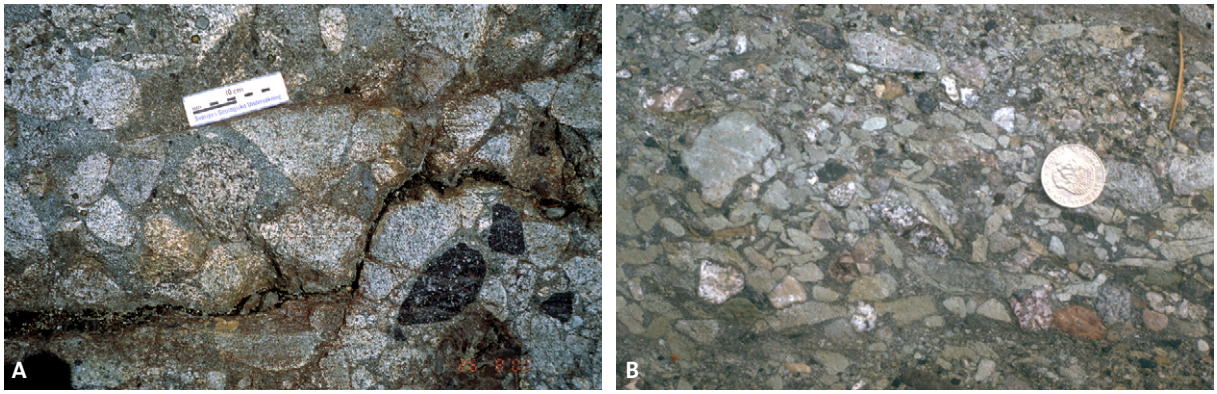


Fig. 28. **A**. Turbiditic greywacke, Vargfors Group. Maurselet at river Skellefteälven, about 19 km south-southwest of Glommersträsk (7229021/1670754). **B**. Graded bedding and mud clasts or lumps in greywacke, Vargfors Group. River Skellefteälven west of Skidberget, about 16 km south-west of Glommersträsk (7234000/1666700). Photo Benno Kathol.

***A**. Turbiditisk gråvacka, Vargforsgruppen. Maurselet vid Skellefteälven, ca 19 km sydsydväst om Glommersträsk. **B**. Graderad skiktning och lerbollar i gråvacka, Vargforsgruppen. Skellefteälven väster om Skidberget, ca 16 km sydväst om Glommersträsk.*



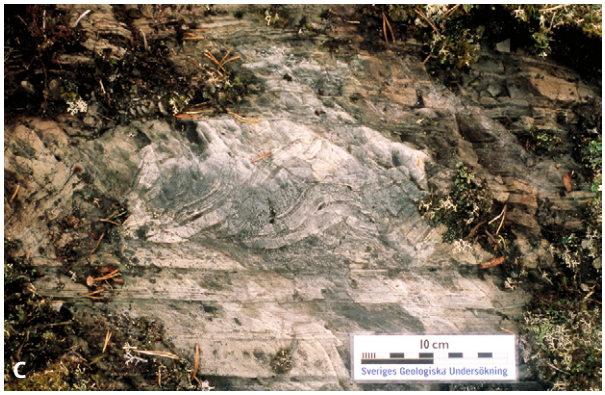


Fig. 29. **A**. Abborrtjärn conglomerate, Vargfors Group. Bjurtjärnen, about 18 km north-northeast of Norsjö (7221087/1683621). **B**. Dödmanberg conglomerate, Vargfors Group. Dödmanberget, about 18 km north-northeast of Norsjö (7218980/1686160). **C**. Syngenetic deformation structures in arenitic greywacke, Vargfors Group. Skavberget, about 17 km north of Norsjö (7223215/1677134). Photo Benno Kathol.

***A**. Abborrtjärnkonglomerat, Vargforsgruppen. Bjurtjärnen, ca 18 km nordnordost om Norsjö. **B**. Dödmanbergkonglomerat, Vargforsgruppen. Dödmanberget, ca 18 km nordnordost om Norsjö. **C**. Syngenetiska deformationsstruktuter i arenitisk gråvacka, Vargforsgruppen. Skavberget, ca 17 km norr om Norsjö.*

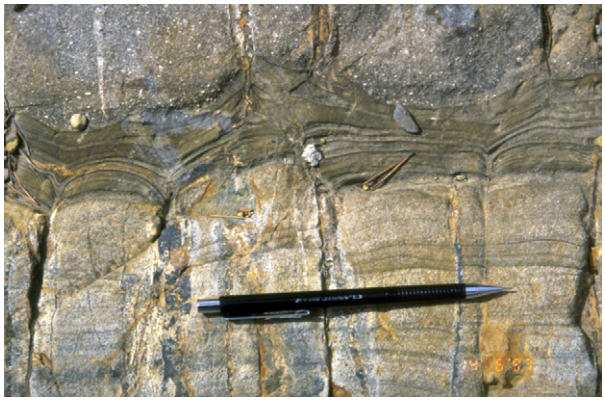


Fig. 30. Boudinage in graded greywackes, Vargfors Group. Fäbodliden, about 26 km west-southwest of Malå (7226780/1613090). Photo Benno Kathol.

Boudinage i graderad gråvacka, Vargforsgruppen. Fäbodliden, ca 26 km västsydväst om Malå.

is dominated by major lenses of coarse clastic rocks which intercalate with or pass laterally into gritty – in places conglomeratic – sandstones. According to Kautsky (1957), these coarse clastic rocks, i.e. the "classic" Vargfors conglomerate, are divided into the Abborrtjärn conglomerate and the overlying Dödmanberget conglomerate. The former is dominated by up to metre-sized, rounded to well rounded clasts of metagranitoids from the Jörn GI suite (Fig. 29a). The polymict Dödmanberget conglomerate is poorly sorted and contains both metagranitoid clasts and clasts of volcanic and subordinate sedimentary rocks, derived from the Arvidsjaur and Skellefte Groups (Fig. 29b). South of the lake Vargforsdammen (7220500/1681040), greywackes of the Vargfors Group exhibit graded bedding with grain sizes ranging from fine to coarse sand. Syngenetic deformation structures such as load casts and rip-up clasts are common (Fig. 29c). Local breccias of rip-up clasts indicate a tectonically active environment during the deposition of these sediments.

One conglomerate unit in the area south of the lake Vargforsdammen (7220500/1681040) consists mainly of clasts of volcanic rocks of the Skellefte Group within a carbonate cemented, arenitic groundmass. Other varieties are redeposited volcanic breccias, which occur in places and represent a transition between volcanic and epiclastic facies environments.

The argillites south of the central Skellefte District and the Kristineberg area are dark grey to black, distinctly foliated rocks, consisting mainly of very fine-grained mica. The argillite sequence contains graphite- and sulphide-bearing, rusty weathering horizons, which can be clearly distinguished on the magnetic anomaly map. Intercalations of greywackes and tuffites have been found within the argillites. Stratigraphically upwards, the argillites pass without a distinct contact into turbiditic greywackes.

The greywacke sequence is dominated by graded, arenitic to argillitic, turbiditic greywackes (Fig. 30), which in some places are interlayered with graphite- and sulphide-bearing horizons and layers of laminated siltstones. Way-up determinations in this unit are usually based on graded bedding. The greywackes consist of quartz and feldspar grains and rock fragments in a finer-grained, micaceous groundmass. In some areas, the greywackes are strongly deformed and, in those cases, contain abundant quartz veins. Intercalations of basaltic to andesitic volcanic rocks and mafic to ultramafic sills and lava flows occur within this succession of the Vargfors Group.

Around Vindelgransele (7225010/1617430), the greywacke sequence (Fig. 31) is a coarsening-upwards sequence deposited on felsic volcanic rocks. This sedimentary succession, which is more than 5 km thick, begins with deposition of organic-rich muddy sediments (D2-type facies of Pickering et al. 1986) and ends with sandy, medium-bedded turbidites (C2.2–C2.3). Convolute bedding is common, suggesting deposition on a slope, i.e. a prograding submarine turbidite fan. Non-graded, massive sandy beds (C1.1) have been recognized locally; some of these massive beds also contain numerous mud clasts.

The sedimentary rocks of the Vargfors Group of the western area (east of Bure, 7274420/1594550) are dominated by turbidite deposited, volcanogenic greywackes with dominating arenitic layers. Graded bedding is common. Thin horizons of polymict conglomerates with clasts of rhyolites and porphyritic andesites of the Arvidsjaur Group and subordinately of grey, medium-grained granitoids occur in places. According to Eliasson et al. (2003), these conglomerate horizons are similar to those found in the lower parts of the Arvidsjaur Group. Basaltic sills (Vargfors Group) and intercalations of rhyolitic lavas and volcaniclastic rocks of the Arvidsjaur Group occur in places. Close to the upper contact, the greywackes contain intercalations of mafic volcaniclastic rocks in varying amounts, and pass without a distinct transition into volcanic sequences of the Arvidsjaur Group.

The sedimentary rocks of the Vargfors Group contain local, more juvenile, volcanic interbeds. At Gallejaur (7229200/1670050), a felsic ignimbrite, interbedded within a mafic volcanic rock within the Vargfors sedimentary sequence, was dated at 1875±4 Ma by Billström & Weihed (1996). The dated ignimbrite contains 1–3 mm large broken fragments of quartz and feldspar crystals. Recrystallized shards are visible, but no obvious welding texture was observed.

The mafic volcanic rocks of the Vargfors Group are mostly magnesium-rich, frequently pyroxene- or hornblende porphyritic basaltic lavas. In the Gallejaur area (7233030/1670330), Kautsky (1957) described the "Vargfors andesite", which is interbedded within the Vargfors conglomerates as a "block lava". Felsic dykes within mafic volcanic rocks of the Vargfors Group have been dated at 1871±5 Ma (Bergström et al. 2003) and are considered to be the youngest component of the Gallejaur magmatism. The mafic volcanic rocks are correlated with the gabbroic rim of the Gallejaur structure. In the turbiditic sedimentary rocks of the Vindelgransele (7225010/1617430) and Vinliden (7266790/1602470) areas, amygdaloidal pillow lavas, hyaloclastite breccias and various volcaniclastic rocks occur.

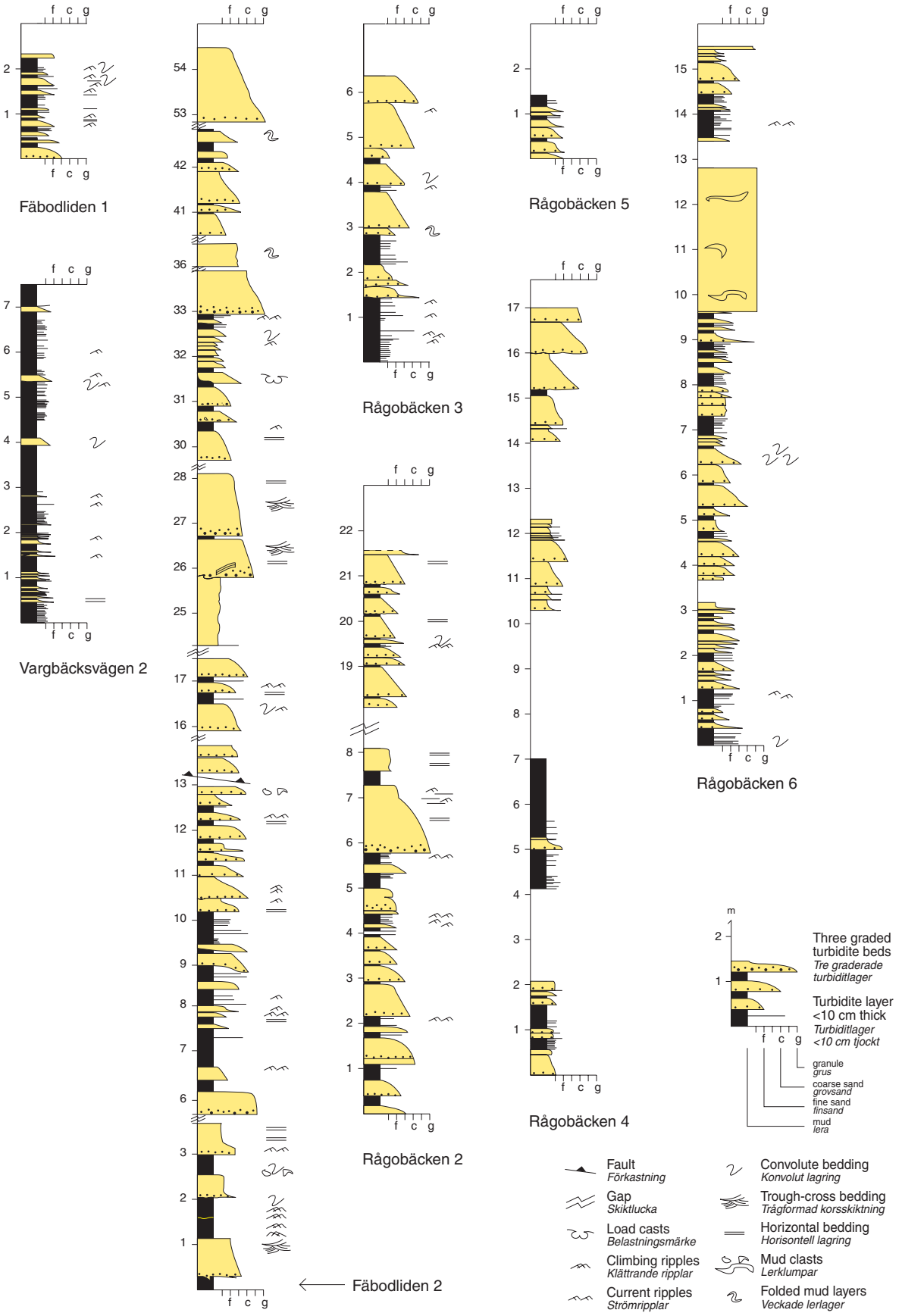


Fig. 31. Sedimentary logs from greywacke sequences of the Vargfors Group at Vargbäcken, Fäbodliden, and Rågobäcken, all situated in the Vindelgransele area.

Sedimentologiska profiler från gråvackesekvenser inom Vargforsgruppen vid Vargbäcken, Fäbodliden och Rågobäcken, alla från Vindelgranseleområdet.

Early Svecokarelian calc-alkaline intrusive rocks

The early Svecokarelian calc-alkaline intrusive rocks (granitoids and associated mafic rocks) range in age from 1.96 to 1.86 Ga. By means of radiometric dating (see Table 1), they have been divided into an assemblage with an age around 1950 Ma (Knaften), a 1920–1900 Ma old assemblage (Björkdal, Blåviksjön, Kristineberg) and one with ages ranging from 1900 to 1860 Ma. The latter comprises the Jörn GI and GII intrusions, the Sikträsk (7197620/1692120) and Karsträsk (7203030/1697360) domes, and the metagranitoids to the south-west of Skellefteå and to the east of Stensele. Also, undated or minor occurrences of calc-alkaline intrusive rocks are included in this assemblage.

Previously, the early Svecokarelian calc-alkaline granitoids, possibly with the exception of the 1950 Ma rocks of the Knaften area, have been summarized under the term "Jörn suite", "Jörn granite" or "Jörn granitoids", with respect to the major intrusion around and to the north of Jörn. However, according to recent observations of chemical compositions and trace element spectra, only the outer parts of the composite Jörn granitoid complex (GI and GII phases) can be included within the early Svecokarelian calc-alkaline granitoids. The central plutons (GIII and GIV phases) are now assigned to the Perthite monzonite suite. Therefore we choose to rename the 1900–1860 Ma calc-alkaline granitoids the "Jörn GI suite" or "Jörn GI granitoids".

The early Svecokarelian calc-alkaline intrusive rocks are concentrated in the southern and eastern parts of the map area, where they are related in time and space with metasedimentary and metavolcanic rocks of the Bothnian Supergroup and the Skellefte Group. They have not been observed in the north-central parts of the map area, where the bedrock is dominated by supracrustal rocks of the Arvidsjaur Group and early Svecokarelian intrusive rocks of the Perthite monzonite suite.

The rocks of the Jörn GI suite generally have positive $\varepsilon_{Nd\ (t=1.9)}$ values, which indicate magma derivation from relatively juvenile sources. Calc-alkaline granitoids of the area around Luleå show negative $\varepsilon_{Nd\ (t=1.9)}$ values, which indicates more mature sources for magma derivation and a closer relationship of these rocks to an Archaean crust (Mellqvist 1999, Mellqvist et al. 2003). These rocks are therefore included in the Haparanda suite (Haparanda series) of Ödman et al. (1949) as described in Ödman (1957). This means that the boundary between the Jörn GI suite and the Haparanda suite is situated about 20 km south-west of Luleå, striking north-west–south-east, parallel to the outcropping of Archaean rocks in the Luleå area.

At least the younger metagranitoids of the Jörn GI suite are intrusive in the supracrustal rocks of the Bothnian and Skellefte Groups, but in other cases, e.g. Kristineberg (7220490/1630480) or Blåviksjön (7192780/1606930), it is not clear whether the metagranitoids are intrusive into or form the basement of the supracrustal sequences.

The early Svecokarelian calc-alkaline metagranitoids normally have a granodioritic to tonalitic (in places granitic) composition. Trondhjemites, quartz monzodiorites and monzonites occur subordinately. The rocks are normally light to dark grey; reddish varieties occur in places. Most of the rocks are equigranular. Subordinate porphyritic types show 5 to 30 mm sized, rectangular or rounded phenocrysts of quartz and feldspar. Some varieties in the south-west (Åsele map sheets) are rich in lath-shaped, cm sized phenocrysts of potassium feldspar, which makes it difficult to distinguish them from late to post Svecokarelian granites of the Skellefte-Härnö suite.

Main minerals are quartz, plagioclase, and potassium feldspar. Biotite and hornblende occur in varying amounts. Accessory minerals are in order of abundance (according to map descriptions): apatite, epidote, titanite, opaque phases, zircon, muscovite, calcite, amphibole, chlorite, cordierite, ilmenite, magnetite, pumpellyite, pyroxene, and sillimanite.

Plagioclase porphyritic dykes and minor intrusions, related to the early Svecokarelian calc-alkaline intrusive rocks, cut through both the Kristineberg massif and adjacent volcanic rocks of the Skellefte Group. Dykes and minor, irregularly shaped intrusions of light grey, fine-grained, quartz porphyritic granite porphyries (Fig. 32) occur within the GI phase of the Jörn granitoid complex and have been dated (U-Pb, zircon) at 1886^{+15}_{-9} Ma by Weihed & Schöberg (1991). A radiometric dating (U-



Fig. 32. Fine-grained, quartz porphyritic granite porphyry, occurring as minor intrusions within the Jörn GI intrusion. Näverliden hill, about 6 km west of Jörn (7222800/1693400). Photo Benno Kathol.

Finkornig, kvartsporfyrisk granitporfyr, som förekommer som mindre intrusioner i Jörn GI intrusionen. Näverliden, ca 6 km väster om Jörn.

Pb, zircon) of a light grey, trondhjemitic tonalite dyke, cutting conglomerates at Pultarliden (7223500/1715820) in the Boliden map area, yielded an age of 1874±3 Ma (Lundström et al. 1999).

Xenoliths of metasedimentary rocks (some of them containing graphite or sulphides) and metabasic volcanic or intrusive rocks are relatively common within the early Svecokarelian calc-alkaline granitoids. Xenoliths of felsic volcanic or intrusive rocks occur subordinately. Magma mingling structures between felsic and mafic members of this rock suite are indicated by the occurrence of mafic enclaves within the felsic rocks and vice versa. A peculiar breccia at Gorpamyran (7156360/1638590) south of Lycksele contains mm to dm sized rounded or angular granitoid fragments in a very fine-grained groundmass of the same composition as the fragments. The breccia is interpreted as a metasomatic breccia or as a gas diatreme. Rounded enclaves of tonalite to quartz diorite are characteristic of the Sorsele and Stensele map areas. Ultramafic enclaves within this area are considered to represent early crystallized parts of the magma.

The calc-alkaline intrusive rocks have undergone deformation and metamorphism in different degrees in different areas. The Jörn GI and GII plutons are almost undeformed; i.e. they show little evidence of penetrative deformation (Fig. 33a), whereas for example the rocks of the Sikträsk (7197620/1692120) and Karsträsk (7203030/1697360) domes are deformed to orthogneisses. In the southern parts of the map area, the rocks have locally been recrystallized, and primary or secondary structures such as foliation are obscured. In the eastern and southernmost parts, the metagranitoids have undergone partial melting together with the sedimentary rocks of those areas and are normally altered to gneisses or migmatites. Migmatization was probably promoted by the presence of xenoliths and sheet-like inclusions of metasedimentary rocks. In the migmatite areas, the early Svecokarelian rocks are intruded by schlieren-like aplitic and pegmatitic (late to post Svecokarelian) granites. This leads in places to difficulty in distinguishing the dominant rock type in outcrops and consequently ambiguities in how to present the rock type on the map. A probably unique tectonic style within Fennoscandian rocks of the map area with flat-lying thrust surfaces can be observed in the Björkdal intrusion in the Björkdal mine. Here, gravity data also suggest that different slabs with different rock types are stacked together along flat-lying thrust surfaces.

Ultramafic intrusive rocks occur mainly as minor bodies in several areas and within different rock types. A larger massif with ultramafic rocks is situated at Gissträsk (7213750/1664910) north-west of Norsjö. Grain sizes range from fine to coarse. The rocks are normally equigranular, massive, and foliated, but locally there are coarsely amphibole porphyritic varie-

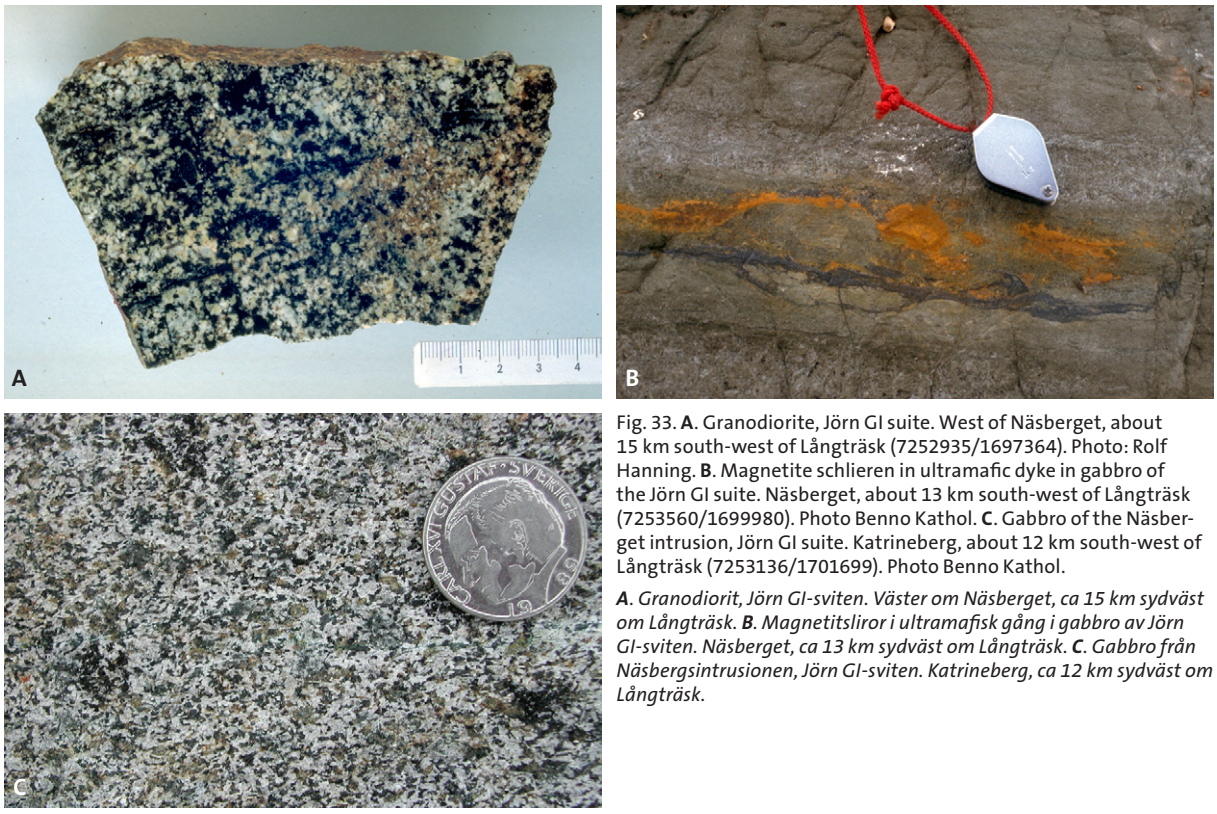


Fig. 33. **A**. Granodiorite, Jörn GI suite. West of Näsberget, about 15 km south-west of Långträsk (7252935/1697364). Photo: Rolf Hanning. **B**. Magnetite schlieren in ultramafic dyke in gabbro of the Jörn GI suite. Näsberget, about 13 km south-west of Långträsk (7253560/1699980). Photo Benno Kathol. **C**. Gabbro of the Näsberget intrusion, Jörn GI suite. Katrineberg, about 12 km south-west of Långträsk (7253136/1701699). Photo Benno Kathol.

***A**. Granodiorit, Jörn GI-sviten. Väster om Näsberget, ca 15 km sydväst om Långträsk. **B**. Magnetitsliror i ultramafisk gång i gabbro av Jörn GI-sviten. Näsberget, ca 13 km sydväst om Långträsk. **C**. Gabbro från Näsbergsintrusionen, Jörn GI-sviten. Katrineberg, ca 12 km sydväst om Långträsk.*

ties. Ultramafic rocks also occur as layers, ultramafic members in layered gabbros, or as composite mafic intrusions, at Svarvaruddliden (7163630/1641960) southeast of Lycksele, and as dykes, containing schlieren of magnetite, in the gabbro intrusion at Näsberget (7253560/1699980, Fig. 33b). The ultramafic members at Svarvaruddliden consist of amphibole, clinopyroxene, serpentine, opaque phases, and talc. Accessory minerals are epidote, titanite, and apatite. Alterations of actinolite to tremolite and serpentine to talc occur in some of the ultramafic intrusions within the Rönnskär–Ånäset map areas.

The gabbros are dark grey, dark greenish grey or black and mainly finely medium-grained to medium-grained. Subordinately fine- or coarse-grained rocks occur, locally showing ophitic textures. They are commonly equigranular and massive (Fig. 33c), but foliated varieties occur in places. An apparent tectonic foliation within the gabbro at Näsberget is interpreted as mineral lamination. Magmatic layering, in places diffuse, occurs in several gabbro massifs. Magma mingling structures with enclaves of felsic intrusive rocks have been reported from the Luleå area. The gabbros consist of plagioclase, commonly altered to sericite or epidote, amphiboles, olivine, and pyroxenes which are partly altered to hornblende. Porphyritic varieties show plagioclase or hornblende phenocrysts. Biotite, opaque phases, apatite, and olivine occur subordinately, and accessory minerals are calcite, chlorite, epidote, quartz, titanite, and zircon.

Diorites, in places quartz diorites, are light to dark grey in colour and fine- to medium-grained. They consist mainly of hornblende and plagioclase, which also occur as phenocrysts in porphyritic varieties. Subordinate minerals are biotite, opaque phases and apatite; calcite, quartz, and zircon occur as accessories. The diorites show mingling structures with associated felsic intrusions or between different dioritic varieties. The 1877±2 Ma old diorite at Stavaträsk (7226380/1721900) in the Boliden map area (Lundström et al. 1997) contains hornfels-altered fragments of sedimentary rocks in marginal parts of the intrusion. A spectacular intrusion breccia (Fig. 34), probably generated close to the roof of a dioritic intrusion, has been reported from Jan Sakrisaberget (7187200/1715700) west of Skellefteå (Kumpulainen 1995).



Fig. 34. Intrusion breccia with clasts derived from both sedimentary and igneous wall rocks of a dioritic intrusion. Jan Sakrisaberget, about 17 km south of Boliden. (7187200/1715700). Photo Benno Kathol.

Intrusionsbreccia med klaster som härstammar från både sedimentärt och magmatiskt sidoberg till en dioritisk intrusion. Jan Sakrisaberget, ca 17 km söder om Boliden.

Early Svecokarelian intrusive rocks (Perthite monzonite suite)

Rocks of the Perthite monzonite suite are restricted to the northern and north-eastern parts of the map area. Towards the south-west, they are bounded by a line trending more or less parallel with the main structures within the central Skellefte District. The rocks of the Perthite monzonite suite are slightly younger (1.88–1.86 Ga) than the metagranitoids of the Jörn GI suite, though their ages overlap. In areas where the bedrock is dominated by Perthite monzonite suite rocks, metagranitoids of the Jörn GI suite are usually absent and vice versa. However, within the composite Jörn granitoid complex, both rock types occur together.

Though the rocks of the Perthite monzonite suite are of early Svecokarelian age, they usually do not show evidence of penetrative deformation, in contrast to large parts of the Jörn GI metagranitoids. Distinct plutons, as for example the Arvidsjaur or Gallejaur intrusions, probably reacted as rigid blocks and most of the strain is concentrated in the surrounding volcanic rocks.

Several intrusions of the Perthite monzonite suite of the map area have previously been grouped under the name "Arvidsjaur suite" (Bergström & Triumf 2002, Eliasson et al. 2003). In order to avoid confusion with the Arvidsjaur Group and because the purpose of this map is to synthesize bedrock information over larger areas, we chose to include these rocks in the Perthite monzonite suite (Witschard 1984), which has its type area farther to the north.

The felsic rocks of the Perthite monzonite suite are dominated by light red to red, fine- to medium-grained (in places coarse-grained) granites or alkali feldspar granites (Figs. 35a,b). Light grey to grey varieties occur locally. Less abundant rock types are monzonites, quartz monzonites, granodiorites, and tonalites. Normally, the felsic rocks of the Perthite monzonite suite are massive. Strongly foliated bedrock within this suite is more or less related to major ductile deformation zones. A weak, penetrative foliation has been observed within the granitic intrusion in the outer parts of the Storsund



Fig. 35. **A**. Granite, Perthite monzonite suite. Långberget, north-west of Renviken. **B**. Granite, Perthite monzonite suite. Antakberget, about 17 km north-east of Glommersträsk. **C**. Feldspar porphyritic granite, Perthite monzonite suite. Tjäckerliden, about 10 km north-northeast of Glommersträsk (7265030/1650770). **D**. Granite, Jörn GIII pluton, Perthite monzonite suite. Road cut at the railway bridge between Glommersträsk and Jörn (7233890/1691940). Photo: Rolf Hanning.

***A**. Granit, Pertitmonzonitsviten. Långberget, nordväst om Renviken. **B**. Granit, Pertitmonzonitsviten. Antakberget, ca 17 km nordost om Glommersträsk. **C**. Fältspatporfyrisk granit, Pertitmonzonitsviten. Tjäckerliden, ca 10 km nordnordost om Glommersträsk. **D**. Granit, Jörn GIII-plutonen, Pertitmonzonitsviten. Vägskärning vid järnvägsövergången mellan Glommersträsk och Jörn.*

structure (7283590/1722290) in the Älvsbyn map area. Most of the felsic rocks of the Perthite monzonite suite are equigranular. Porphyritic varieties occur among the granites, with feldspar (microcline) as predominant and quartz or plagioclase as subordinate phenocryst minerals (Fig. 35c).

Compared with the metagranitoids of the Jörn GI suite, the rocks of the Perthite monzonite suite have more alkaline compositions, as confirmed by the occurrence of the sodium amphibole riebeckite within the Arvidsjaur pluton (Muller 1980). Characteristic for most of the felsic rocks is the unusually low content of mafic minerals. Magnetite is enriched in marginal facies of fine-grained to finely medium-grained granitic rocks, which are regarded as subvolcanic intrusions.

Megaxenoliths of predominantly felsic volcanic rocks of the Arvidsjaur Group occur throughout the intrusions of the Perthite monzonite suite within the Storavan and Arvidsjaur map areas. Minor xenoliths consist of felsic and mafic volcanic rocks and granites. Xenoliths of metasedimentary rocks of the Vargfors Group occur in contact areas between the two rock units. Metagranodiorite xenoliths within the Jörn GIII intrusion support the age relationship between the GIII and the GI intrusions.

At least the more distinct plutons at Arvidsjaur and Antakberget (7254830/1692420), the irregularly shaped intrusion in the northern parts of the Arvidsjaur map area, and the Gallejaur intrusion are considered to be intrusive into the surrounding rocks of the Arvidsjaur and Vargfors Groups, respectively. This relationship has been demonstrated by truncated minor structures in the field or regional map scale structures within the volcanic rocks of the Hej area (see p. 100). At Urikberget (7256030/1694750), dykes of fine-grained, red granite, cutting through the Urikberget conglomerate, are correlated by trace element spectra with the 1879^{+15}_{-12} Ma Antak intrusion. Furthermore, contact metamorphism within the volcanic rocks close to the contacts support the intrusive nature of the granites.

Additionally, data from radiometric datings and trace element chemistry from the Antak (1879^{+15}_{-12} Ma) and Arvidsjaur (1877^{+8}_{-7} Ma) intrusions indicate that these intrusions are coeval and comagmatic with the surrounding felsic volcanic rocks of the Arvidsjaur Group (1878±2 Ma at mount Skyberget and 1877±9 Ma at

mount Fågelberget). The Antak intrusion is interpreted as a flat, high level or subvolcanic intrusion, constituting a site for an eruptive centre of the Arvidsjaur Group volcanism (Kathol & Triumf 1996, Kathol & Rapp 1996). The Arvidsjaur pluton and some minor intrusions are also regarded as similar high-level intrusions.

A close relationship between the rocks of the Perthite monzonite suite and the Arvidsjaur Group is also indicated by transition from normal granite via porphyritic granite to subvolcanic rhyolites over relatively short distances (<100 m). This feature is characteristic of the felsic rocks of the Perthite monzonite suite between Arvidsjaur and Vistheden.

The central part of the composite Jörn granitoid complex consists of massive, red, coarsely medium-grained granite with a very low content of mafic minerals (Fig. 35d). This so-called Jörn GIII intrusion lacks deformation structures, except for a few major brittle faults. Its composition is similar to the granitic intrusions of the Perthite monzonite suite farther to the north (Arvidsjaur, Antak and related intrusions).

The Jörn GIII intrusion has been dated (U-Pb, zircon) at 1873^{+18}_{-14} Ma by Wilson et al. (1987b) and at 1873±12 Ma (SGU unpublished). A similar granite, situated close to the GIII intrusion, has been dated at 1862±14 Ma (U-Pb, titanite) by Lundström et al. (1997). Within the central part of the GIII intrusion a core of light reddish grey granodiorite to granite occurs, which was called GIV by Wilson et al. (1987).

A probable explanation for the composite nature of the Jörn granitoid complex might be as follows: The magma of the Jörn GIII intrusion was mobilized and derived from different source areas within the crust than the GI magma, but used the same conduits as the latter for rising and final emplacement in the central part of the Jörn GI pluton.

The circular Gallejaur intrusion in the Norsjö map area consists of a gabbroic rim and a monzonitic to quartz monzonitic core. The gabbros are normally finely medium-grained to medium-grained dark grey rocks, consisting of plagioclase and amphibole with small amounts of epidote and chlorite. The rocks of the felsic core are massive, medium-grained to coarsely medium-grained, pale greyish red and consist of quartz, plagioclase, microcline, and subordinate mafic minerals. The gabbroic rim of the Gallejaur intrusion is dated (U-Pb, zircon) at 1876±4 Ma (Skiöld et al. 1993) and the core at 1873±10 Ma (Skiöld 1988). Mingling structures between the gabbroic rim and the felsic core are common, and gabbroic enclaves make up a certain volume of the core. In places, magma mixing led to hybrid rocks of quartz monzodioritic to granodioritic composition. Mafic dykes, cutting through the Jörn granitoid complex and volcanic rocks of the Skellefte and Vargfors Groups are tentatively correlated with the "Gallejaur magmatism".

A feldspar porphyritic, foliated and locally gneissose granodiorite north-east of Luleå (Degerberg granite) has outside the map area been dated at 1880±7 Ma and 1888±17 Ma (Wikström et al. 1996c). We have chosen to include this granodiorite in the Perthite monzonite suite. Magma mingling structures are common within this rock.

The mafic intrusions of the Perthite monzonite suite are similar to those of the Jörn GI suite. This concerns both macroscopic investigations and geochemical analyses with trace element spectra. In several cases, these mafic intrusions are assigned to the Perthite monzonite suite merely because of their spatial relationship with felsic rocks of that suite. In places, magma mingling structures support this classification.

The similarities in chemical composition between the mafic rocks of the two suites are interpreted to be the result of magma derivation from similar sources within the mantle. Further segregation, transport and emplacement into different tectonic environments may have affected the felsic, more fractionated magmas to a higher degree than the more primitive mafic melts.

The mafic members of the Perthite monzonite suite are gabbros, diorites, and quartz diorites; monzodiorites and quartz monzodiorites occur subordinately. The gabbros and diorites are normally medium-grained, in places fine-grained to finely medium-grained, massive rocks. Dominating minerals are amphibole (hornblende) and plagioclase. Biotite and, in places, magnetite are significant constituents. Minor amounts of epidote and chlorite occur as well. Mingling structures between different mafic rock types or between mafic and associated felsic rocks are common. Magmatic breccias (Fig. 36) from peripheral parts of the gabbro massif at Rengårdsheden west of Långträsk (7261080/1710820) are interpreted as either intrusion breccias or the results of back-veining processes.

In the Älvsbyn map area, the gabbro intrusion around Storsund (7283590/1722290) is surrounded by granitic subvolcanic intrusions, felsic volcanic rocks of the Arvidsjaur Group, and granites of the Perthite monzonite suite. This elliptical, concentric structure is clearly visible on the magnetic anomaly map.



Fig. 36. Magmatic breccia in peripheral parts of the gabbro massif at Rengårdsheden, Perthite monzonite suite. Tallberg, about 6 km west of Långträsk (7262656/1704994). Photo Benno Kathol.

Magmatisk breccia i randzonen av gabbromassivet vid Rengårdsheden, Pertitmonzonitsviten. Tallberg, ca 6 km väster om Långträsk.

Late to post Svecokarelian granites (Skellefte-Härnö suite)

Rocks of the Skellefte-Härnö suite occur in close spatial relationship with metasedimentary rocks of the Bothnian Supergroup. The magmas probably originate from the middle to upper parts of the crust and are related to regional metamorphism. In general, the rocks of the Skellefte-Härnö suite can be divided into two types. One heterogeneous variety is interpreted as the result of partial melting related to migmatization and generation of veined gneisses, followed by only local migration of the melt. The other type is more homogeneous and has a more intrusive character. These granites are considered to be slightly younger than the migmatite related rocks (Lundström & Antal 2000). They have been dated by Eliasson & Sträng (1997) at 1809±8 Ma (U-Pb, monazite) at lake Blaiksjön (7245220/1567730) and at 1798±4 Ma (U-Pb, zircon and titanite) by Weihed et al. (2002a) at Vitberget (7194750/1745850) north of Skellefteå. These ages imply a certain overlap in time of emplacement of rocks of the Skellefte-Härnö suite and rocks of the Transscandinavian Igneous Belt (se below).

The heterogeneous granites or migmatite granites are light grey, normally medium-grained and subordinately fine-grained to finely medium-grained, and massive (Fig. 37a). In places, porphyritic varieties with centimetre sized potassium feldspar phenocrysts have been observed. The granites contain xenoliths, consisting of metasedimentary rocks and granodioritic to tonalitic orthogneisses. Late to post Svecokarelian granitic, pegmatitic or aplitic veins and dykes occur as intrusions in either older intrusive and supracrustal rocks or within the migmatite granites themselves. These veins and dykes are interpreted as products of partial melting of older intrusive or supracrustal rocks. Areas where early Svecokarelian bedrock is interspersed with a dominating amount of this leucosome are assigned to the Skellefte-Härnö suite on the map. Tourmaline-bearing pegmatites between Åkerberg (7224550/1732500) and Åselet (7243730/1716670) are associated with the migmatite granites. A pegmatite dyke, about 1 km long and 30 m wide, has been observed at Lövsele (7147290/1763860) about 5 km south-southwest of Lövånger. Dykes of late to post Svecokarelian granite, pegmatite, and aplite also occur within the early Svecokarelian intrusive rocks in varying amount all over the map area, but seem to be abundant in the south-eastern part.

The late to post Svecokarelian rocks of more intrusive character are light grey to grey or reddish grey, fine- to medium-grained granites (Figs. 37b,c). Locally, granodioritic to tonalitic or trondhjemitic varieties occur. Both potassium feldspar porphyritic rocks and equigranular varieties exist. In places, the porphyritic granites are similar to granites belonging to the TIB. However, lath-shaped phenocrysts and low susceptibility values indicate that these granites belong to the Skellefte-Härnö suite. The rocks are mostly massive, but a weak foliation is reported from the Åsele, Järvsjö, and Vilhelmina map areas. A monzogranitic to granodioritic variety from the Stensele map area shows weak to moderate foliation. Partly assimilated xenoliths of metasedimentary rocks and orthogneisses occur in varying, but in places large amounts. Apart from the main minerals quartz, potassium feldspar, and plagioclase, varying quantities of biotite, muscovite, and amphibole (hornblende) also occur. Accessory minerals are apatite, zircon, opaque phases, andalusite, chlorite, cordierite, epidote, garnet, monazite, sillimanite, thorite, titanite, and xenotime.

Biotite aggregates, 1–2 cm in diameter, occur within minor massifs of the Skellefte-Härnö suite in the Åsele map area. In places where the granites contain xenoliths of older granites, the biotite aggregates seem to have grown over the contacts between both granites. As the Skellefte-Härnö suite lacks mafic members, mingling structures and enclaves are absent, which is in contrast to the other intrusive suites in the region.

Transscandinavian Igneous Belt (TIB): Supracrustal rocks (Dobblon Group)

Within the Dobblon area (7275960/1557000) northwest of Sorsele (Fig. 38), well preserved, mainly coarse clastic sedimentary rocks and felsic volcanic rocks of the Dobblon Group (Einarsson 1979) rest with a structural

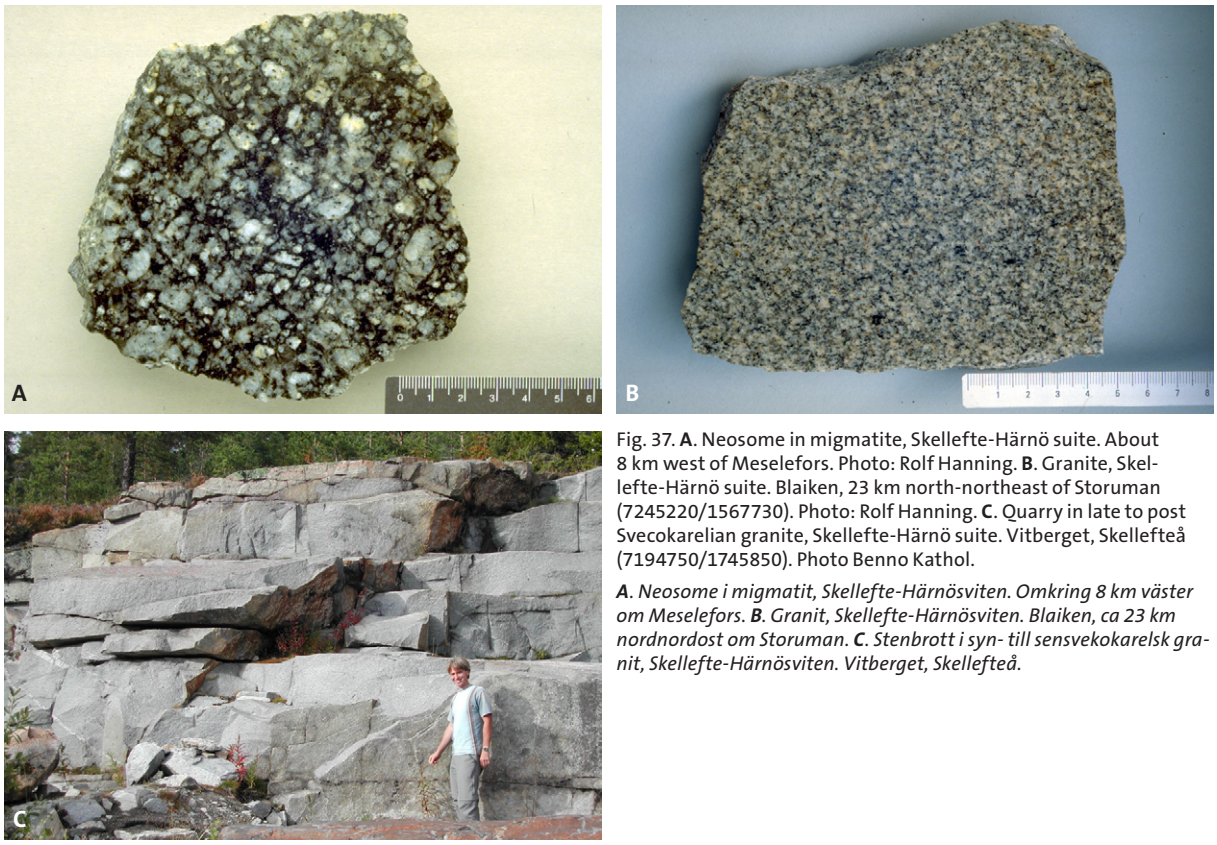


Fig. 37. **A**. Neosome in migmatite, Skellefte-Härnö suite. About 8 km west of Meselefors. Photo: Rolf Hanning. **B**. Granite, Skellefte-Härnö suite. Blaiken, 23 km north-northeast of Storuman (7245220/1567730). Photo: Rolf Hanning. **C**. Quarry in late to post Svecokarelian granite, Skellefte-Härnö suite. Vitberget, Skellefteå (7194750/1745850). Photo Benno Kathol.

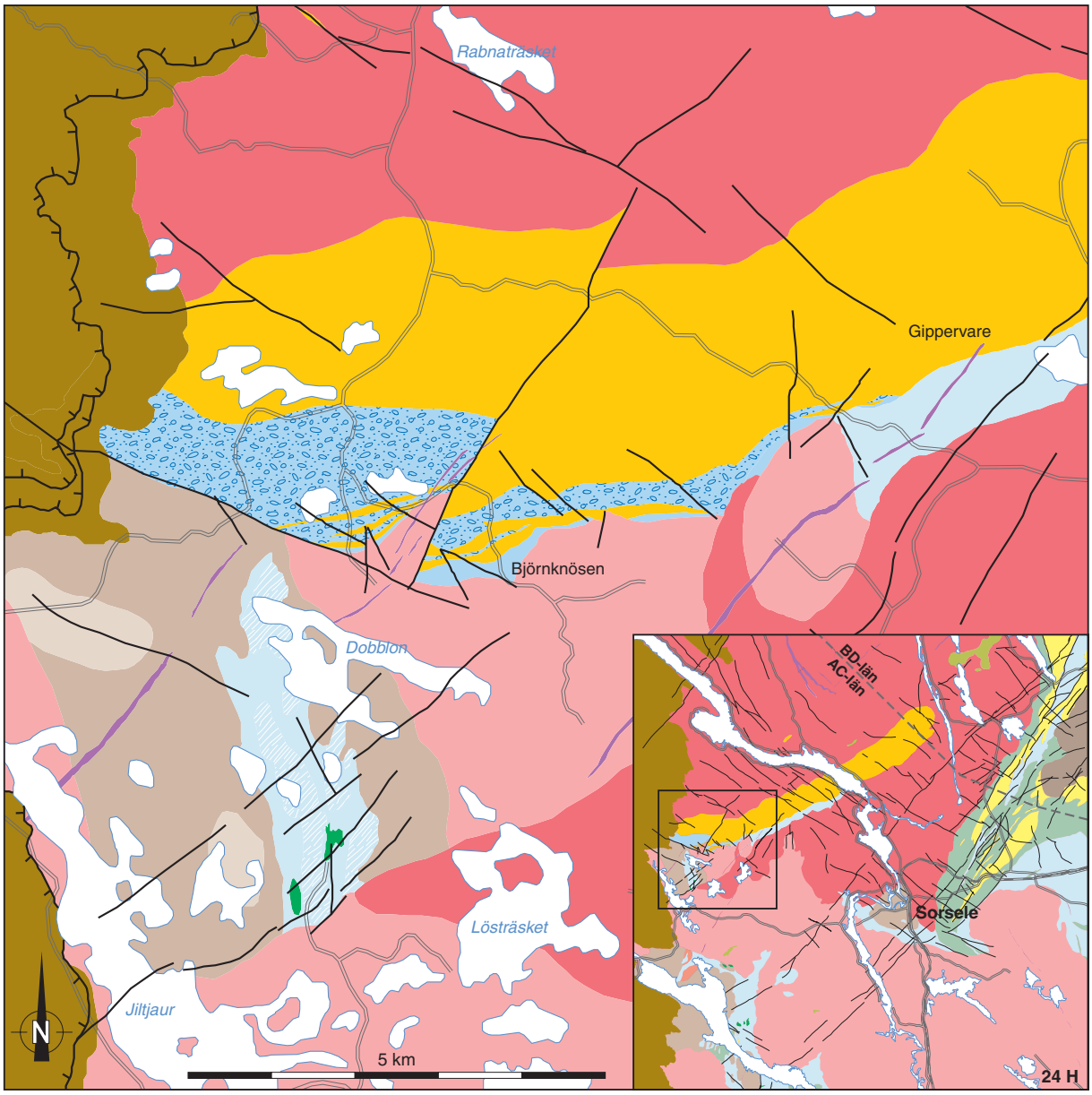
***A**. Neosome i migmatit, Skellefte-Härnösviten. Omkring 8 km väster om Meselefors. **B**. Granit, Skellefte-Härnösviten. Blaiken, ca 23 km nordnordost om Storuman. **C**. Stenbrott i syn- till sensvekokarelsk granit, Skellefte-Härnösviten. Vitberget, Skellefteå.*

unconformity on tight to isoclinally folded metagreywackes of the Bothnian Supergroup or on granitoids of the Revsund suite. In the west, the Dobblon Group is overlain by Neoproterozoic to Early Palaeozoic sedimentary cover rocks and Caledonian nappes. The Dobblon Group and the underlying metagreywackes are intruded by the late to post Svecokarelian intrusive rocks of the Sorsele suite (cf. Högbom 1937).

The supracrustal rocks of the Dobblon area, also spelled Duobblon on older maps or in older papers, were mentioned for the first time by Högbom (1931) and described in detail by Einarsson (1979) who assembled the metagreywackes under the designation "Paksjo Group". The overlying Dobblon Group (Einarsson 1979) has been divided into the mainly sedimentary Björnknösen Formation and the volcanic Gippervare Formation. A quartz porphyritic rhyolite of the Gippervare Formation was dated (U-Pb, zircon) at 1803±15 Ma by Skiöld (1988). A sample from the Sorsele granite, which intrudes the Dobblon Group, yielded a U-Pb zircon age of 1791±22 Ma (Skiöld 1988). Thus, the Dobblon Group was emplaced around 1.8 Ga ago and is contemporaneous with the intrusive rocks of the TIB.

The sedimentary succession of the Dobblon Group (Björnknösen Formation) consists of a conglomerate-dominated lower part, grading upwards into a medium-grained arkose. The conglomerates consist of either debris-flow units or sorted traction-deposit units. Furthermore, distinctly laminated fine-grained units are common in the very lowermost part of the conglomerate succession. The conglomerates in the lowermost parts of the Björnknösen Formation are oligomict, and the clasts are derived either from the underlying granitoids (Fig. 39a) or the metagreywackes of the Paksjo Group (Fig. 39b). Higher up in the succession, the conglomerates are polymict and contain clasts of volcanic rocks, coarse-grained porphyritic granites, jasper and brownish red, subaerial sandstones (Fig. 39c). The sandstone part of the succession is dominated by horizontally laminated and cross-bedded sandstones. These sedimentological characteristics of the Björnknösen Formation support the interpretation that this succession was deposited in alluvial to fluvial settings.

The clastic succession of the Björnknösen Formation is intercalated by at least three rhyolitic, ignimbritic ash flow deposits with interlayered thin horizons of conglomerate. The matrix of these ash-flow deposits consists largely of flattened fragments of devitrified volcanic glass, but Einarsson (1979) reports scattered phenocrysts or phenoclasts of potassium feldspar, quartz, and albite. The clasts consist of rock fragments and pumice, partly with an eutaxitic texture. Up to 15 cm large lithophysae are characteristic of the unit (Fig. 40a), and spherulitic and perlitic textures and amygdales occur. True weld-



Nappe boundary, thrust
Skollgräns, överskjutning

Deformation zone
Deformationszon

Caledonian rock
Fjällberggrund

Dolerite, Mesoproterozoic
Diabas, mesoproterozoisk

Late to post Svecokarelian rocks, c. 1.82–1.76 Ga (TIB)
Sen- till postsvekokarelska bergarter, ca 1,82–1,76 Ga (TMB)

Polymictic conglomerate
Polymikt konglomerat

Conglomerate
Konglomerat

Rhyolite
Ryolit

Granite–quartz monzonite
Granit–kvartsmonzonit

Granite
Granit

Gabbro–quartz diorite
Gabbro–kvartsdiorit

Late to post Svecokarelian rocks, c. 1.82–1.78 Ga (Skellefte-Härnö suite)
Sen- till postsvekokarelska bergarter, ca 1,82–1,78 Ga (Skellefte-Härnösviten)

Granite of crustal origin
Granit av krustalt ursprung

Perthite monzonite suite, c. 1.88–1.86 Ga
Pertitmonzonitsviten, ca 1,88–1,86 Ga

Gneissic granite
Gnejsgranit

Early Svecokarelian calc-alkaline granitoids, c. 1.96–1.86 Ga
Tidigsvekokarelska kalk-alkaline granitoider, ca 1,96–1,86 Ga

Gneissic granite–gneissic granodiorite
Gnejsgranit–gnejsgranodiorit

Gneissic tonalite–meta-quartz diorite
Gnejstonalit–metakvartsdiorit

Meta-diorite–meta-quartz diorite
Metadiorit–metakvartsdiorit

Svecofennian supracrustal rocks, c. 1.96–1.86 Ga
Svekofenniska ytbergarter, ca 1,96–1,86 Ga

Metagreywacke
Metagråvacka

Metaargillite
Metaargillit

Mafic metavolcanic rock
Mafisk metavulkanisk bergart

Felsic metavolcanic rock
Felsisk metavulkanisk bergart

Fig. 38. Bedrock map of the Dobblon area. For location of the area, see Fig. 50.

Berggrundskarta över Dobblonområdet. Områdets läge framgår av fig. 50.

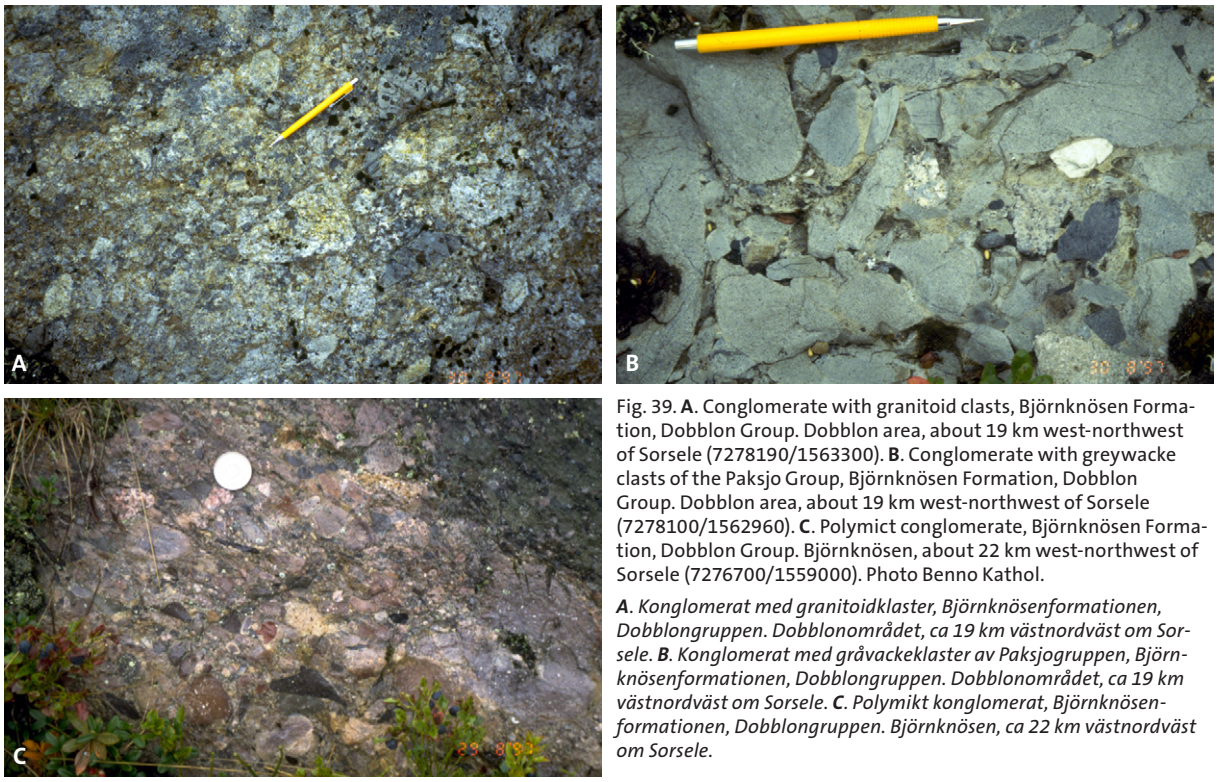


Fig. 39. **A**. Conglomerate with granitoid clasts, Björnknösen Formation, Dobblon Group. Dobblon area, about 19 km west-northwest of Sorsele (7278190/1563300). **B**. Conglomerate with greywacke clasts of the Paksjo Group, Björnknösen Formation, Dobblon Group. Dobblon area, about 19 km west-northwest of Sorsele (7278100/1562960). **C**. Polymict conglomerate, Björnknösen Formation, Dobblon Group. Björnknösen, about 22 km west-northwest of Sorsele (7276700/1559000). Photo Benno Kathol.

***A**. Konglomerat med granitoidklaster, Björnknösenformationen, Dobblongruppen. Dobblonområdet, ca 19 km västnordväst om Sorsele. **B**. Konglomerat med gråvackeklaster av Paksjogruppen, Björnknösenformationen, Dobblongruppen. Dobblonområdet, ca 19 km västnordväst om Sorsele. **C**. Polymikt konglomerat, Björnknösenformationen, Dobblongruppen. Björnknösen, ca 22 km västnordväst om Sorsele.*

ing is indicated by the overprinting of flattened glass fragments and eutaxitic textures by lithophysae and spherulites. The ash flow deposits represent several emplacement units, as they are interbedded with conglomerate and sandstone beds. In places, cross-bedding and slide structures indicate that the unit is right-way-up and younging towards the north (Einarsson 1979). This volcano-sedimentary unit hosts a stratabound uranium mineralization, which was investigated in the 1970s (Lindroos & Smellie 1979).

The Gippervare formation rests concordantly on the Björnknösen Formation and consists essentially of rhyolitic tuffs, ignimbrites, and volcanic breccias (Einarsson 1979). Recently, coherent volcanic rocks have also been identified (Fig. 40b). The ignimbrites are quartz or feldspar porphyritic and show eutaxitic textures. They are associated with crystal tuffs, rich in angular crystal fragments but almost devoid of rock fragments. Y-shaped glass splinters occur, enhancing the volcanic character of these rocks. The tuffs are quite massive and unstratified in most areas, but bedded varieties do occur in a few places. North of the Skravelberget hill (7276880/1562150) in the Dobblon area, volcanic breccias consist of volcanic clasts and a matrix of volcanic origin with eutaxitic texture. In this area, the breccias coexist with both ignimbrites and tuffs, which Einarsson (1979) suggests indicate a local volcanic centre.

According to Einarsson (1979), porphyritic varieties are common in the marginal parts of the of the Sorsele granite. Geochemically, the volcanic rocks of the Dobblon Group are similar to the igneous rocks of the Sorsele and Revsund suites (Bark & Claesson 2001). Furthermore, many fine-grained, porphyritic varieties of the Sorsele granite are petrographically similar to the volcanic rocks. Consequently, the volcanic rocks of the Dobblon Group are interpreted as extrusive varieties of the Sorsele granite that intruded slightly after the emplacement of the volcanic rocks.

The rocks of the Dobblon Group were studied in some detail during uranium exploration in the late 1970s. The stratigraphy and true thickness of the different units of the Dobblon Group, derived from drill hole data and geological maps, were presented by Lindroos (1979) and Lindroos & Smellie (1979). These investigations show that the Dobblon Group dips gently towards north-northwest and rests on an eroded basement of porphyritic granite, which is interpreted as belonging to the Revsund suite (called "older granite" by Einarsson 1979) and Svecofennian metagreywacke. The total thickness of the Dobblon Group is estimated at approximately 2400 m, of which the lower, sedimentary, best studied formation is about 430 m thick (Lindroos 1979).

The lowermost unit in the Björnknösen Formation consists commonly of oligomict erosion breccias, where the composition of the angular to subrounded clasts is similar to that of the basement (Figs. 39a,b). From drill hole logs it is evident that the transition between the basement granite and the breccia varies from clear



Fig. 40. **A** Lithophysae in rhyolitic, ignimbritic ash flow deposits. Björnknösen Formation, Dobblon Group, Dobblon area, about 19 km west-northwest of Sorsele (7278110/1563140). Photo Benno Kathol. **B**. Peperitic lower contact of the Gippervare formation. Osaberget quarry, southern part (7282153/1571688). Photo Ingmar Lundström.

***A**. Litofyser i ryolitiska, ignimbritiska askflödesavlagringar. Björnknösenformationen, Dobblongruppen, Dobblonområdet, ca 19 km västnordväst om Sorsele. **B**. Peperitisk undre kontakt i Gippervareformationen. Stenbrott Osaberget (24H) södra delen.*

and sharp to more diffuse with a zone of reworked palaeo-weathered granitic material. Fracturing and alteration, found in the basement granite, are interpreted as belonging to this palaeo-weathering (e.g. Einarsson 1985a). The overlying polymict conglomerate contains clasts of volcanic material similar to the volcanic rocks in the overlying Gippervare formation. This indicates that the volcanism had already started elsewhere when the coarse clastic sediments were deposited.

Transscandinavian Igneous Belt (TIB): Intrusive rocks (Revsund–Sorsele–Adak–Edefors–Ale suites)

The intrusive rocks of the Transscandinavian Igneous Belt (TIB) cover large parts of the Fennoscandian Shield in the western and south-western parts of the map area. The TIB rocks were formed predominantly by felsic magmas, which were to only a minor extent accompanied by mafic magmas. South of the Skellefte District or roughly south of river Skellefteälven, most TIB intrusions are surrounded by rocks of amphibolite facies, whereas the intrusions north-east of river Skellefteälven are situated within greenschist facies rocks.

The major part of the TIB is composed of rocks of the Revsund suite (Högbom 1894, Lundqvist et al. 1990). Minor intrusive assemblages are the Sorsele suite (Högbom 1937) in the north-west, the Adak suite (Bergström & Triumf 2002) in the north-central part of the area, and the Edefors and Ale suites (Öhlander & Schöberg 1991, Öhlander & Skiöld 1994) in the north-east of the map area. Previously, only the Sorsele suite had been included in the TIB, but recent interpretations also include the Revsund suite (Gorbatschev & Bogdanova 1993). Here, we also include the coeval Adak, Edefors, and Ale suites in the TIB.

The bedrock of the TIB within the map area consists of numerous tabular intrusions. They probably formed by melts that were emplaced just below the ductile–brittle transition zone in the crust, which is interpreted as now dipping south-west and being cut obliquely by the present erosion surface. In most cases, these intrusions are both laterally and vertically in contact with each other. In places, they show microcline- and quartz porphyritic, chilled margins against each other. These adjacent intrusions are not differentiated on the bedrock map, but can be recognized locally on the magnetic anomaly map. Where individual plutons are confined by early Svecokarelian rocks, they commonly show circular to elliptic intrusion shapes. Examples of isolated intrusions of this kind (emplaced into greenschist facies rocks) are the tabular-shaped plutons in the western part of lake Storavan, around Slagnäs (7278560/1608870), around lake Månsträsket (7275440/1633820), and at lake Släppträsket (7231900/1627830). Isolated intrusions into higher grade rocks are situated south-east of Storuman (Joran dome, 7205360/1576950), west of Blåviksjön (7192780/1606930) to the north-west of Kåge, around lake Skråmträsket (7181140/1729380), and south of Kalvträsk (7180040/1690560).

The rocks of the Revsund suite intruded mainly during the final phase of the Svecokarelian orogeny into a consolidated crust. The intrusions clearly post-date all Svecokarelian tectonic structures. Magmatic textures (isotropic or magmatic foliation) are well preserved; tectonic foliation, mylonite structures or alteration are observed only in younger deformation zones.

The rocks of the Revsund suite were formed by high-temperature, volatile-poor (pegmatite-poor) magmas (Kousa & Lundqvist 2000). They show a differentiation trend from rare gabbro to quartz monzodiorite, quartz monzonite, granodiorite, and granite (Persson 1978). Subordinate volumes of mafic rocks can be closely re-

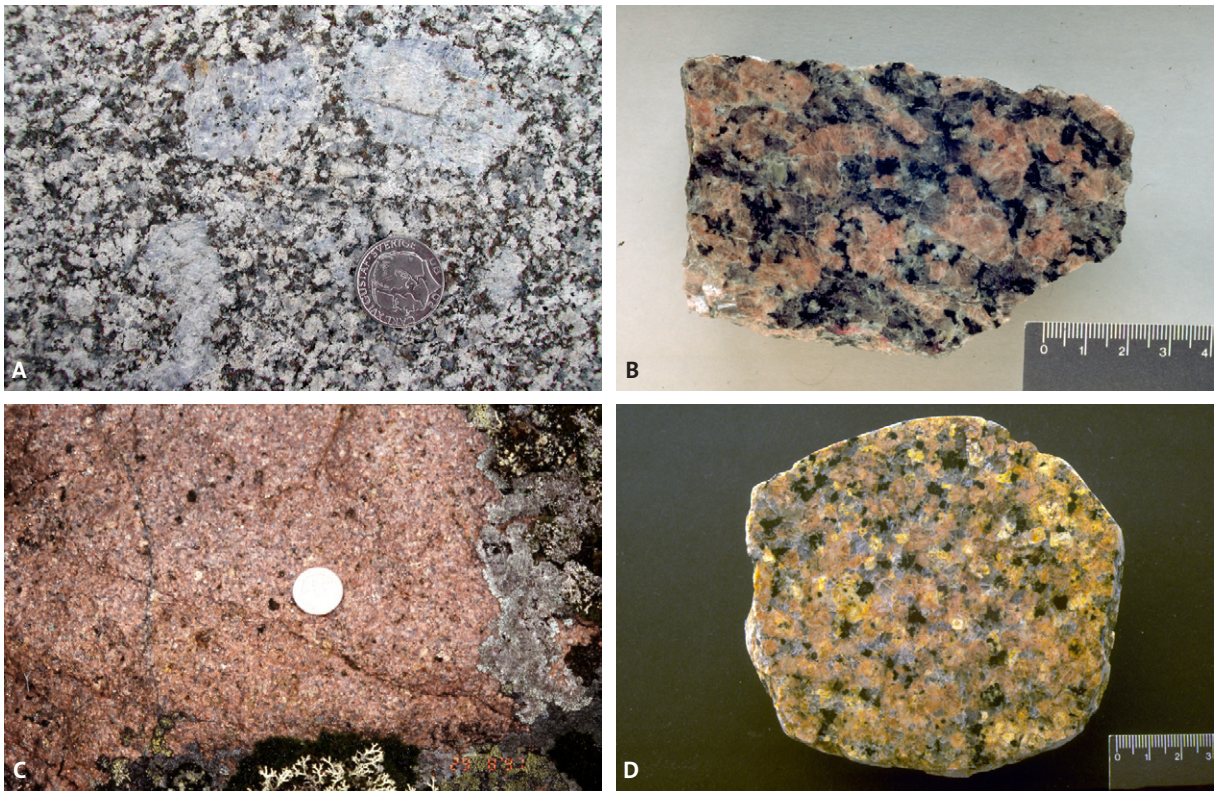


Fig. 41. **A**. Granite, Revsund suite, Transscandinavian Igneous Belt (TIB). Dorotea (7128390/1530040). Photo Benno Kathol. **B**. Granite, Revsund suite, Transscandinavian Igneous Belt (TIB). Nyhem close to Dorotea. Photo: Rolf Hanning. **C**. Medium-grained granite of the Sorsele suite, Transscandinavian Igneous Belt (TIB). Liksgelisen, about 14 km north-west of Sorsele (7279165/1567500). Photo Benno Kathol. **D**. Granite, Adak suite, Transscandinavian Igneous Belt (TIB). Boulder from near Gåsberget, about 17 km south-southwest of Arvidsjaur. Photo: Rolf Hanning.

***A**. Granit, Revsundssviten, Transskandinaviska magmatiska bältet (TMB). Dorotea. **B**. Granit, Revsundssviten, Transskandinaviska magmatiska bältet (TMB). Nyhem vid Dorotea. **C**. Medelkornig granit i Sorselesviten, Transskandinaviska magmatiska bältet (TMB). Liksgelisen, ca 14 km nordväst om Sorsele. **D**. Granit, Adaksviten, Transskandinaviska magmatiska bältet (TMB). Block från Gåsbergetområdet, ca 17 km sydsydväst om Arvidsjaur.*

lated to the felsic members by mingling and mixing phenomena.

The Revsund suite is dominated by grey to red, in most cases medium- to coarse-grained, coarsely feldspar porphyritic granites (Figs. 41a,b), quartz monzonites, and subordinate granodiorites and tonalites. Besides the main minerals potassium feldspar, quartz and plagioclase, hornblende and biotite are common constituents. Subordinate and accessory minerals are apatite, allanite, epidote, titanite, zircon, muscovite, ilmenite, calcite, chlorite, fluorite, garnet, monazite, thorite, xenotime, haematite, magnetite, and unspecified opaque phases. Chlorite and sericite often occur as alteration products of biotite and plagioclase respectively. Dark grey, charnockitic Revsund granitoids, so-called "black Revsund granites" have been encountered in several areas. These rocks contain up to 20% hypersthene and less quartz and feldspar than "normal" Revsund granitoids. Hydrothermally altered, intensely red secondary coloured varieties are in places restricted to younger deformation zones. Normally they have high contents of chlorite and epidote and are in places enriched with magnetite.

The phenocrysts are rectangular or round and normally range in size from 20 to 40 mm, locally up to 100 mm. They consist of potassium feldspar (microcline), in places with a rim of plagioclase. Phenocrysts of blue quartz occur subordinately. Magmatic orientation of rectangular phenocrysts is locally developed, in marginal facies commonly parallel with the contacts with other rocks. Even-grained, coarse-grained varieties occur in places as a marginal facies type.

The Revsund granites commonly contain more or less assimilated fragments. These range from basic or mica-rich "schlieren" over minor fragments of quartz-feldspar rich rocks to larger fragments, consisting of metagreywackes, metavolcanic rocks and older metagranitoids. The presence of fragments of rocks from the Skellefte-Härnö suite has been used as a criterion for distinguishing between Revsund and Skellefte suite rocks, which in places is problematic. Elongated and concentrically arranged megaxenoliths of volcanic rocks of the Arvids-

jaur Group, up to 1 km^2 in size within the Månsträsket intrusion, can be distinguished on and are partly inferred from the magnetic anomaly map. Mafic and felsic, sparsely potassium feldspar porphyritic enclaves with sizes ranging from a few centimetres to several tens of metres are interpreted as the result of magma mingling between granitoid magmas and minor volumes of mafic magma.

Quartz monzonitic to trondhjemitic veins and dykes in the Stensele area are regarded as late fractionation products of the Revsund suite. Dolerite dykes in the Storavan map area are interpreted as late to post Svecokarelian. Pegmatite, aplite, and granitic dykes occur in varying amounts within the Revsund granitoids.

The Sorsele suite consists of red, medium-grained, biotite-hornblende-bearing monzogranites (Fig. 41c). Characteristic of these rocks are granular, anhedral textures with irregularly formed crystal shapes. The plagioclase grains are commonly sericite-altered and saussuritized in their central parts, which produces typically green coloured plagioclase crystals, especially within the red granites. Myrmekite (quartz and plagioclase) and antiperthite (microcline in plagioclase) are common. Mafic minerals, mainly amphibole and biotite, and subordinate titanite, haematite, magnetite, and ilmenite have been observed as small aggregates. Subordinately, there are grey to brownish grey, medium-grained, honblende- and pyroxene-bearing quartz monzonites and quartz syenites. Sericite or saussurite alteration is absent, which indicates a relatively low volatile content in these magmas. Mafic members range in composition from gabbro to quartz diorite.

The rocks of the Sorsele suite are considered to be slightly younger than the granitoids of the Revsund suite and the supracrustal rocks of the Dobblon group (se above). According to Högbom (1937) and Einarsson (1979) the Sorsele rocks exhibit intrusive contacts that truncate internal structures within the Dobblon Group. At Skravelberget hill (7276880/1562150) in the Dobblon area, chilled margins of Sorsele granite against Revsund granite are exposed. A radiometric dating (U-Pb, zircon) from a Sorsele granite from Stor-Gidna (7299000/1579400) gave an age of 1791±22 Ma (Skiöld 1988).

The Adak suite consists of red, even- to uneven-grained, medium- to coarse-grained, in places gritty weathering granites with the same composition as the Revsund granites (Fig. 41d). The intrusions are tabular with depths not exceeding 2 km from the present erosion surface (Isaksson et al. 1994). Adak granite from the Släppträsket intrusion about 10 km west of Malå has been dated (U-Pb zircon) at 1802±3 Ma (Bergström & Sträng 1999a).

A red, medium-grained syenite with granitic parts, situated at Älvsbyn, can be clearly distinguished from adjacent rocks of the Perthite monzonite suite on the magnetic anomaly map. This intrusion has been dated (U-Pb, zircon) at Hundberget (7296680/1739929) at 1803±4 Ma (SGU, unpublished) and is therefore assigned to the 1800 Ma Edefors suite, situated farther to the north.

TIB related c. 1800 Ma old intrusive rocks occur in two massifs within the Luleå area in the north-east. Both show normal zoning with more felsic varieties in the central parts and more mafic members (gabbros and hybrids) in their peripheral parts. Monzonitic and syenitic varieties also occur. The gabbroic intrusions contain sporadic anorthosites. Magma mingling structures are common in the contact areas between mafic and felsic members. The central part of the eastern Ale massif has been dated at 1802±3 Ma (Öhlander & Schöberg 1991), and a granite from peripheral parts of the massif yielded an age of 1796±2 Ma (Öhlander & Schöberg 1991).

Mesoproterozoic rocks

Jotnian supracrustal rocks

Jotnian supracrustal rocks constitute parts of the bedrock beneath the Bothnian Bay to the east of the Baltic coast of the map area. They are not shown on the map. For further information, see Lundqvist et al. (1996a) and Winterhalter (2000).

Dolerites

Dolerites occur as swarms of vertical to subvertical dykes or systems of thick, flat-lying dykes and sills with differing orientation in different areas. Normally they are fine- to medium-, in places coarse-grained, massive rocks with intergranular to ophitic textures. There are different generations of dolerites, but a common feature is that they cut through all other Precambrian rocks of the map area.

East-northeast striking dolerite dykes in the area around Dorotea belong to a swarm of vertically to subvertically dipping dolerite dykes, which has its largest extension south-west of Åsele, just south of the present map area. Due to selective weathering, these dykes have been observed only in a few places. However, they are clearly distinguishable as positive anomalies on the magnetic anomaly map and their positions on the geological map could in most cases be inferred from magnetic data. Where observed in outcrop, they are normally 0.5 to 2 m wide, locally up to 70 m. Geophysical modelling indicates that several dykes cause anomalies on the magnetic

anomaly map, even though they do not crop out at the surface. Palaeomagnetic data indicate an age of at least 1400 Ma for these dykes (S.-Å. Elming pers. com., in Björk & Kero 2000).

Another system of dolerite intrusions is situated between Storuman and Gargnäs (7247250/1600780) in the north and Lycksele and Åsele (outside the map area) in the south. These dolerites occur at the surface as more or less continuous, north-northwest or north-striking streaks, which in several cases cause positive or negative anomalies on the magnetic anomaly map. In many places, they are interpreted as minor vertical to subvertical dykes, which branch off from several hundred metres thick, flat lying sills. These sills crop out at the surface west of Lycksele and in the northern parts of the Åsele map area (21H). However, a considerably larger extension below surface of these dolerite sills is indicated by gravity highs in areas where the bedrock at the surface consists of granitoids of the Transscandinavian Igneous Belt with relatively low densities. Systems of north-northwest to north-west striking streaks in the southern Järvsjö (22H) and northern Åsele map areas (21H) are interpreted with the aid of geophysical data as the outcropping parts of slightly south-east dipping, bowl-shaped, more than one kilometre thick sheets.

The dolerites are dark grey to black, fine-grained to very fine-grained (Fig. 42). Main minerals are sericitized plagioclase, amphibole, pyroxene, chloritized biotite, serpentinized olivine, and opaque phases. Less abundant are quartz, calcite, titanite, apatite and talc. The mineral content varies between different dyke systems.

The natural magnetic remanence is homogeneous within large parts of this dyke–sill system. This indicates that large volumes of dolerite melt have roughly the same age and that they have been emplaced by just a few intrusive pulses. The age of the dolerites, belonging to this system, has been determined by palaeomagnetic data to c. 1270 Ma (Elming & Matsson 2001). The geophysical properties of the flat-lying dolerite sheets are almost identical with those of the Ulvö dolerites at Nordingrå in central Sweden (outside the map area), described in detail by Larsson & Magnusson (1976) and Magnusson (1976).

North-west-striking and gently south-west-dipping, somewhat undulating dolerite dykes within the Stensele map area are correlated with the above named system of flat-lying dolerite dykes or sills. They are up to about 30 m thick and normally show chilled, i.e. darker and finer grained, margins against the host rocks. The dolerites consist of titanium augite, plagioclase, olivine, titanomagnetite, biotite, and apatite (Stålhös 1958). The chemical and mineralogical composition of a dolerite from the area south of Storuman infers correlation with the c. 1250 Ma old Central Scandinavian Dolerite Group (CSDG) as described by Gorbatschev et al. (1979) and Greiling (1992). The dolerites cause clearly distinguishable anomalies on the magnetic anomaly map.

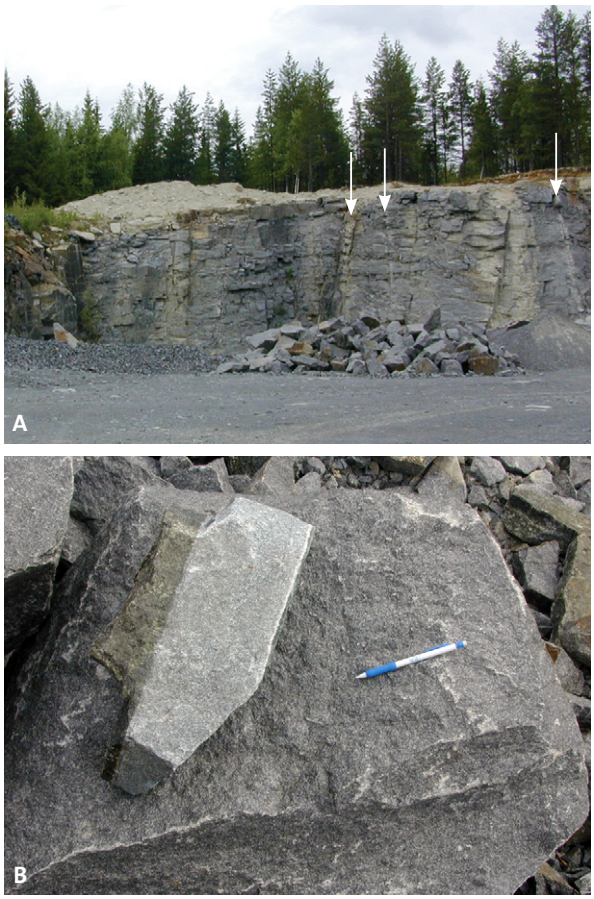


Fig. 42. **A**. A sill of dark grey, fine- to coarse-grained, ophitic dolerite is intruded by narrow, steeply dipping dykes of light grey, fine-grained leuco-dolerite (indicated by arrows). Orrkulla dolerite quarry, approximately 13 km west-southwest of Lycksele (7164250/1625320). **B**. Close-up of both rock types. Photo Leif Björk.

***A**. Lagergång av finkornig till grovkornig, ofitisk diabas, intruderad av smala, brantstående gångar av ljusgrå, finkornig leukodiabas (vid pilarna). Orrkulla diabasbrott, ca 13 km västsydväst om Lycksele. **B**. Närbild av båda bergartstyperna.*

The dolerite dyke systems in the Arvidsjaur and Luleå map areas are mostly inferred from characteristic anomalies on the magnetic anomaly map. They have been verified at Holmträskberget (7290755/1699191) north-west of Långträsk (7261080/1710820).

Petrophysical and spectrometry data constraints on the subdivision of different rock units

The petrophysical and spectrometric properties of different groups of rocks from the project area are presented in the following diagrams:

– Magnetic susceptibility versus density (M-D diagram. Figs. 43:1, 5, 9, 13, 17)
– Magnetic susceptibility versus Königsberger ratio Q (M-Q diagram. Figs. 43:2, 6, 10, 14, 18)

The spectrometry is presented in two diagrams:
– Thorium versus potassium (Th-K diagram. Figs. 43: 3, 7, 11, 15, 19)
– Uranium/thorium versus potassium (U/Th-K diagram. Figs. 43:4, 8, 12, 16, 20)

Palaeoproterozoic metaintrusive rocks (early Svecokarelian calc-alkaline granitoids) and Archaean metaintrusive rocks (metatonalite, metatrondhjemite)

Petrophysical and spectrometry data for early Svecokarelian calc-alkaline granitoids and Archaean metaintrusive rocks are shown in Figures 43:1–4. The distributions in M-D and M-Q diagrams of early Svecokarelian calc-alkaline granitoids resemble the distributions of the felsic intrusive rocks of the TIB, presented below. However, in the diagrams showing data from field gamma ray spectrometry a difference may be noted in the potassium content, which is generally higher in the TIB rocks.

The Archaean rocks occupy approximately the same portions of the diagrams, though more mafic components are noted. A few Archaean samples show very high remanent magnetizations.

Palaeoproterozoic metasedimentary and sedimentary rocks of the Bothnian, Skellefte, Arvidsjaur, Vargfors, and Dobblon Groups

Petrophysical and spectrometry data for the metasedimentary and sedimentary rocks of the Bothnian, Skellefte, Arvidsjaur, Vargfors, and Dobblon Groups are shown in Figures 43:5–8. The M-D and M-Q diagrams for these rock groups show marked differences from diagrams for other rock groups. Here the silicate density trend lines in the M-D diagram reflect the effects of pyrrhotite (Henkel 1991), whereas the effect of magnetite is dominant in other rock clusters. The strong remanent magnetization in the Bothnian Supergroup is attributable to the pyrrhotite content. The data follow the so-called "pyrrhotite variation trend" of Henkel (1991) in the M-Q diagram.

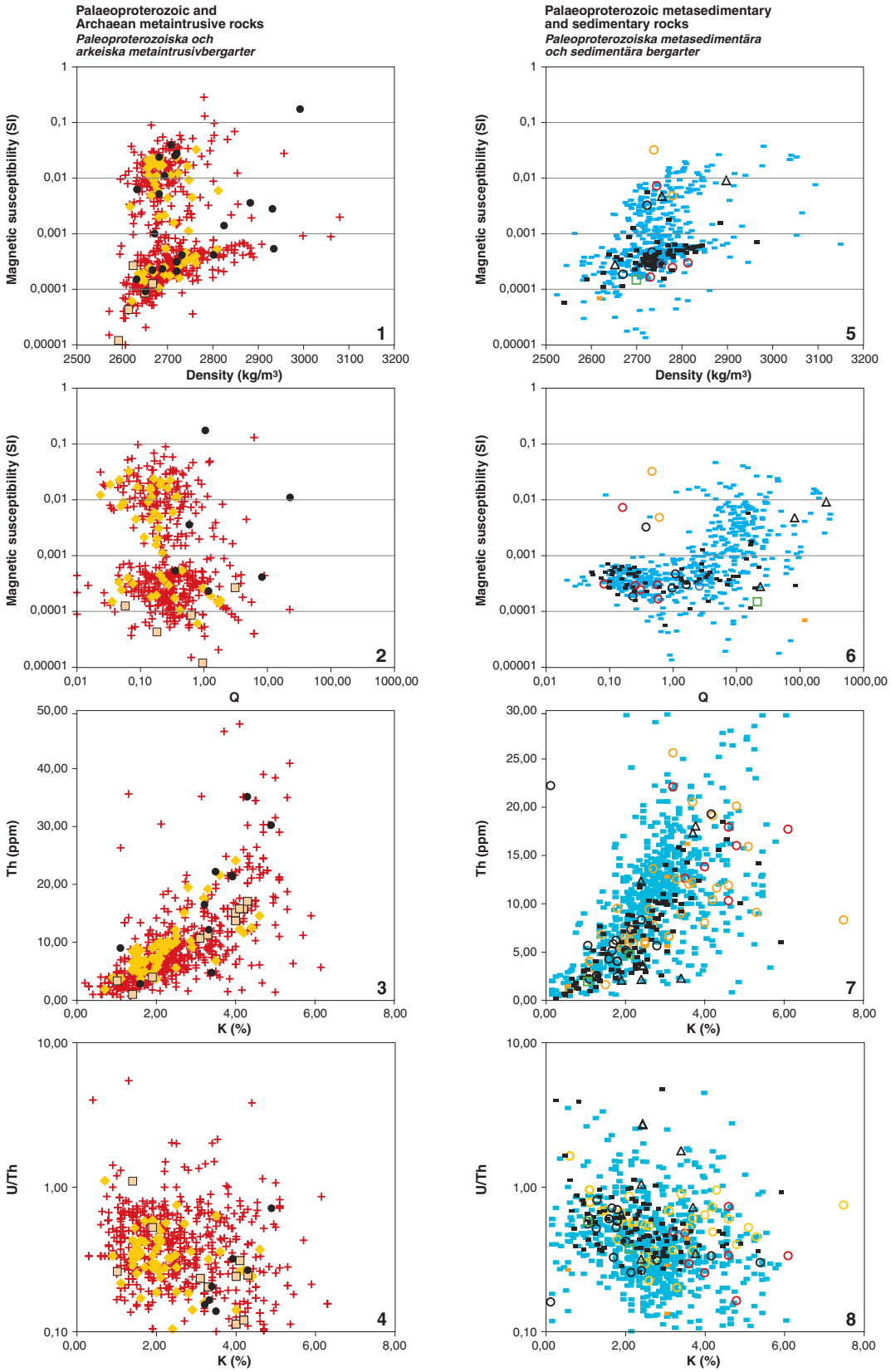
In the Bothnian Supergroup, high susceptibilities are found due to the pyrrhotite content. Kero (1982) has shown that the total field magnetic anomalies in the Bothnian Supergroup can be as high as in magnetite-bearing rocks due to the high remanence. The metasedimentary rocks of the Skellefte Group have, in general, low magnetic susceptibilities and follow the paramagnetic trend. In the Th-K diagram, the content of potassium and thorium varies from very low to quite high. As mentioned above, the metasedimentary rocks of the Bothnian Supergroup generally show higher Th/K ratios than the Skellefte Group.

Palaeoproterozoic metavolcanic and volcanic rocks of the Bothnian, Skellefte, Arvidsjaur, Vargfors, and Dobblon Groups

Petrophysical and spectrometry data for Palaeoproterozoic metavolcanic and volcanic rocks of the Bothnian, Skellefte, Arvidsjaur, Vargfors, and Dobblon Groups are shown in Figures 43:9–12. The volcanic rocks in the Bothnian Supergroup all have low magnetic susceptibilities and appear to follow the biotite-amphibole paramagnetic trend in the M-D diagram. The mafic metavolcanic rocks of the Bothnian Supergroup show a very heterogeneous quality in classification where many high potassium and thorium values are found, which is not expected from mafic rocks. In the database for the density and magnetic properties, only mafic rocks were taken into account; all other rocks were sorted out, leaving only a few. This distinction on rock type was however not possible in the database for spectrometry.

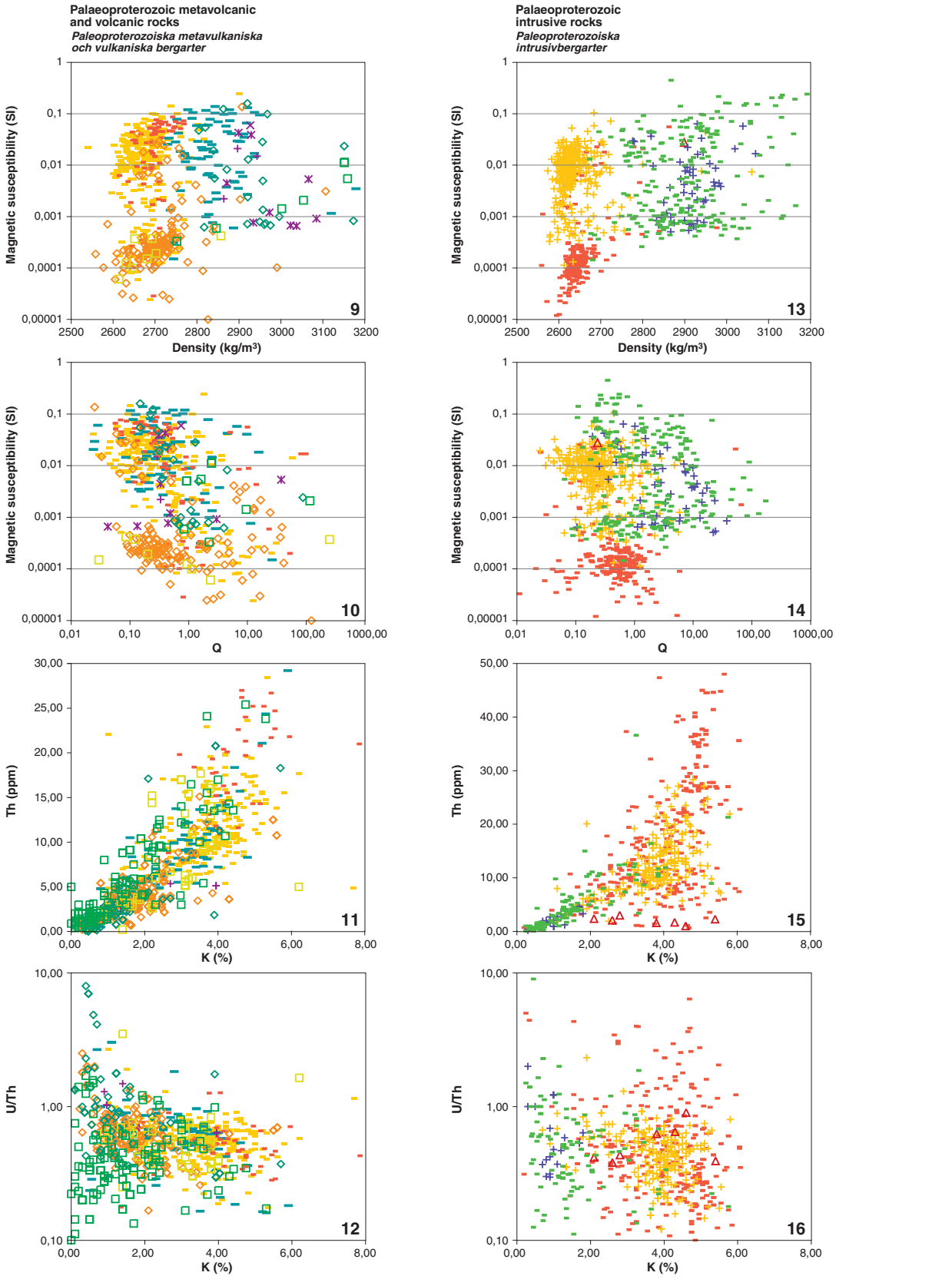
Fig. 43. **1**. Petrophysical diagram (n=20), Magnetic susceptibility versus density (M-D diagram). **2**. Petrophysical diagram (n=20), Magnetic susceptibility versus Q values (M-Q diagram). **3**. Thorium versus potassium (Th-K diagram). **4**. Uranium/thorium versus potassium (U/Th-K diagram). **5**. Magnetic susceptibility versus density (M-D diagram). **6**. Magnetic susceptibility versus Q values (M-Q diagram). **7**. Thorium versus potassium (Th-K diagram). **8**. Uranium/thorium versus potassium (U/Th-K diagram). **9**. Magnetic susceptibility versus density (M-D diagram). **10**. Magnetic susceptibility versus Q values (M-Q diagram). **11**. Thorium versus potassium (Th-K diagram). **12**. Uranium/thorium versus potassium (U/Th-K diagram). **13**. Magnetic susceptibility versus density (M-D diagram). **14**. Magnetic susceptibility versus Q values (M-Q diagram). **15**. Thorium versus potassium (Th-K diagram). **16**. Uranium/thorium versus potassium (U/Th-K diagram). **17**. Magnetic susceptibility versus density (M-D diagram). **18**. Magnetic susceptibility versus Q values (M-Q diagram). **19**. Thorium versus potassium (Th-K diagram). **20**. Uranium/thorium versus potassium (U/Th-K diagram).

1. *Magnetisk susceptibilitet mot densitet (M-D-diagram).* ***2***. *Magnetisk susceptibilitet mot Q-värden (M-Q-diagram).* ***3***. *Torium mot kalium (Th-K-diagram).* ***4***. *Uran/torium mot kalium (U/Th-K-diagram).* ***5***. *Magnetisk susceptibilitet mot densitet (M-D-diagram).* ***6***. *Magnetisk susceptibilitet mot Q-värden (M-Q-diagram).* ***7***. *Torium mot kalium (Th-K-diagram).* ***8***. *Uran/torium mot kalium (U/TH-K-diagram).* ***9***. *Magnetisk susceptibilitet mot densitet (M-D-diagram).* ***10***. *Magnetisk susceptibilitet mot Q-värden (M-Q-diagram).* ***11***. *Torium mot kalium (Th-K-diagram).* ***12***. *Uran/torium mot kalium (U/Th-K-diagram).* ***13***. *Magnetisk susceptibilitet mot densitet (M-D-diagram).* ***14***. *Magnetisk susceptibilitet mot Q-värden (M-Q-diagram).* ***15***. *Torium mot kalium (Th-K-diagram).* ***16***. *Uran/torium mot kalium (U/Th-K-diagram).* ***17***. *Magnetisk susceptibilitet mot densitet (M-D-diagram).* ***18***. *Magnetisk susceptibilitet mot Q-värden (M-Q-diagram).* ***19***. *Torium mot kalium (Th-K-diagram).* ***20***. *Uran/torium mot kalium (U/Th-K-diagram).*



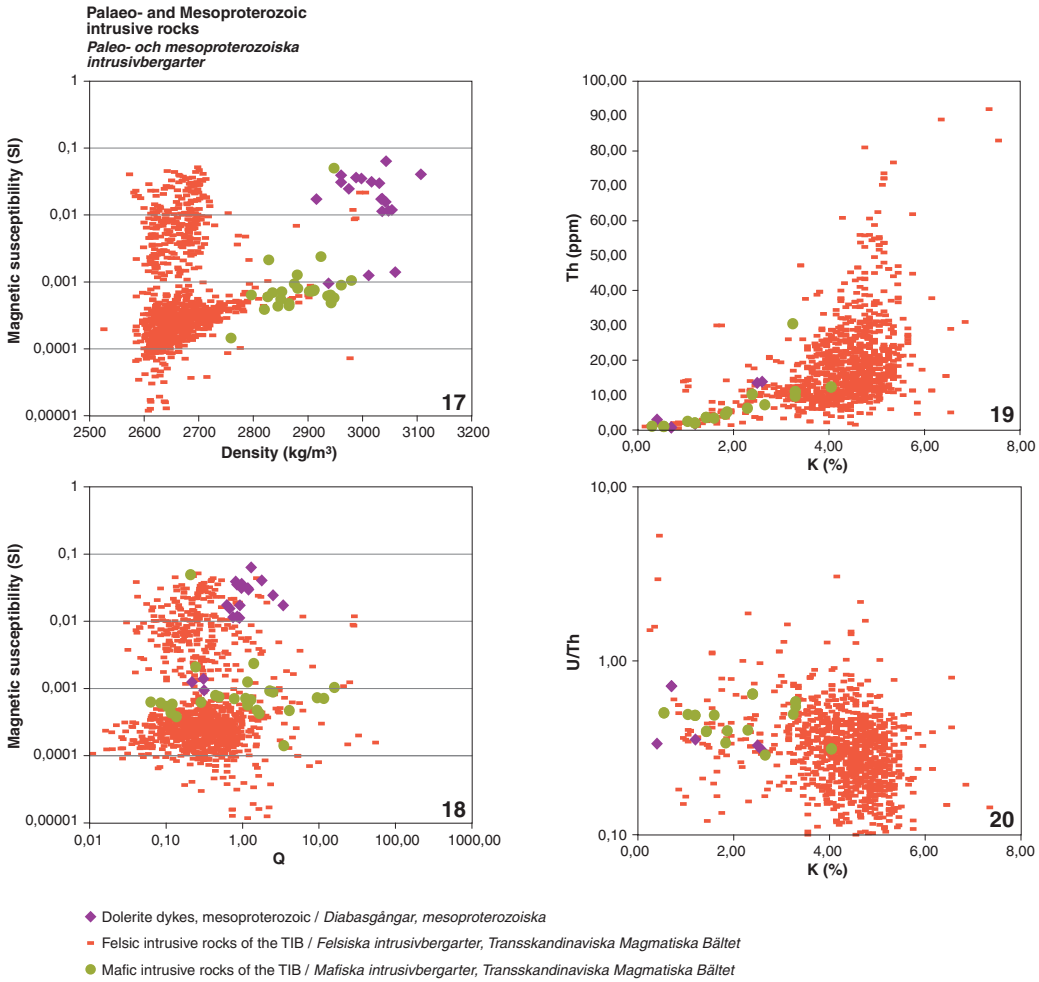
- Knaften area, c. 1950 Ma / *Knaftenområdet, ca 1950 Ma*
- Björkdal, Blåviksjön, Kristineberg, and others, 1920–1900 Ma *Björkdal, Blåviksjön, Kristineberg, m.fl., 1920–1900 Ma*
- Jörn GI suite, 1900–1860 Ga / *Jörn GI-sviten, 1900–1860 Ma*
- Archaean rocks / *Arkeiska bergarter*
- Conglomerate, breccia, sandstone, Dobblon Group *Konglomerat, breccia, sandsten, dobblongruppen*
- Conglomerate, Vargfors Group / *Konglomerat, Vargforsgrupen*
- Conglomerate, Arvidsjaur Group / *Konglomerat, Arvidsjaurgruppen*
- Sandstone, siltstone, argillite, Arvidsjaur Group / *Sandsten, siltsten, argillit, Arvidsjaurgruppen*
- Metasandstone, metasiltstone, meta-argillite, metagreywacke, Skellefte Group *Metasandsten, metasiltsten, meta-argillit, metagråvacka, Skelleftegruppen*
- Metagreywacke, Bothnian Supergroup / *Metagråvacka, Bottniska supergruppen*
- Conglomerate, Bothnian Supergroup / *Konglomerat, Bottniska supergruppen*
- Black shale, Bothnian Supergroup / *Svartskiffer, Bottniska supergruppen*
- Crystalline carbonate rock, Bothnian Supergroup *Kristallin karbonatsten, Bottniska supergruppen*

Fig. 43 continued



- Felsic volcanic rocks, Dobblon Group / *Felsiska vulkaniter, Dobblongruppen*
- Mafic volcanic rocks, Vargfors Group / *Mafiska vulkaniter, Vargforsgruppen*
- Komatiites, Vargfors Group / *Komatiiter, Vargforsgruppen*
- Ultramafic rocks, Vargfors Group / *Ultramafiter, Vargforsgruppen*
- Felsic volcanic rocks, Arvidsjaur Group / *Felsiska vulkaniter, Arvidsjaurgruppen*
- Mafic volcanic rocks, Arvidsjaur Group / *Mafiska vulkaniter, Arvidsjaurgruppen*
- Felsic metavolcanic rocks, Skellefte Group / *Felsiska vulkaniter, Skelleftegruppen*
- Mafic metavolcanic rocks, Skellefte Group / *Mafiska vulkaniter, Skelleftegrupen*
- Felsic metavolcanic rocks, Bothnian Supergroup / *Felsiska vulkaniter, Bottniska supergruppen*
- Mafic metavolcanic rocks, Bothnian Supergroup / *Mafiska vulkaniter, Bottniska supergruppen*
- Granites, Skellefte-Härnö suite / *Granit, Skellefte-Härnösviten*
- Felsic intrusive rocks, Perthite monzonite suite / *Felsiska intrusivbergarter, Pertitmonzonitsviten*
- Mafic intrusive rocks, Perthite monzonite suite / *Mafiska intrusivbergarter, Pertitmonzonitsviten*
- Mafic intrusive rocks, 1.96–1.86 Ga / *Mafiska intrusivbergarter, 1.96–1.86 Ga*

Fig. 43 continued



Most of the samples shown in Figures 43:9–12 belong to either the Arvidsjaur or the Skellefte Group. In the M-D diagrams, the felsic and mafic volcanic rocks of the Arvidsjaur Group have higher magnetic susceptibilities than those of the Skellefte Group. According to Grant (1984/85), the factors "oxygen fugacity" and "temperature" have a greater impact on the formation of magnetite than does bulk chemistry. Thus, differences in these factors may be the explanation underlying the differences in magnetic susceptibility between the two groups. Differences in properties between these groups have also been commented by Triumf et al. (2000). The Th-K diagram (Fig. 43:11) shows a typical signature in the subaerial Arvidsjaur Group where the thorium and potassium levels are often higher than in the subaqueous Skellefte Group. Signs of potassium enrichment are only weakly indicated by a few exceptions among the volcanic rocks. The data indicates that fewer than ten samples appear to have been affected by potassium enrichment.

With respect to magnetic susceptibility, the felsic volcanic rocks of the Dobblon Group resemble those of the Arvidsjaur Group, though a slightly increased density is evident. The Dobblon Group appears in a narrow density interval, resembling the variations in the Sorsele suite with higher density. Compared with other rock groups, a tendency to greater remanent magnetization in parts of the felsic volcanic rocks of the Skellefte Group and the Dobblon Group is observed in the M-Q diagram (Fig. 43:10). The Dobblon Group data cluster in the high potassium and thorium corner in the Th-K diagram (Fig. 43:11). Quite high potassium and thorium values were found in this group.

Palaeoproterozoic intrusive rocks: late to post Svecokarelian granites (Skellefte-Härnö suite), early Svecokarelian intrusive rocks (Perthite monzonite suite), and mafic intrusive rocks associated with the early Svecokarelian calc-alkaline granitoids

Petrophysical and spectrometer data for Palaeoproterozoic intrusive rocks are shown in Figures 43:13–16. The granites of the Skellefte-Härnö suite are characterized by low magnetic susceptibilities in general and densities below 2660 kg/m^3. Within the Perthite monzonite suite,

magnetic susceptibilities are generally higher or above 0.0005 SI, commonly reaching 0.03–0.04 SI. The thorium content reaches higher levels in the Skellefte-Härnö suite than in the Perthite monzonite suite.

According to Weihed & Antal (1999), the Jörn GIII intrusion of the Perthite monzonite suite shows higher potassium and thorium contents than the Jörn GI intrusion which belongs to the early Svecokarelian calc-alkaline granitoids.

The mafic rocks in the Perthite monzonite suite show different patterns in the M-D diagram than those shown by the early Svecokarelian calc-alkaline granitoids. The former occupy a limited density interval, approximately 2800–3000 kg/m^3, compared with the latter where densities range from 2750 to around 3200 kg/m^3. Furthermore, the mafic rocks in the Perthite monzonite suite display a uniform variation in magnetic susceptibility, from 0.0008 to 0.08 SI, following the silicate density trend. The early Svecokarelian calc-alkaline mafic rocks appear to be distributed bimodally or occupying the paramagnetic and magnetite variation trends (Henkel 1991).

In the M-Q diagram the mafic intrusive rocks of both suites appear to follow a curved path apparently built up by the two trends described by Henkel (1991) namely the "magnetite exsolution trend" and the "ilmenite exsolution trend".

Palaeoproterozoic intrusive rocks of the Transscandinavian Igneous Belt (TIB) and Mesoproterozoic dolerite dykes

Petrophysical and spectrometry data for Palaeoproterozoic intrusive rocks of the Transscandinavian Igneous Belt (TIB) and Mesoproterozoic dolerite dykes are shown in Figures 43:17–20. In these diagrams, the intrusive rocks of the Transscandinavian Igneous Belt (TIB) have not been divided into the Revsund, Sorsele, Adak, Edefors, and Ale suites. However, some general differences between rocks of the TIB have been observed and are briefly commented on below.

Revsund and Adak granites are characterized by relative low magnetic susceptibilities, generally below 0.0008 SI. In the M-D diagram, most of the samples are distributed along the biotite-amphibole paramagnetic trend (Henkel 1991). The substantial variation in density within the Revsund granites between 2600 and 2750 kg/m^3 is attributed to the variations in content of mafic minerals. Thus, such density variations in rock volumes dominated by granites of the Revsund suite may account for apparent gravity anomalies from deep-seated sources to the south of the Bure area. In the present study, however, the gravity maximum is explained solely on the basis of the density distribution found in outcrops.

Sorsele granites have relatively high susceptibilities, commonly above 0.002 SI. The density shows a bimodal distribution, with maxima around 2620–2630 kg/m^3 and 2690 kg/m^3, respectively.

The mafic intrusive rocks of the TIB show a distribution dominated by the magmatic differentiation trend of Henkel (1976).

With potassium values ranging from 1% up to 8%, the felsic intrusive rocks of the TIB show large heterogeneity. Normally, contents lower than approximately 4% are typical for mafic rocks.

There are two categories of dolerite dykes: one with low magnetic susceptibility and low Q-values, and one with high magnetic susceptibility and moderate to high Q-values. The former follows the paramagnetic trend in the M-D diagram and appears as a continuation of the gabbro group. Dolerite dykes are quite common in the central and western parts of the Skellefte District and surrounding areas, where they are identified as linear anomalies, commonly with apparent negative magnetization due to the high Q-values, and directions of the remanent magnetization more or less opposite to the direction of the earth's magnetic field.

Alterations, mineralizations and spectrometry

A compilation of studies concerning the potential of gamma ray spectrometry in mineral prospecting and geological mapping was presented by Shives et al. (1995).

During the fieldwork in bedrock mapping at the Geological Survey of Sweden (SGU) spectrometry has been used to investigate a few mineralizations located in the Skellefte District and surrounding areas and certain alteration zones. Antal (1999) studied the correlation between potassium, uranium, and thorium content and different alteration modes of felsic volcanic rocks in the Skellefte Group. In the same study it was shown how potassium and uranium contents increased and the thorium content decreased in the Boliden Mine in relation to the unaffected volcanic rocks outside the alteration zone.

Adjacent to the Gråberget copper mineralization, spectrometry indicated high potassium values due to assumed hydrothermal processes. The normal background values for unaltered rock were found to be around 5% potassium, increasing to more than 7% in altered zones.

In the Dobblonbäcken mineralization, the potassium content ranges between 3.5 and 6.1%, where the higher values were reagarded as anomalous.

No anomalous potassium, thorium or uranium contents were found in the Björkdal and Åkerberg gold mineralizations, compared with the surrounding rocks.

THE NEOPROTEROZOIC–EARLY PALAEOZOIC SEDIMENTARY COVER

Along the Caledonian erosional front and below the overthrusted Caledonian bedrock, a thin autochthonous succession of tectonically almost undisturbed sedimentary rocks rests unconformably on the Palaeoproterozoic rocks of the Fennoscandian Shield. In northern Scandinavia this Neoproterozoic to Early Palaeozoic succession is called the "Dividal Group" (Pettersen 1878, Føyn 1985).

Between lake Storuman and lake Storvindeln, the exposed part of the Dividal Group starts from below with conglomerates and coarse-grained, crossbedded grey to white sandstones. This succession, the Såvvovare Formation (Willdén 1980) thins to the south and is absent in the southern part of the map area. Upon the Neoproterozoic Såvvovare Formation or, where it is absent, directly upon the Proterozoic basement lies the Early Cambrian Grammajukku Formation (Willdén 1980), consisting of mudstones, siltstones, and grey to dark brown sandstones. These rocks are overlain by black mudstones and shales, rich in organic matter (alum shales), of the Alum Shale Formation (cf. Gee 1972, Bergström & Gee 1985). According to Andersson et al. (1985), the Alum Shale Formation ranges in age from the Middle to Late Cambrian, locally to the earliest Ordovician.

The sedimentary succession of the Dividal Group is truncated at different levels by the floor thrust of the overlying nappe pile. West of Vilhelmina and Dorotea, the allochthonous sequences of the Caledonides rest directly on the Palaeoproterozoic rocks of the Fennoscandian Shield.

THE CALEDONIDES

The Scandinavian Caledonides are built up by a sequence of westerly-derived nappes, thrusted onto the Fennoscandian Shield and its autochthonous sedimentary cover. The tectonostratigraphic sequence of the Caledonides is conveniently divided into the Lower, Middle, Upper, and Uppermost Allochthons (Kulling 1972, 1982, Gee & Zachrisson 1979, Gee et al. 1985). In general, the lower and easternmost emplaced tectonostratigraphic units originate from areas situated at the Neoproterozoic to Early Palaeozoic margin of Baltica, while the higher units are derived from the Baltica–Iapetus transition zone (Seve Nappes and lowermost Köli Nappes) or from marine, island arc environments (higher Köli nappes). These are now situated in the central and western parts of the orogenic belt.

Greiling et al. (1998) divided the orogenic wedge of the central Scandinavian Caledonides into three distinct "tiers" A, B, and C. Tier A, corresponding to the Lower Allochthon of the above-mentioned, classic division, has undergone exclusively Scandian (Middle to Late Silurian) deformation and metamorphism. Tier B comprises the Middle Allochthon and the Seve Nappes of the Upper Allochthon. The rocks of these units show traces of Finnmarkian (Early Ordovician) events. Tiers A and B are both interpreted as parts of the imbricated and shortened margin of Baltica. Tier C consists of exotic or outboard terranes (Köli Nappes of the Upper Allochthon) and parts of the continent Laurentia (Uppermost Allochthon) which were amalgamated with the Baltoscandian platform during the collision of the continents Baltica and Laurentia.

The establishment of the Lower Allochthon (tier A) post-dates the emplacement of the Middle and Upper Allochthon (tiers B and C). Imbrication and formation of duplex structures within the Lower Allochthon led to deformation of the Middle and Upper Allochthons and of the boundary between the Seve and Köli nappes. A final emplacement of the whole nappe pile into its present position on the Baltoscandian platform occurred during the Silurian and Early Devonian (Greiling & Zachrisson 1999 and Greiling et al. 1999).

Final uplift and formation of the present mountain range of the Scandinavian Caledonides are related to the opening of the Atlantic Ocean in Tertiary, c. 65 Ma ago (Greiling & Zachrisson 1999).

The Caledonian bedrock of the map area comprises units of the Lower and Middle Allochthons and the Seve Nappes of the Upper Allochthon. The following description of the Caledonian allochthonous bedrock is based mainly on Greiling et al. (1996), Zachrisson (1996), Zachrisson & Greiling (1996), Febbroni (1997), Greiling & Zachrisson (1999), Greiling et al. (1999), and Björk et al. (2000),

The Lower Allochthon

The Lower Allochthon represents the eastern- and lowermost tectonostratigraphic unit within the Caledonian thrust rocks of the map area. It crops out with varying thickness, extending north-west to south-east along the Caledonian front from lake Storjuktan in the north to the area south of lake Ormsjön and west of Dorotea. The Lower Allochthon is built up by structural slices and horses, consisting of different sedimentary

sequences and minor occurrences of basement-derived crystalline rocks.

The structural slices form a system of imbricate fans which, in places where the roof thrust (floor thrust of the Middle Allochthon) is preserved, can be designated duplexes. Larger duplexes are the Flakaträsk Duplex north of lake Storuman, the Vojmsjön Duplex around the central part of lake Vojmsjön and the Lövnäs Duplex at lake Malgomaj.

A synform, occupied by rocks of the Middle Allochthon, separates the marginal thrust systems along the Caledonian front in the east from a major regional, north-northeast–south-southwest trending antiform, which exposes nappe complexes of the Lower Allochthon. The easternmost parts of the Njakafjäll Duplex and the Krutsjön Nappe, both belonging to this antiform, extend into the map area.

Basement-derived crystalline rocks occur chiefly within the lower parts of the eastern marginal thrust system between lake Storuman and lake Malgomaj. They normally consist of porphyritic, green-greyish coloured granites to syenites. Despite their colour and some cataclastic deformation, they are comparable to rocks of the Revsund suite of the Transscandinavian Igneous Belt (TIB), which are exposed in vast areas to the east of the present Caledonian thrust front. A quartz syenite from a minor occurrence of crystalline rocks in the Lower Allochthon from Mörrösjöbäcken (7217850/1504290, not shown on the map) has been dated (U-Pb, zircon) by Greiling et al. (2002) at 1798±6 Ma. This age is more or less consistent with data obtained from the TIB rocks in the basement east of the Caledonian front. A minor slice of mafic crystalline rocks, too small to show on the map, occurs at river Matskanån (7220740/1509550), about 9 km west of lake Vojmsjön.

The sedimentary sequence of the Lower Allochthon of the map area is divided in to the Risbäck, the Sjoutälven and the Tåsjön Groups. The lower part of the sedimentary succession (Risbäck and Sjoutälven) are best developed in the northern part of the map area. South of lake Malgomaj, lower units are absent and the Lower Allochthon is represented by rocks of the Sjoutälven and Tåsjön Groups. In the area around lake Storuman, the Lower Allochthon is absent and the floor thrust of the Middle Allochthon cuts into rocks of the sedimentary cover (Dividal Group) or the crystalline rocks of the Fennoscandian Shield. These relationships indicate that the deposition of the sedimentary succession of the Lower Allochthon started at different times and levels in different areas, probably depending on the rhombohedral fault pattern and the resulting topography of the Neoproterozoic peneplain (Bax 1989, Romer & Bax 1992, Romer et al. 1994).

The Risbäck Group (Kumpulainen 1982, Zachrisson 1997) varies in thickness from several metres to several hundred metres. Basal polymict conglomerates are overlain by arkoses and subordinate conglomeratic arkoses which, in the older literature, were called "sparagmites". At the top of the group, dolomites and breccias constitute the Kalvberget Formation, which is the uppermost part of the Risbäck Group. Rocks of the Kalvberget Formation are confined to minor occurrences in the northern part of the Lower Allochthon.

In most areas, the arkoses of the Risbäck Group are overlain either by tillites (Långmarkberg Formation, Kulling 1942) or quartzites (Gärdsjön Formation) of the Sjoutälven Group. The tillites are confined to minor lenses with a maximum thickness of about 30 m. They contain angular to sub-angular up to metre-sized clasts of granitoids and arkoses in an arenitic to argillitic matrix. The Gärdsjön Formation is dominated by massive, coarse- to fine-grained, white to light grey quartzites. Close to the base of the Gärdsjön Formation there is a characteristic layer of conglomerate, about 10 m thick, with well rounded quartz and feldspar clasts. Higher up, irregular layers of silt- and mudstone as well as greenish or, in places, red shales are intercalated with the quartzites. Towards the top of the Gärdsjön Formation, graded psammites pass into an alternation of fine-grained sandstones, siltstones, impure carbonates, and marls.

The Sjoutälven Group is followed by the Fjällbränna Formation (Gee et al. 1974) of the Tåsjön Group. This formation comprises black mudstones and alum shales of Middle to Late Cambrian and, locally, earliest Ordovician age. Laterally consistent, cm to dm thick layers of fossiliferous limestone occur, especially in the upper parts of the Fjällbränna Formation. The alum shales normally rest on top of the Gärdsjön Formation of the Sjoutälven Group. However, south of lake Vojmsjön, they overlie a strongly reduced sequence of the Gärdsjön Formation or rest directly on the basement-derived rocks of the Lower Allochthon. This feature is interpreted as a primary basement–cover relationship, which implies that the Risbäck Group and the lower parts of the Sjoutälven Group are primarily missing. Furthermore, this implies that those parts of the Proterozoic basement, now present as slices within the Lower Allochthon, have been topographic highs during the deposition of the Neoproterozoic to Early Palaeozoic cover sequence.

The Uppermost stratigraphic unit of the Lower Allochthon within the map area is the Norråker Formation. It is best developed between lake Malgomaj and lake Ormsjön, where it rests with an erosional contact or a hiatus on the underlying Fjällbränna Formation. From below, it starts with sandy to silty or calcareous layers of Arenigian to lower Llanvirnian age. The major

part of the Norråker Formation is formed by thick, turbiditic units of fine-grained, dm-scale-layered greywackes and shales. This greywacke–shale succession ranges in age into the Middle Ordovician.

The Middle Allochthon

The Middle Allochthon within the map area (Stalon Nappe according to Kulling 1942, 1955) extends from the western part of lake Malgomaj in the south to lake Storvindeln in the north. In the southern part of that area, between lake Malgomaj and lake Vojmsjön, the rocks of the Middle Allochthon occupy the central parts of a north-northeast striking synform. They are confined by the Njakafjäll Duplex and the Krutsjön Nappe in the west, and the marginal thrust system of the Lower Allochthon in the east. To the north of lake Vojmsjön, the western margin (trailing edge) of the Middle Allochthon is buried by the Seve Nappes of the Upper Allochthon.

The Middle Allochthon comprises crystalline, basement-derived rocks with different degrees of deformation and metasedimentary, mainly arenitic rocks. The lithological units occur as or within different slices, separated by shear zones. Primary contacts between crystalline and metasedimentary rocks are not preserved (Greiling 1985, 1989). The crystalline, basement-derived rocks, preferably occurring in the western part of the nappe complex, are divided into greenish mylonites, coarse-grained and mineralogically altered metagabbros, metasyenites, and subordinate felsic gneisses. A foliated meta-quartz syenite from a small basement slice east of Harrvik (7242220/1524030) has been dated (U-Pb, zircon) at 1766^{+15}_{-12} Ma by Greiling et al. (2002).

The metasedimentary sequence consists of metaarkoses with minor pelitic intercalations and several layers of coarse-grained polymict conglomerates. This metasedimentary sequence is correlated to the Risbäck Group of the Lower Allochthon (Greiling & Zachrisson 1999), though the rocks of the Middle Allochthon have a higher metamorphic grade (greenschist facies) and higher intensity of deformation. A sequence of alternating pelitic rocks and cm to dm thick, locally feldspathic quartzites extends from the area around the north-western part of lake Vojmsjön to the river Matskanån (7220740/1509550) in the south-west. This sequence is speculatively correlated with the Gärdsjön Formation of the Lower Allochthon (Greiling & Zachrisson 1999).

The Upper Allochthon

The Upper Allochthon rests with a deformed contact on top of the imbricated nappe system (Stalon Nappe) of the Middle Allochthon. Within the map area, the Upper Allochthon is represented by amphibolite grade rocks of the Seve Nappes. Rocks of the Köli Nappes only occur in the north-westernmost corner of the map area, but they build up the bedrock in large areas farther to the west and north-west.

The Seve Nappes of the map area are divided into a lower and an upper unit. The lower unit consists of mica schists, gneisses, and subordinate quartzite. In the Dikanäs area (7237060/1508930), these Dikanäs schists (Zachrisson & Greiling 1993) vary from muscovite-dominated mica schists with abundant biotite and garnet porphyroblasts to more quartzo-feldspathic, gneissic varieties or more quartz-rich metapsammitic rocks (Greiling & Zachrisson 1999). The quartz-rich metapsammitic units of the Seve nappes are lithologically very similar to the metapsammites in the Stalon Nappe of the Middle Allochthon. However, the main difference for distinguishing the two units is the generally higher degree of recrystallization within the Seve rocks. Primary structures as cross-bedding or graded bedding can be observed within the Stalon Nappe, but are not preserved within the Seve nappes.

In the north-western part of the map area, i.e. the Umnäs map area, the mica schists and gneisses of the lower Seve unit are overlain by the upper unit which is completely dominated by amphibolites. Minor slices of quartzites, marbles, and ultramafic rocks occur, but are not shown on the map. Both units are part of the Eastern Schist and Amphibolite Belt of Trouw (1973). These rocks have been described in detail from the Fatmomakke area to the west of the western margin of this map area.

IMPACTS

The possible existence of impact structures in Sweden was already mentioned by A.G. Högbom (1910) but not accepted by the Swedish geologic community. Fredriksson & Wickman (1963) published a list of five possible impact sites in Sweden. Wickman (1988) discussed 15 possible impact structures in Sweden, including the Dobblon and Ledfat structures situated within the project area. Studies within the project area, addressing the geological evolution of circular structures as being related to meteorite impacts, have recently been carried out in several other places.

A large circular structure in the area around Lycksele has been identified from satellite imagery (Holmquist et al. 1982, Witschard 1984) and topographic, drainage, and geophysical data (Nisca 1995, Nisca et al. 1996). Nisca (1995) has provided a genetic model for the structure and interprets it as principally based on doming,

but he does not exclude the possibility of an impact. Thunehed et al. (1999) have suggested this structure to be a remnant of an old meteorite impact, supporting their hypothesis with modelling of gravity data. According to Henkel & Pesonen (1992), the Burträsk structure to the west of Skellefteå is another possible impact structure, though Nisca (1995) presents an alternative explanation based on interfering structural elements related to faulting.

Henkel & Pesonen (1992) reported the occurrence of impact breccias in the Dobblon area. Later, Lilljequist & Reimold (1999) interpreted the Dobblon structure as a suspected impact formation. They consider the ignimbritic rhyolite layer within the sedimentary succession of the Björnknösen Formation (c.f. Einarsson 1979) to be an impact melt. The coarse clastic sedimentary rocks of the Björnknösen Formation are interpreted as being crater-fill sediments. Further evidence of a suspected impact origin of the Dobblon structure is, according to the authors, given by brecciated granite with pseudotachylitic veins, passing upwards into a matrix-supported, autochthonous breccia, which underlies the western part of the structure. Shock metamorphic minerals with suspected planar deformation features (PDF) have been reported from two drill holes. By assuming that the coarse clastic units are part of a circular structure, Lilljequist & Reimold (1999) infer a hypothetical crater diameter of about 80 km. The age of the impact event is assumed to be c. 1.8 Ga.

The Gallejaur structure is visible on maps over the magnetic total field and the gravity field as an almost circular maximum. Lundberg (1980) classified the structure as a cauldron, while Nisca (1995) further develops the model, classifying the structure as a collapse structure due to cauldron subsidence. Lilljequist (2000) presents several factors indicating the structure to be impact related. He emphasizes differences in the structural features of the Vargfors Group sedimentary rocks and the underlying rocks of the Skellefte Group, interpreting this feature as evidence of an impact-related origin of the Vargfors rocks in the Gallejaur area. Different types of breccias in the surroundings of the Gallejaur structure are regarded as impact-generated rocks, although shock metamorphic minerals have not yet been identified. The highly magnetic rim of the structure is interpreted as an impact melt body with varying amounts of predominantly mafic, more or less absorbed, basement-derived clasts. Furthermore, the monzonite in the middle of the structure is believed to have originated as a crystallized impact melt. Its age, 1873±10 Ma (Skiöld 1988), is considered to be the age of the impact event. Due to the appearance of the gravity anomaly at Gallejaur, Lilljequist (1999) suggested a central uplift of 10–12 km in diameter and a final crater diameter of 50–60 km.

The above-named suspected impact sites are not shown on the bedrock map of the Skellefte District and surrounding areas (Ba 57:1) because, at the time the map was prepared, they had not been accepted by the Earth Impact Database (2003) over confirmed impact craters.

Explanation to the metamorphic, structural and isotope age map

Compared with the bedrock map, where the structural information is limited to deformation zones, morphologically indicated lineaments, zones of increased magnetization and electric conductivity, thrusts, and a selection of structural measurements, the "Metamorphic, structural and isotope age map" displays more complete structural information from the databases over the project area. The deformation pattern is complemented by antiforms, anticlines, synforms, and synclines. Two types of form lines were constructed from observations on tectonic foliations and bedding surfaces respectively. Furthermore, the map contains a more complete set of structural measurements in the field.

Point information, regarding metamorphic conditions, is given by PT determinations and index minerals. The sample sites for U-Pb isotope age determinations (see Table 1a on page 16) are included, and the ages are given in million years (Ma).

The structural pattern and the point information on metamorphic conditions and isotope ages are presented against a generalized geological background, compiled from the database of the original bedrock map (Ba 57:1) on a scale of 1:250,000. On this generalized background, the bedrock of the Fennoscandian Shield is divided into Archaean and Karelian rocks, Svecokarelian intrusive rocks, Svecofennian supracrustal rocks, and Mesoproterozoic rocks. Low-, medium- and high-grade metamorphic conditions are shown by different colours within the Svecofennian supracrustal rocks and the early Svecokarelian calc-alkaline intrusive rocks. In order to distinguish the latter from the Svecofennian supracrustal rocks, they have additionally been shaded on the map. Early Svecokarelian intrusive rocks (Perthite

monzonite suite), late to post Svecokarelian rocks of the Skellefte-Härnö suite and the Transscandinavian Igneous Belt (Revsund–Sorsele–Adak–Edefors–Ale suites) and Mesoproterozoic dolerites are all distinguished by different colours. The Neoproterozoic to Early Palaeozoic sedimentary cover is shown as a single unit, while the overthrusted nappe sequences of the Caledonides are divided into the Lower, Middle and Upper Allochthons.

The division into low-, medium-, and high-grade metamorphic conditions has been inferred mainly from the "Metamorphic, structural and isotope age map of Central Fennoscandia" (Lundqvist et al. 1997). In the map areas 23K Boliden (Lundström & Antal 2000), 23I Malå (Bergström & Sträng 1999b) and 24L Luleå (Wikström & Söderman 2000), this division has now been modified according to results of the bedrock mapping programme of the Geological Survey of Sweden (SGU), obtained after the publication of the "Metamorphic, structural and isotope age map of Central Fennoscandia" (Lundqvist et al. 1997). A simplified metamorphic and structural map of the Skellefte District and surrounding areas is shown in Figure 44.

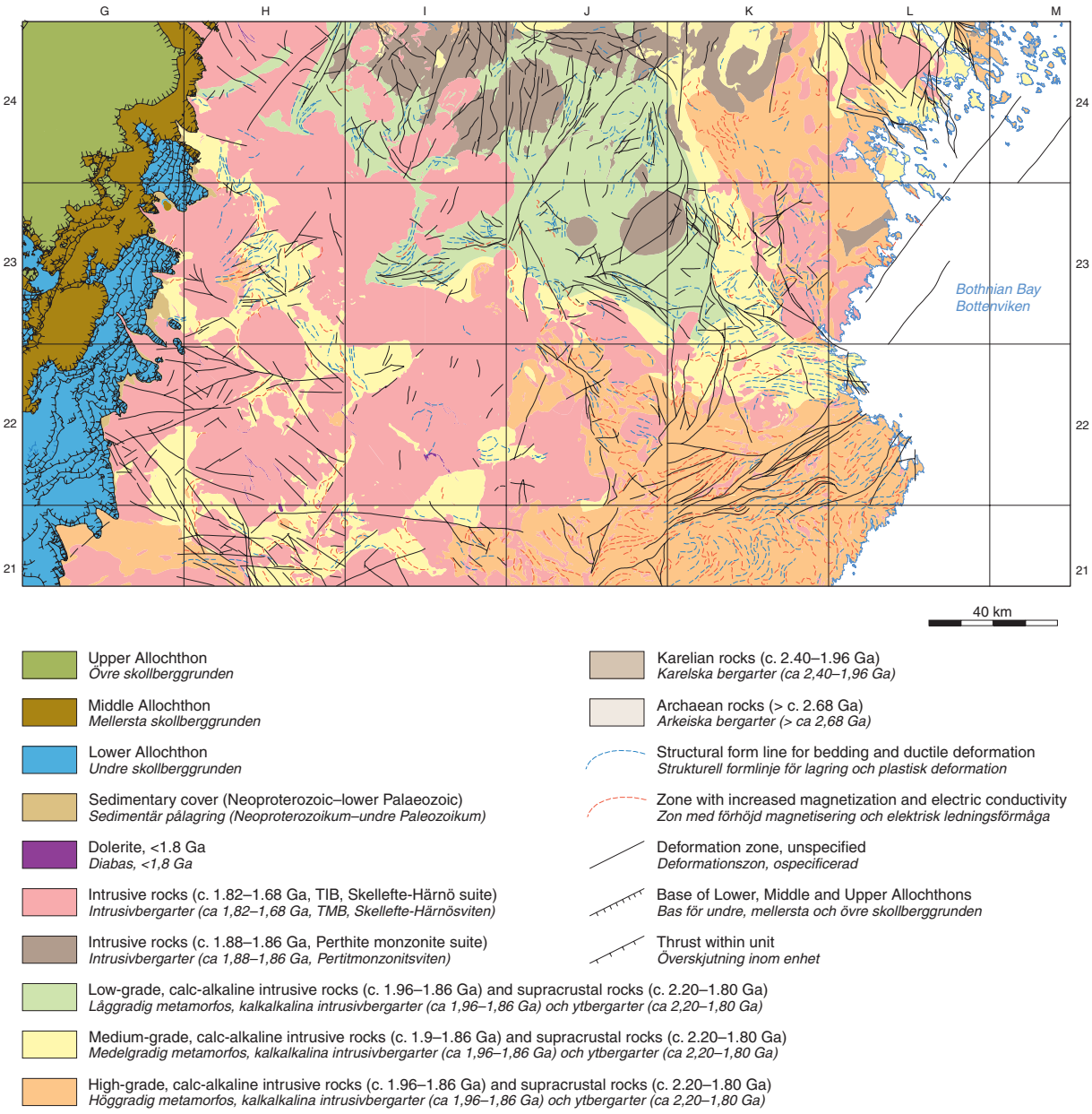


Fig. 44. Simplified metamorphic and structural map of the Skellefte District and surrounding areas.
Förenklad karta över metamorfosgrad och strukturer över Skelleftefältet med omnejd.

STRUCTURE AND TIMING OF DEFORMATION

Svecokarelian deformation and regional metamorphism affected the Svecofennian supracrustal rocks (Bothnian, Skellefte, Arvidsjaur, and Vargfors Groups) and the 1.96 to 1.86 Ga old early Svecokarelian intrusive rocks. Within the latter group, the calc-alkaline intrusive rocks usually display a higher degree of deformation than the rocks of the Perthite monzonite suite. This may be due to the predominant occurrence of the Perthite monzonite suite rocks within areas consisting of low-grade, supracrustal rocks of the Arvidsjaur and Vargfors Groups. Their occurrence as isolated plutons may have led to strain partitioning and concentration of deformation within the surrounding supracrustal rocks of the Arvidsjaur and Vargfors Groups. Some early Svecokarelian calc-alkaline massifs have also acted as rigid blocks and affected and complicated the strain pattern within the supracrustal rocks of the Bothnian Supergroup – and to a minor extent the rocks of the Skellefte Group (Kousa & Lundqvist 2000).

In time, the main deformational and metamorphic event of the Svecokarelian orogeny is bracketed by the age of the youngest, deformed supracrustal or calc-alkaline intrusive rocks on the one hand, and the oldest undeformed intrusions of the late to post Svecokarelian intrusive rocks of the Skellefte-Härnö suite and the Transscandinavian Igneous Belt (TIB) on the other hand. For the map area, these rock assemblages define a time interval for Svecokarelian deformation and metamorphism of approximately 1850 to 1810 Ma (Bergman Weihed et al. 1996).

However, older phases of deformation before 1875–1860 Ma have been suggested – at least for the northern and north-eastern parts of the map area by Wikström et al. (1996c), Lundström et al. (1997, 1999) and Kathol et al. (2002). Wikström et al. (1996c) showed that deformation structures and migmatites formed prior to the within-plate emplacement of dykes at c. 1880 Ma. Structural relationships between a particular intrusion, dated at 1877±2 Ma (Stavaträsk, 7226380/1721900 north of Boliden) and the surrounding metasedimentary rocks of the Bothnian Supergroup were reported by Lundström et al. (1997, 1999). The intrusion caused contact-metamorphic hornfels alteration which obscures the penetrative foliation in the metasedimentary sequence. This foliation must therefore have formed prior to 1877 Ma. Kathol et al. (2002) suggest that early Svecokarelian deformation and metamorphism must have occurred within a period spanning 1909–1857 Ma and point out the diachronous nature of this early Svecokarelian event.

For the area south of Skellefteå, Rutland et al. (1997, 2001a,b) described deformation structures and migmatization events from the period 1900–1890 Ma and a younger phase of deformation and veining around 1860 Ma (Fig. 45). Due to the structural history, the authors suggest that the rocks of their Southern Province are older than those of the Skellefte Group, as the latter lack any traces of an early (their D1) deformation, which is ubiquitous within the Robertsfors Group (Rutland et al. 2001a) of the Southern Province. The authors therefore propose that the high-grade metagreywackes and graphite-bearing meta-argillites of the Robertsfors Group form the basement of the Skellefte Group. They regard the latter as being a supracrustal sequence, deposited in a rift setting, rather than a juvenile volcanic arc.

According to Bergman Weihed (2001), two major phases of folding affected the rocks of the Skellefte District. The first phase of regional deformation resulted in upright, tight to isoclinal folds. These folds have north-east striking axial surfaces in the western and eastern parts of the Skellefte District, whereas folds with north-west striking axial surfaces dominate the central part of the district. An early foliation probably formed as an axial planar cleavage, related to the folds of the first deformation phase. Stretching lineations of this deformation have the same orientation as minor fold axes (Bergman Weihed et al. 1996). Penecontemporaneous reverse, oblique-slip movements (south side up) along cleavage-parallel shear zones are common, especially within the central part of the district. These shear zones formed before or during the metamorphic peak.

Within the central Skellefte District, the early folds occur in lower-strain lenses, which are confined by north-west striking shear zones, whereas shearing along the north-east striking axial surfaces is less intense within the western and eastern parts of the district. Both the early folds and the shear zones are believed



Fig. 45. Contact between strongly foliated metagreywackes and c. 1860 Ma old migmatite leucosome. Bjuröklubb, about 18 km north-east of Lövånger. Width of photograph is c. 70 cm. Photo Benno Kathol.

Kontakt mellan kraftigt folierad metagråvacka och ca 1860 Ma gammalt migmatitleukosom. Bjuröklubb, ca 18 km nordost om Lövånger. Fotots bredd är ca 70 cm.

to have been formed by oblique convergence from the south-east (Bergman Weihed 2001). This deformation occurred between 1.85 and 1.80 Ga and may represent the final stage of convergence during subduction within an early subduction system.

The pronounced east-northeast–west-southwest structural trend in the Nickel zone in the south-eastern part of the map area is caused by foliations, lithological boundaries, and shear zones that are subparallel (Kousa & Lundqvist 2000). These structures are thought to have formed during the first deformation event.

The second major phase of folding produced open folds with steep north to north-east striking axial surfaces. The intensity of this second folding phase increases towards the south within the central Skellefte District, where the folds have larger amplitudes and a more intense cleavage than the spaced cleavage in the northern areas. The subaerial rocks of the Arvidsjaur Group north of the Skellefte District proper are folded around north-east trending axes, and the intensity of deformation is lower than that in the rocks of the Skellefte Group within the Skellefte District (Lundberg 1980).

During and after the second folding phase and after peak metamorphism, north-striking shear zones with reverse dip-slip components formed in the Skellefte District and surrounding areas (Bergman Weihed 1997). The kinematics of these shear zones indicates an east–west shortening. These late shear zones deform all Palaeoproterozoic rocks of the Fennoscandian Shield in the map area, and must therefore have been active after c. 1.8 Ga.

Major extensional events in the Mesoproterozoic are indicated by the intrusions of mafic, gently dipping sills and dykes of the Central Scandinavian Dolerite Group (CSDG) at c. 1.27 Ga (Elming & Matsson 2001). This tectonic event affected the south-western part of the map area. Dolerites with the same magnetization have not been identified north of the Skellefte District, which implies that the district marked a significant boundary within the Fennoscandian Shield at least 1.27 Ga ago (Elming & Matsson 2001). The dolerite intrusions have tholeiitic compositions that indicate magma derivation from mantle sources in a continental intraplate setting. The tensional regime, indicated by the intrusion of these extended dolerite complexes in the central Fennoscandian Shield (Baltica), is interpreted as resulting from the break up of the Baltica/Laurentia supercontinent (Elming & Matsson 2001).

The autochthonous cover sequence, which underlies the Caledonian nappes, is generally undeformed. However, some faults at the Caledonian front around river Vindelälven north-west of Sorsele cut through the Svecokarelian basement, the cover sequence and the Lower and Middle Allochthons (Eliasson et al. 2003). The Lower Allochthon is dominated by "thin skin tectonic" style thrusting with imbricate fans, duplex structures and out of sequence thrusts. It has undergone exclusively Middle to Late Silurian, Scandian phase deformation, whereas the Middle Allochthon and the Seve nappes of the Upper Allochthon show traces of Early Ordovician, Finnmarkian events (Stephens 1988, Greiling et al. 1998). The Caledonian nappe pile shows inverted metamorphic grade, from low grade within the Lower Allochthon, to amphibolite grade conditions within the Seve nappes of the Upper Allochthon.

Two systems of late to post-glacial faults occur in the eastern part of the map area (Rodhe et al. 1990). The first extends from the southern shore of lake Burträsket (7165750/1734680) towards lake Bygdeträsket and farther to the south-west. The other system can be observed in the area north-east of lake Bastuträsket (7209240/1713340) and between lake Abborrtjärnen (7196490/1706480) east of Bastuträsk and lake Yttre Åträsket (7175360/1705580). Both fault systems occur as 5–10 m high, north–south or north-east–south-west striking slopes in the terrain, and in both cases the western side has been downfaulted relative to the eastern side.

METAMORPHISM

The metamorphic information on the "Metamorphic, structural and isotope age map" (cf. Fig. 44) is based on three principal datasets: (1) classification of metamorphic conditions into low grade, medium grade, high grade, and anatectic melts, (2) occurrences of selected index minerals, and (3) sample localities for pressure–temperature determinations.

Metamorphic grade

The metamorphic conditions are divided into low grade, medium grade, and high grade. The high-grade zones include the occurrences of anatectic melts, the late to post Svecokarelian granites. The assignment of metamorphic grade to a particular rock unit is based on the interpretation of textural and structural features and the presence of different index minerals in supracrustal rocks. However, the metamorphic status of the volcanic Skellefte and Arvidsjaur Groups in the northern part of the area is more difficult to interpret than that of the large areas of metasedimentary rocks in the southern part of the investigated area, due to the lack of minerals suitable for thermobarometry. Large areas of early Svecokarelian calc-alkaline granitoids provide less information.

Low grade designates rocks within lower to upper greenschist facies. They are usually texturally well preserved, even though localized high strain zones and granoblastic varieties may occur. Typical metamorphic minerals in the low-grade supracrustal rocks are chlorite, actinolite, and muscovite.

Medium grade designates rocks in lower and medium amphibolite facies. Primary textures are locally preserved, but recrystallization and granoblastic textures are much more common than in areas with low-grade conditions. Medium grade is characterized by the presence of several index minerals such as andalusite, cordierite, and hornblende.

High grade designates rocks in the upper amphibolite and granulite facies. Original textures are not preserved and the rocks are mainly veined gneisses and migmatites. Characteristic index minerals are sillimanite and abundant garnet.

We have defined the shift from low to medium grade according to a number of mineral reactions; the most common is the transformation of chlorite (and actinolite) in low-grade to hornblende in medium-grade mafic rocks. This reaction, which also defines the transformation from greenschist to amphibolite facies, is both temperature and pressure dependent, as epidote is formed on the hornblende side of the reaction if the pressure exceeds 3.3 kbar (Spear 1993). The scarcity of epidote in the project area is a general indication of low pressures. The temperature of the border zone is generally believed to be c. 550 °C and, depending on a miscibility gap, actinolite and hornblende may coexist for a short interval (Spear 1993).

In our definition, the shift from medium to high grade is characterized by the occurrence of veined gneiss structures on the high-grade side. This situation normally coincides with the disappearance of andalusite and the introduction of sillimanite. The transformation is temperature and pressure dependent, but would generally correspond to a situation within the temperature interval 600–650 °C for the prevailing pressures.

The melting of pelitic metasedimentary rocks to form anatectic granitic melts corresponds to a temperature of c. 650–700 °C in the presence of water, contributed mainly from the breakdown of micas in the pelites. Increased pressure may lower the melting temperature.

The low-grade rocks include most of the exposed volcanic Skellefte and Arvidsjaur Groups in the northern part of the investigated area (Fig. 44). The medium-grade rocks fringe the low-grade area and occupy a large area in the south-entral and western parts of the investigated area. The high-grade parts of the investigated area lie in the south-east, the east, and in the areas around Storuman and between Vilhelmina and Dorotea in the western and south-western part. High-grade rocks and associated anatectic granitoids are confined mainly to the areas with abundant metasedimentary rocks.

A steep metamorphic gradient with a rapid transformation from low- to high-grade metamorphism over a short distance is evident in some areas, for example in the Karsträsk area in the south of the Skellefte District. Here the increase in metamorphic grade coincides with a zone of intense deformation. A steep metamorphic gradient in the Storuman area can also be discerned, but the metamorphic grade here is controlled by the distance from the large anatectic late to post Svecokarelian granite intrusion north of Storuman (Blaiken granite massif). This granite may be regarded as the core of the metamorphism with the highest pressure–temperature signature (Lundström 1998).

The distribution of index minerals does not invariably follow the general patterns of the different metamorphic grades defined above, but can differ in occurrence according to local conditions. Abundant garnet is one characteristic feature of the high-grade metamorphic area around Burträsk and farther to the south, but it is rare in other high-grade areas, for example in the above mentioned Storuman area where garnet is noted only within the anatectic Blaiken granite. Garnet is also present in the low-grade Kristineberg area in hydrothermally altered volcanic rocks, where the rock composition promoted garnet growth during later greenschist facies metamorphism. A similar explanation is suggested for the actinolite distribution in the Boliden area, where alteration processes have produced a strong actinolite overprint in both low-grade and medium-grade rocks. Cordierite occurs in both medium- and high-grade zones and has probably a dual origin, from both regional and contact metamorphism.

Pressure and temperature determinations

A reconnaissance study with a limited number of thermobarometric determinations (Table 2) has been performed on geographically distributed samples, indicated by stars on the "Metamorphic, structural and isotope age map" (Ba 57:2), in order to establish quantitative values on the metamorphic grade (cf. Fig. 44). The samples were selected from suitable mineral assemblages, mainly garnet, but also including amphibole and tourmaline. The chosen thermometers are garnet–biotite (Ferry & Spear 1978), hornblende–plagioclase (Holland & Blundy 1994), and tourmaline–biotite (Colopietro & Friberg 1987). For pressure estimation, we used the garnet–andalusite–sillimanite–plagioclase barometer, GASP (Spear 1993) and some general pressure estimates from sodium–aluminium content in

hornblende. Data computation was performed using mainly TWEQUE software (Berman 1991). The pressure–temperature data are shown in Table 2. Correlation between the metamorphic grades and the geothermobarometric results is reasonably good. The shift between low and medium grade is bracketed by some determinations in the Kristineberg area, suggesting a temperature of about 550 °C and a pressure of about 3 kbar. The boundary between medium grade and high grade has not been determined accurately anywhere due to non-equilibrated assemblages, but results from the Storuman and Burträsk areas indicate high-grade gneisses and anatectic granites with temperatures exceeding 700 °C and with a wide range of pressures. A pressure–temperature determination of a garnet–grunerite assemblage in a shear zone in medium-grade amphibolite north-east of Boliden placed some values on the retrograde part of the pressure–temperature loop.

Metamorphism in the Skellefte District and surrounding areas

The central Skellefte District and the Arvidsjaur District in the northern part of the project area are low grade and pressure–temperature determinations may be as low as 400 °C and below 2 kbar, as deduced from the Holmtjärn area (7228630/1677070, Nicholson 1993). Many well preserved areas in the Arvidsjaur District suggest an even lower metamorphic grade. The grade increases in all directions from this low-grade core. Gavelin (1955) was the first to publish a general picture of the change from the chlorite zone (middle greenschist facies) to biotite zone (upper greenschist facies) in altered felsic metavolcanic rocks of the Skellefte Group, and these results are still valid. The isograd is more or less parallel to the structural trend of the Skellefte Group metavolcanic rocks.

In the metasedimentary rocks surrounding the exposed Skellefte Group, towards the east and south, the metamorphic grade increases abruptly. To the south, the metamorphic gradient coincides with increasing strain in the different rock types. Towards the eastern and western parts of the exposed Skellefte Group rocks, pressure–temperature determinations from upper greenschist facies metavolcanic rocks of the Boliden and Kristineberg areas suggest temperatures around 550 °C and pressures of 2–2.5 kbar. A pressure–temperature determination from medium-grade metavolcanic rock east and south of Kristineberg suggests temperatures around 600 °C and a pressure not much above that of the low-grade rocks. A general conclusion regarding the metamorphic character of the Skellefte District suggests that the metamorphism is of a low pressure type. To the east of the Skellefte District, there are large masses of migmatites and anatectic granites, whereas the inferred metamorphic gradient in the eastern part of the district is truncated by the intrusions of the Transscandinavian Igneous Belt (TIB).

A rather large area of medium-grade rocks, with abundant andalusite and cordierite, occurs in the south-central part of the project area. Unfortunately, no pressure–temperature determinations are available from this area, but a fair assumption is that the conditions are similar to those of the Storuman area farther towards north-west, where Lundström (1998) investigated a similar metamorphic assemblage within similar metagreywackes. The temperature range for the rocks in the Storuman area is 550–650 °C with an estimated pressure of 2.7 kbar. The higher temperatures are found closer to granitoid intrusions. The metamorphic core in the Storuman area is the large anatectic Blaiken granite massif surrounded by a steep metamorphic gradient. The metamorphic patterns, including similar relationships between metamorphic gradients and anatectic

Table 2. Pressure-temperature determinations from metamorphic mineral assemblages in the Skellefte District and surrounding areas.
Tryck- och temperaturbestämningar av metamorfa mineralparageneser i Skelleftefältet med omnejd.

Sample	N-coord	E-coord	P	T	Host rock	Method	Reference
JPN950065	7244160	1563750	3,7	700	granite	garnet–biotite/GASP	Lundström, H. (1998)
TEN930042	7203740	1552960		577	metagreywacke	tourmaline–biotite	Lundström, H. (1998)
GSO950228	7230600	1567450		581	metagreywacke	tourmaline–biotite	Lundström, H. (1998)
LHS950434	7230220	1570120		500	metagreywacke	tourmaline–biotite	Lundström, H. (1998)
97LKS1	7135300	1705250	4,45	712	migmatized metagreywacke	garnet–biotite/GASP	
97LKS2	7137500	1741650	3,3	580	migmatized metagreywacke	garnet–biotite/GASP	
MGN930258	7216930	1634140		605(core)/4	amphibolite dyke	hornblende–plagioclase	
UJB960018	7225020	1619720		580(c+e)/2	amphibolite dyke	hornblende–plagioclase	
UJB930019	7226020	1624190	2,5	527	chlorite altered metarhyolite	garnet–biotite/GASP/muscovite	
UJB930108	7218030	1628470		590(core)	metatonalitic porphyry	tourmaline–biotite	
Holmtjärn	7228300	1676800	1,8	350	metabasalt	prehnite–pumpellyite–actinolite–epidote	Nicolson, D. (1993)

GASP = garnet–andalusite–sillimanite–plagioclase barometer

granites, are disturbed in this southern area by the voluminous intrusions of the Revsund suite.

High-grade rocks dominate in the Burträsk area in the south-eastern part of the project area. Here the bedrock in large areas consists of muscovite-free, migmatitic metagreywackes with abundant garnet. In this area, the dominant west-southwest–east-northeast striking shear zone, the Nickel zone, is the principal northern front of the garnet-bearing rocks, but veined gneisses of high grade occur farther to the north. Pressure–temperature determinations suggest a general southward increase in pressure to approximately 4 kbar south of the shear zone. Sillimanite is also abundant south of the Nickel zone in the area south of Bygdsiljum and around Ånäset, whereas cordierite increases in abundance in the same rock types from Bygdsiljum and Robertsfors towards the east and north-east possibly reflecting lower pressures.

Explanation to the Map of mineral and bedrock resources and hydrothermal alterations

The map of "Mineral and bedrock resources and hydrothermal alterations" (Ba 57:3) is divided into six different thematic maps. They are: 1) main map of ores and mineralizations (scale 1:500,000), 2) gold and intrusion related deposits (scale 1:500,000), 3) volcanogenic massive sulphide deposits (VMS) deposits: eastern Skellefte District (scale 1:100,000), 4) volcanogenic massive sulphide deposits (VMS) deposits: western Skellefte District (scale 1:100,000), 5) Ni deposits in the so-called Nickel zone (scale 1:200,000), and 6) volcanogenic massive sulphide deposits (VMS) deposits: central Skellefte District (scale 1:100,000). Included on the composite map is also a table listing all metallic and industrial mineral deposits of the area.

The mineral deposits and bedrock resources have been separated into the following types:

Volcanic arc related deposits
1 Volcanogenic massive sulphide deposits (VMS)
2 Replacement copper-zinc (Cu±Zn) deposits
3 Porphyry copper-gold (Cu-Au) deposits
4 Epithermal gold (Au) deposits

Magmatic deposits related to ultramafic and mafic rocks
5 Ultramafic associated nickel (Ni) deposits
6 Mafic associated nickel (Ni) deposits

Gold deposits
7 Orogenic gold (Au) deposits

Deposits related to late to post Svecokarelian intrusive rocks
8 Tin-tungsten (Sn-W) deposits
9 Uranium (U) deposits

Unspecified deposits
10 Unspecified copper (Cu) deposits
11 Unspecified zinc-lead (Zn-Pb) deposits
12 Unspecified gold (Au) deposits

Iron deposits
13 Iron (Fe) deposits

Industrial mineral deposits
14 Andalusite
15 Graphite
16 Dolomite, calcite
17 Quartz, feldspar
18 Fluorite
19 Diatomite

This subdivision is partly based on commodity type and partly on a genetic classification of the various deposits. It should be emphasized that the genetic classification is based on the current concept of the genesis of some of the listed deposits, and that the uncertainty of the genetic classification is considerable, especially for minor, less thoroughly studied deposits. Types 10–12 have been included for such unspecified deposit types of copper (Cu), zinc-lead (Zn-Pb) and gold (Au) respectively. The mineralization styles as well as some important individual mineral deposits are described in greater detail in the following chapter "Ores and mineralizations".

MAIN MAP OF ORES AND MINERALIZATIONS (scale 1:500,000)

The main map of ores and mineralizations shows all the deposits listed in Table 3. These deposits are plotted on a simplified geological map, showing Archaean rocks, Karelian rocks, crystalline carbonate rock (undifferentiated), metavolcanic rocks (Bothnian Supergroup, Skellefte Group), volcanic rocks (Arvidsjaur Group, Vargfors Group), volcanic rocks (Dobblon Group), Svecofennian sedimentary and metasedimentary rocks,

and also basalts of the Bothnian Supergroup undifferentiated, early Svecokarelian calc-alkaline intrusive rocks (Jörn GI suite, Knaften), early Svecokarelian intrusive rocks (Perthite monzonite suite), late to post Svecokarelian intrusive rocks (Skellefte-Härnö suite, Transscandinavian Igneous Belt (TIB), mesoproterozoic dolerites, Neoproterozoic to Early Palaeozoic sedimentary rocks, and the Lower, Middle and Upper Allochthons of the Caledonian orogen.

GOLD AND INTRUSION RELATED DEPOSITS (scale 1:500,000)

A further subdivision of intrusive rocks corresponding to that of the bedrock map (Ba 57:1), compared with the main map, is made on the map of gold and intrusion related deposits on the same scale as the main map, covering the entire project area. This map shows the geographical position of deposit types 3, and 6–12. The full subdivision of intrusive rocks is made so that it will be easier to show the relationship between intrusive suites and deposit types. For example, most porphyry copper type deposits occur in intrusions of the Jörn GI suite, whereas Sn-W deposits are related to late to post Svecokarelian intrusive rocks (Skellefte-Härnö suite, Transscandinavian Igneous Belt).

Gold deposits of the orogenic type (7) and unspecified type (12) are also commonly structurally controlled. Deformation zones, formlines, and zones with increased magnetization and electric conductivity from the metamorphic, structural and isotope age map (Ba 57:2) have therefore been added to the map of gold and intrusion related deposits to help the reader form an impression of the relationship between the various gold deposits and major structures.

VMS DEPOSITS: EASTERN, CENTRAL, AND WESTERN SKELLEFTE DISTRICT (scale 1:100,000)

The main type of ore deposits in the project area, and by far the economically most important, are the volcanogenic massive sulphide deposits (VMS), which with few exceptions occur within the Skellefte Group metavolcanic rocks. For the purpose of showing as detailed geology as possible, the geographical positions of these deposits are shown separately on three maps covering the eastern, central, and western Skellefte District respectively on a scale of 1:100,000. The geological information on these maps is taken from the digital 1:50,000 scale databases covering the map sheets 23I Malå (Bergström & Sträng 1999b), 23J Norsjö (Bergström et al. 2003), 23K Boliden (Lundström & Antal 2000) and 22K Skellefteå (Nilsson & Kero 1998a). All polygon and line data, and certain point data – particularly hydrothermal alteration and metamorphic minerals from these databases – have been added to the three maps.

NICKEL (Ni) DEPOSITS IN THE SO-CALLED NICKEL ZONE (scale 1:200,000)

Several nickel deposits are located in a limited zone south-east of the Skellefte District proper. This area, commonly referred to as the "Nickel zone" or "Burträsk Nickel line", is shown on the map of nickel (Ni) deposits in the so-called Nickel zone, presented at a scale of 1:200,000. The geological and structural information on this map is taken from the bedrock map (Ba 57:1). Deposit types 5 and 6 are shown on the map. As these deposits are related to mafic and ultramafic intrusions of very limited areal extent, the information (either as polygons or points on the map) on these intrusions was extracted from the digital 1:50,000 scale databases of the area (cf. Nilsson & Kero 1986, 1998a,b, Weihed & Antal 1998, and Thelander & Kero 2004a).

TABLE OF MINERAL DEPOSITS

All the deposits displayed on the different maps are listed in the table of mineral deposits on the map of "Mineral and bedrock resources and hydrothermal alterations" (see Ba 57:3 and Table 3). Information given in the table was taken from the official mineral deposit database of the Geological Survey of Sweden (SGU). The table includes the following columns: Name, Id-code (referring to the identity code in the SGU "Mineral and bedrock resources database"), Number (shown on the maps), Type (according to the subdivision in Table 4), Status, Tonnage, Grades of gold (Au, ppm), silver (Ag, ppm), copper (Cu, %), zinc (Zn, %), lead (Pb, %), arsenic (As, %), sulphur (S, %), platinum group elements (PGE, ppm), nickel (Ni, %), cobalt (Co, %), tungsten (W, %), uranium (U, %), iron (Fe, %), Coordinates (metres in the national grid RT90), Size (according to the subdivision in Table 4), Commodity, Map sheet, and Square. In the "Status" column, the deposits are divided into active mine, closed mine, prospect, and mineralization. The subdivision between prospect and mineralization is rather arbitrary, but generally indicates that a prospect has been worked on substantially and usually has an ore grade and tonnage calculation.

Many of the deposits are described in detail in the literature and figures for tonnage and grade can be presented in many cases. Other deposits lack official data or are not sufficiently well known to give tonnage or

grade. There are three different sizes of the symbol representing the deposits, depending on total tonnage and the combined content and economic importance of the commodities contained (Table 4). The largest size corresponds to larger ore bodies, often economically exploitable, the intermediate size to smaller ores and important, though subeconomic prospects, and small size denotes small and uneconomic mineralizations.

Ores are formed in response to concentration processes in the crust during tectonic events. Metal concentrations are linked to certain rock units, or structures, or a combination of both. The mineralization type may be a diagnostic feature of the specific lithotectonic unit. The ores and mineralizations are associated with "preferred host rocks" and different alteration systems, which are commonly arranged in zoned patterns. In the "Ores and mineralizations" chapter below, the ore deposits of the Skellefte District and surrounding areas are grouped according to their lithotectonic setting, geographic position, metal content, and alteration characteristics.

Explanation to the Magnetic anomaly map

The Geological Survey of Sweden (SGU) started airborne measurements of the earth's magnetic total field in 1960; measurements in the project area started in 1969, the most recent being carried out in 1999. The line separation was nominally held at 200 m. Prior to 1995, the ground clearance was kept at 30 m and the sampling interval at 40 m. From 1995 and onwards, all data were collected with a ground clearance of 60 m and a sampling interval of 17 m. Today, positioning is maintained with radar altimeter and the Global Positioning System (GPS). The flight direction varied between east–west and north–south, depending on the strike direction of predominant geological structures (Fig. 46a). In the 1960s, the magnetometers had an accuracy of approximately 10 nT, which later improved to 4 nT and 1 nT. Today, the airborne magnetometers are accurate to 0.1 nT.

Besides SGU, several other operators have carried out airborne magnetic measurements for different clients over the years, chiefly for mineral exploration. The databases of the SGU include data from airborne surveys conducted by SGAB (Swedish Geological Company) for the client NSG (The State Mining Property Commission), mostly covering comparatively minor areas.

On the "Magnetic anomaly map" (Ba 57:4), the total field data have been calculated to epoch 1965, and corrected for the geomagnetic reference field DGRF 1965.0. The data have been processed using a grid cell size of 50 m × 50 m. Relief impression is created by illumination with solar inclination of 60° and declination of 22.5°. Operational mines and closed mines of size classification 1 and some closed mines of size classification 2 (see Table 4) have been added to the map. A magnetic anomaly map with resolution lower than on Ba 57:4 is shown in Figure 46b.

Explanation to the Bouguer anomaly map

The Geological Survey of Sweden (SGU) first started systematic gravity measurements in the late 1950s in connection with the iron ore inventory of Northern Sweden. Regional gravity surveys on a national scale were initiated in the mid-1960s, mainly to support bedrock mapping.

These measurements are usually carried out along roads. In areas with a sparse road network, a snowmobile or helicopter is used for transportation between the measuring sites. The measurements in the Gulf of Bothnia were carried out on thick ice during extremely cold winters during the 1970s and 1980s. The surveys on ice have been conducted as joint projects together with the National Land Survey (LMV) and the Geodetic Institute (GL) in Helsinki, Finland.

During regional gravity surveying at SGU, the objective is to attain a sampling distance of 1½–2 km, whereas the National Land Survey, which is responsible for the mapping of the entire territory of Sweden, uses a sampling distance of 5 km. As the accuracy of the Bou-

Table 3. Mineral deposits in the Skellefte District and surrounding areas.

Mineralförekomster i Skelleftefältet med omnejd.

Name	ID-Code	Nr	Type	Status	Tonnage	Au (ppm)	Ag (ppm)	PGE	Cu (%)	Zn (%)	Pb (%)	Ni (%)	U (%)	W (%)	As (%)	S (%)	Co(%)	N-coord	E-coord	Size	Commodity	Sheet	Square
Bastuheden mellersta	ORED05001	1	1	Prospect	91	0,2	15		1,39	0,11						5,2		7207700	1710700	3	Cu	23K	1c
Bastuheden norra	ORED05002	2	1	Prospect	68	1,7	86		0,07	4,6	1,06					20,5		7208700	1711250	2	Cu-Zn-Pb	23K	1c
Bastuheden södra	ORED05003	3	1	Prospect	290	0,7	6		0,96	0,08						3,8		7207200	1710300	2	Cu	23K	1c
Bastuheden östra	ORED05004	4	1	Prospect														7208700	1712050	3	Cu-Zn	23K	1c
Bjurfors mellersta	ORED00762	5	1	Prospect	600	0,25	18			3,5	0,2				0,36	31		7216950	1679250	2	Cu-Zn-Pb	23J	3f
Bjurfors västra	ORED05007	6	1	Prospect														7217200	1678870	3	Fe-sulphides	23J	3f
Bjurfors östra	ORED05008	7	1	Closed mine	200	0,5			2,6							27		7216800	1679560	2	Cu	23J	3f
Bjurliden	ORED00788	8	1	Prospect	720	0,3	46		0,1	3,5	0,35					17,6		7215900	1683100	2	Zn-Cu-Pb	23J	3g
Bjurträsk	ORED00767	9	1	Prospect	377	0,25	7		0,3	6,6						23,2		7215680	1684930	2	Cu-Zn	23J	3g
Bjurträsk södra	ORED15539	10	1	Prospect	27,9				0,03	1,69						3,7		7215590	1684840	3	Cu-Zn	23J	3g
Bjurvattnet	ORED05309	11	1	Prospect														7203000	1711600	3	Cu	23J	3g
Björkliden	ORED00802	12	1	Mineralization														7214550	1636120	3	Fe-sulphides	23I	2h
Boliden södra	ORED05707	13	1	Prospect														7204100	1716600	3	Cu-Zn- Pb	23K	0d
Brattmyrhögen	ORED00677	14	1	Mineralization														7226900	1645250	3	Cu-Zn- Pb	23I	5j
Brattmyrhögen norra	ORED05078	15	1	Prospect												33		7225000	1646700	3	Fe-sulphides	23I	5j
Brännan	ORED05017	16	1	Prospect														7205550	1709000	3	Cu-Zn-Pb	23K	1b
Elvaberget	ORED05026	17	1	Prospect	930	0,5	22		0,46	1,69	0,18					30		7219600	1667300	2	Cu-Zn-Pb	23J	3d
Fjällboheden	ORED05155	18	1	Prospect	200		3		0,5	0,2						24		7217580	1713020	3	Cu-Zn	23K	2c
Granlunda	ORED00807	19	1	Closed mine	125		15		0,76	1,3	0,9					6,3		7225330	1621730	3	Cu-Zn-Pb	23I	5e
Holmtjärn	ORED04107	20	1	Closed mine	500	7,4	92		0,4	4	0,4				0,9	22		7227920	1676820	2	Cu-Zn-Pb-Au	23J	5f
Hornträskviken m.	ORED00709	21	1	Closed mine	880	0,6	65		1,08	4,6	0,5							7223220	1627910	1	Cu-Zn-Pb	23I	4f
Hornträskviken östra	ORED05040	22	1	Prospect	600				1	2,3								7223460	1628250	2	Cu-Zn-Pb	23I	4f
Högkulla östra	ORED05147	23	1	Closed mine	113	0,6	110		0,18	12,6	0,65					28,2		7217709	1673984	2	Cu-Zn-Pb	23J	3e
Kankberg	ORED05046	24	1	Closed mine	1800	2,6	52		1,4	1,8	0,3				1,2	35		7209450	1711000	1	Cu-Zn	23K	1c
Kedträsk	ORED05049	25	1	Closed mine	3900	0,5	24		0,4	2,9	0,2				0,3	40		7211540	1692770	1	Cu-Zn-Pb	23J	2i
Kimheden	ORED05050	26	1	Closed mine	1000	0,4	6		1,17	0,07						19,6		7223400	1631200	2	Cu	23I	4g
Kristineberg	ORED05053	27	1	Mine	23049	1	35		1	3,7	0,5					25		7220600	1629950	1	Cu-Zn-Pb	23I	4g
Lillholmsberget	ORED00705	28	1	Mineralization														7223000	1617750	3	Zn-Pb	23I	4d
Lomviken	ORED05066	29	1	Prospect		0,38	12,7		0,8	0,7	0,06				1,39	18,9		7222420	1668940	3	Cu-Zn-Pb	23J	4d
Långdal	ORED05067	30	1	Closed mine	4330	1,9	149		0,1	5,8	1,7					12		7198570	1710070	1	Cu-Zn-Pb	22K	9c
Långsele	ORED05068	31	1	Closed mine	12000	0,9	25		0,6	3,9	0,3				0,4	35		7201150	1712050	1	Cu-Zn-Pb	23K	0c
Långträskåsen	ORED00889	32	1	Prospect														7226290	1620900	3	Cu-Zn-Pb	23I	5e
Långviken	ORED05069	33	1	Prospect	105	0,5	19		1,5	0,68	0,11				1,69	25,8		7221730	1669050	3	Cu-Zn	23J	4d
Maurliden norra	ORED05484	34	1	Prospect	868	0,7	27		0,14	1,06	0,16					11		7221656	1676603	2	Cu-Zn-Pb	23J	4f
Maurliden västra	ORED00737	35	1	Mine	6900	0,9	49		0,2	3,4	0,4					39		7222554	1674690	1	Cu-Zn-Pb	23J	4e
Maurliden östra	ORED04185	36	1	Prospect	1265	0,8	16		0,84	0,51						31		7221409	1676350	2	Cu-Zn	23J	4f
Mörkliden	ORED00813	37	1	Mineralization	335	0,3	69		0,18	3,56	0,34					4,7		7218060	1625170	2	Cu-Zn-Pb	23I	3f
Mörkliden 3	ORED15478	38	1	Mineralization	82	0,6	5		0,88	0,1						4,3		7218400	1627380	3	Cu	23I	3f
Mörkliden 4	ORED00812	39	1	Prospect	115	0,1	25		0,17	4,9	0,4					4,1		7218540	1627840	2	Cu-Zn-Pb	23I	3f
Norrliden norra	ORED04187	40	1	Prospect	2952	0,4	44		0,8	2,5	0,2					21		7218173	1678351	1	Cu-Zn-Pb	23J	3f
Norrliden södra	ORED00741	41	1	Mineralization														7217910	1677978	3	Fe-sulphides	23J	3f
Nyborg	ORED00678	42	1	Prospect	296	0,2	41		0,53	4,8	0,5					11,7		7227025	1636325	2	Cu-Zn-Pb	23I	5h
Näset	ORED00757	43	1	Mineralization														7216970	1685640	3	Fe-sulphides	23J	3h
Näsliden	ORED00665	44	1	Closed mine	5012	1,3	35		1,1	3	0,3				1,4	28		7225900	1654950	1	Cu-Zn	23J	5a
Näsliden norra	ORED05083	45	1	Closed mine	900	0,9	28		0,6	1,8	0,2				0,5			7226350	1655060	2	Cu-Zn-Pb	23J	5b
Petiknäs norra	ORED05104	46	1	Mine	1300	5,6	103		1,3	5,6	0,9				2,7	14		7210720	1700580	1	Cu-Zn-Pb-Au	23K	2a
Petiknäs södra	ORED05087	47	1	Mine	6500	2,3	108		1,1	4,8	0,9				0,4	37		7210150	1700300	1	Cu-Zn-Pb	23K	2a
Rakkejaur	ORED05088	48	1	Closed mine	>20000	1	50		0,3	2,4	0,2				1,6	26		7230700	1657250	1	Cu-Zn-Pb	23J	6b

Name	ID-Code	Nr	Type	Status	Tonnage	Au (ppm)	Ag (ppm)	PGE	Cu (%)	Zn (%)	Pb (%)	Ni (%)	U (%)	W (%)	As (%)	S (%)	Co(%)	N-coord	E-coord	Size	Commodity	Sheet	Square
Renström kyrkväg	ORED05057	49	1	Prospect		2,8	155		0,8	6	1,7							7209620	1702940	2	Cu-Zn-Pb	23K	1a
Renström västra	ORED05089	50	1	Mine	9261	2,8	155		0,8	6,5	1,5				0,2	15		7209120	1702900	1	Cu-Zn-Pb	23K	1a
Renström östra	ORED05090	51	1	Closed mine														7208940	1703440	2	Cu-Zn-Pb	23K	1a
Rudtjebäcken	ORED05093	52	1	Closed mine	4743	0,3	10		0,9	2,9	0,1					33,6		7256240	1635125	1	Cu-Zn-Pb	24I	1h
Rundklumpen	ORED05092	53	1	Prospect			17		0,08	1,6	0,1				0,1	28,1		7223220	1668940	3	Cu-Zn	23J	4d
Rutselheden	ORED00758	54	1	Mineralization														7216090	1682215	3	Fe-sulphides	23J	3g
Rågången	ORED05094	55	1	Prospect		0,7	18		1,4	0,4	0,1							7222370	1668410	3	Cu	23J	4d
Rävliden	ORED05095	56	1	Closed mine	1936	0,6	67		1,9	3,14	0,1					22		7220500	1625750	1	Cu-Zn	23I	4f
Rävlidmyran	ORED05096	57	1	Closed mine	6823	0,8	51		1	3,9	0,6					18		7221900	1625350	1	Cu-Zn-Pb	23I	4f
Salmon linders malm	ORED00806	58	1	Closed mine														7226260	1626850	3	Cu	23I	5f
Sjömalmen inre	ORED05042	59	1	Closed mine	2300	0,8	47		0,5	2,2	0,5					31		7223480	1667400	1	Cu-Zn-Pb	23J	4d
Sjömalmen yttre	ORED05133	60	1	Prospect	100	2,9	50		2,1	3,65	0,39				2,3	33		7223750	1666850	2	Cu-Zn-Pb	23J	4d
Skoberget	ORED05101	61	1	Mineralization														7202800	1711800	3	Fe-sulphides	23K	0c
Skäggträskberget	ORED05103	62	1	Prospect														7217707	1673137	3	Cu-Zn-Pb	23J	3e
Snåttermyran	ORED00735	63	1	Prospect	100		15		0,3	6,6	0,17					34		7215414	1686929	3	Zn-Pb	23J	3h
Stenbrånet	ORED05108	64	1	Mineralization														7193350	1696180	3	Cu-Zn-Pb	22J	8j
Svansele	ORED05117	65	1	Prospect	2900	0,2	4		0,28	0,32	0,06					36		7214180	1689420	2	Fe-sulphides	23J	2h
Svansele sel	ORED15353	66	1	Prospect														7214230	1690450	3	Fe-sulphides	23J	
Svansele väg	ORED05118	67	1	Prospect	360	0,9	7		0,25	3,14	0,04							7214100	1690050	2	Cu-Zn-Pb	23J	2i
Tistelmyran östra	ORED00732	68	1	Mineralization														7225270	1673750	3	Fe-sulphides	23J	4e
Udden	ORED04106	69	1	Closed mine	5946	0,7	36		0,4	4,3	0,3					24		7212150	1690450	1	Cu-Zn-Pb	23J	2i
Vikborg	ORED15359	70	1	Prospect														7201900	1701600	3	Cu-Zn-Pb	23K	0a
Vindelgransele	ORED05130	71	1	Prospect	14	1	145		0,23	16,6	3,7					26,5		7223780	1617228	3	Cu-Zn-Pb	23I	4d
Åkulla västra	ORED05136	72	1	Closed mine	980	0,7	12		1							34		7207700	1710320	2	Cu	23K	1c
Åkulla östra	ORED05137	73	1	Prospect	200	2,1	14		1,7							27		7208150	1710650	2	Cu	23K	1c
Åliden	ORED05138	74	1	Mineralization		1	24		0,1						0,3	21		7225400	1678900	3	Fe-sulphides	23J	5f
Åsen vm	ORED05140	75	1	Prospect	700	1	64		1,74	1,84	0,46					23		7209800	1692850	2	Cu-Zn-Pb	23J	1i
Åsen västra	ORED15355	76	1	Prospect														7210420	1691600	3	Cu, Zn	23J	
Åsen öm	ORED05700	77	1	Closed mine		0,7	34		1,22	0,84	0,2							7209150	1693950	2	Cu-Zn	23J	1i
Åsen östra	ORED15357	78	1	Prospect														7208500	1694850	3	Cu, Zn	23J	
Österbäcken	ORED05146	79	1	Prospect														7218036	1680986	3	Cu-Zn-Pb	23J	3g
Boliden	ORED00664	80	1,4	Closed mine	8280	15,5	50		1,43	0,92	0,27				6,83	25		7204250	1716500	1	Cu-Zn-Pb-Au	23K	0d
Adak	ORED05000	81	2	Closed mine	900	0,3	8		1,9									7254940	1631880	1	Cu	24I	0g
Brännmyran	ORED15483	82	2	Closed mine	978				1,7									7254325	1633700	1	Cu	24I	0g
Karlsson	ORED05150	83	2	Closed mine	14				4,29	0,08								7255380	1632580	3	Cu	24I	1g
Lindsköld	ORED05064	84	2	Closed mine	1700	0,6	16		1,7									7255230	1632250	1	Cu	24I	1g
Långreven	ORED05153	85	2	Mineralization					1									7254580	1632630	3	Cu	24I	0g
Sarvasåive	ORED00715	86	2	Mineralization														7292200	1703470	3	Cu	24K	8a
Stavsträsk	ORED00632	87	2	Prospect			12		0,04									7286000	1728160	3	Cu	24K	7f
Storliden	ORED05705	88	2	Mine	1800	0,3	30		4	10								7238900	1644600	1	Cu-Zn	23I	7i
Svartliden	ORED05119	89	2	Prospect														7248100	1669000	2	Cu	23J	9d
Arnberg	ORED05362	90	3	Mineralization														7203000	1670300	3	Cu	23J	0e
Granberg	ORED04112	91	3	Prospect	1500				0,2									7249200	1694000	3	Cu	23J	9i
Tallberg	ORED00697	92	3	Prospect	44000	0,2	1		0,27									7221600	1693250	2	Cu	23J	4i
Stentjärn	ORED05109	93	4	Mineralization														7193180	1708660	3	Au-Cu	22K	8b
Backviken	ORED00740	94	5	Mineralization					0,27			0,46				1,2	0,02	7149230	1722120	3	Ni-Cu-(Co)	21K	9e
Brännorna	ORED00654	95	5	Prospect	350				0,04			0,63				1,08	0,02	7165810	1743310	2	Ni-Cu-(Co)	22K	3i
Byske (samuelsberget)	ORED00652	96	5	Mineralization														7218270	1755050	3	Ni-Cu-(Co)	23L	3b
Gårkälen	ORED00888	97	5	Prospect	35				0,18			0,4				3,9	0,02	7137550	1681600	3	Ni-Cu-(Co)	21J	7g
Holmsvattnet	ORED00794	98	5	Mineralization														7170000	1751500	3	Ni-Cu-(Co)	22L	4a
Källmyrberget	ORED04186	99	5	Prospect								0,5						7132575	1656610	3	Ni-Cu-(Co)	21J	6b

Name	ID-Code	Nr	Type	Status	Tonnage	Au (ppm)	Ag (ppm)	PGE	Cu (%)	Zn (%)	Pb (%)	Ni (%)	U (%)	W (%)	As (%)	S (%)	Co(%)	N-coord	E-coord	Size	Commodity	Sheet	Square
Lappbäcken	ORED00770	100	5	Mineralization														7167500	1745600	3	Ni-Cu-(Co)	22K	3j
Lappvattnet	ORED00653	101	5	Closed mine	1000				0,21			1				4,4	0,02	7165100	1741400	1	Ni-Cu-(Co)	22K	3i
Mjödvattnet östra	ORED00656	102	5	Mineralization	37				0,05			0,34						7168520	1747770	3	Ni-Cu-(Co)	22K	3j
Mjövattnet	ORED15713	103	5	Prospect	169				0,19			1,4				4,9	0,02	7168080	1746430	2	Ni-Cu-(Co)	22K	3j
Munkviken	ORED00651	104	5	Mineralization														7146100	1767000	3	Ni-Cu-(Co)	21L	9d
Njuggträskliden a	ORED00769	105	5	Prospect	106			0,5	0,17			0,69				7,9	0,05	7196150	1664165	2	Ni-Cu-(Co)	22J	9c
Njuggträskliden b	ORED05074	106	5	Mineralization														7196090	1664270	3	Ni-Cu-(Co)	22J	9c
Njuggträskliden c	ORED05075	107	5	Prospect	190				0,12			0,65				1,5	0,02	7195310	1665090	2	Ni-Cu-(Co)	22J	9d
Njuggträskliden d	ORED05076	108	5	Prospect	261	1,2		4,9	0,11			0,7				6,6	0,05	7195430	1665105	2	Ni-Cu-(Co)	22J	9d
Rörmyrberget	ORED00912	109	5	Prospect	4239				0,06			0,76				1,4		7140250	1694700	2	Ni-Cu-(Co)	21J	8i
Uttersjön	ORED00680	110	5	Mineralization														7165270	1767000	3	Ni-Cu-(Co)	22L	3d
Vallen	ORED04163	111	5	Prospect	25				0,11			0,5						7164000	1752200	3	Ni-Cu-(Co)	22L	2a
Öretorp	ORED00981	112	5	Mineralization														7142200	1640400	3	Ni-Cu-(Co)	21I	8i
Bastutjärn	ORED05005	113	6	Prospect	2400				0,12			0,16						7212500	1676500	3	Ni-Cu-(Co)	23J	2f
Gisträsk	ORED05034	114	6	Prospect														7214100	1661395	3	PGE	23J	2c
Kalvtjärnen	ORED05456	115	6	Prospect														7163800	1689800	3	PGE	22J	2h
Lainijaur	ORED00668	116	6	Closed mine	119				1			2,2				23		7240850	1648120	2	Ni-Cu-(Co)	23I	8j
Storbodsund	ORED05111	117	6	Prospect	60				0,6			2,3				21	0,09	7293000	1619700	3	Ni-Cu-(Co)	24I	0a
Älgliden	ORED04111	118	6	Prospect	570				0,69			0,25				6,1		7222300	1694400	2	Ni-Cu-(Co)	23J	4i
Barsele 1	ORED05487	119	7	Prospect	2261	2,26												7216300	1580600	2	Au	23H	3g
Barsele 2	ORED15248	120	7	Prospect														7217600	1579450	3	Au	23H	
Björkdal	ORED04105	121	7	Closed mine	20000	2,6												7211600	1726150	1	Au	23K	2f
Fäbodliden a	ORED00659	122	7	Prospect	100	3												7225080	1613850	3	Au	23I	5c
Fäbodliden b	ORED05708	123	7	Prospect														7224420	1614820	3	Au	23I	4c
Fäbodliden c	ORED00662	124	7	Prospect		2												7224040	1614930	3	Au	23I	4c
Grundfors södra	ORED05036	125	7	Prospect														7193600	1718100	3	Au	22K	8d
Häbbersfors	ORED04105	126	7	Mineralization														7211600	1726150	3	Au	23K	2f
Krångfors västra	ORED05054	127	7	Closed mine														7193470	1718240	3	Au	22K	8d
Krångfors östra	ORED05055	128	7	Prospect														7193200	1719500	3	Au	22K	8d
Långtjärn	ORED00690	129	7	Prospect	556	1												7273100	1556900	3	Au	24H	4b
Middagsberget	ORED00649	130	7	Prospect	300	3												7222780	1615850	2	Au	23I	4d
Nippas	ORED05346	131	7	Mineralization														7248750	1571850	3	Au	23H	9e
Pålsträsk	ORED00672	132	7	Prospect														7295380	1746860	3	Au-Cu	24K	8j
Rengård	ORED04109	133	7	Prospect														7206800	1699700	3	Au-Cu	23J	1j
Skäggträskberget södra	ORED05701	134	7	Mineralization														7217334	1673159	3	Au	23J	3f
Storklinten	ORED00914	135	7	Mineralization														7226600	1713600	3	Au	23K	4c
Storliden	ORED04137	136	7	Prospect														7257225	1562250		Au	24H	
Stöverfors	ORED05115	137	7	Prospect														7194800	1726400	3	Au	22K	8f
Tallberg södra	ORED05709	138	7	Prospect														7220900	1693000	2	Au	23J	4i
Vargbäcken	ORED05706	139	7	Prospect														7225700	1618400	3	Au	23I	5d
Vinliden	ORED05131	140	7	Prospect														7268200	1600010	3	Au	24H	3j
Vitberget	ORED00717	141	7	Mineralization														7246430	1760850	3	Au	23L	9c
Åkerberg	ORED15669	142	7	Closed mine	1100	3												7224550	1732500	1	Au	23K	4g
Älgträsk	ORED05143	143	7	Prospect														7219350	1696200	3	Au	23J	3j
Önusberget	ORED05144	144	7	Mineralization														7219429	1676089	3	Au	23J	4e
Bäckmyrbäcken	ORED05023	145	8	Mineralization														7225800	1569450	3	W	23H	5d
Gunnarsjön	ORED05037	146	8	Mineralization														7228300	1567040	3	Sn-W	23H	5d
Metartjärn	ORED00730	147	8	Mineralization														7227630	1566540	3	W	23H	5d
Rostberget	ORED05091	148	8	Mineralization			15							0,038				7199250	1577250	3	Sn-W	22H	9f
Rostbäcksheden	ORED00688	149	8	Mineralization														7198695	1587520	3	Sn-W	22H	9h
Sorvatliden	ORED00708	150	8	Mineralization														7277000	1567000	3	Sn-W	24H	5d

Name	ID-Code	Nr	Type	Status	Tonnage	Au (ppm)	Ag (ppm)	PGE	Cu (%)	Zn (%)	Pb (%)	Ni (%)	U (%)	W (%)	As (%)	S (%)	Co(%)	N-coord	E-coord	Size	Commodity	Sheet	Square
Stabburbäcken	ORED00714	151	8	Prospect														7254200	1558300	3	W	24H	1b
Stenmyrberget	ORED00712	152	8	Mineralization														7243688	1569256	3	W	23H	8d
Storträsket	ORED04078	153	8	Mineralization														7212090	1584365	3	Sn-W	23H	2g
Svärtträsk	ORED00814	154	8	Prospect	240									0,17				7230295	1567770	2	W	23H	6d
Tolvmanmyran	ORED04079	155	8	Mineralization														7211830	1585255	3	W	23H	2h
Tvåtjärnmyran N	ORED00682	156	8	Prospect														7246025	1570500	3	Sn-W	23H	9e
Arresåive	ORED04223	157	9	Mineralization														7281900	1594450	3	U-Th	24H	6i
Björklund	ORED04222	158	9	Prospect	200								0,15					7269790	1624175	3	U-Th	24I	3e
Björkråmyran	ORED15273	159	9	Prospect	1093								0,14					7142700	1596150	2	U-Th	21H	8j
Brånaberget	ORED04220	160	9	Mineralization									0,05					7277700	1563300	3	U-Th	24H	5c
Duobblon	ORED04217	161	9	Prospect	162								0,027					7276650	1558800	3	U-Th	24H	5b
Gipperträsket	ORED15456	162	9	Mineralization														7280700	1564900	3	U-Th	24H	6d
Järntjärnbäcken östra	ORED15486	163	9	Prospect														7294700	1637900	3	U-Th	24I	8h
Laisbäck	ORED04211	164	9	Mineralization														7234000	1556000	3	U-Th	23H	6b
Långträsk	ORED15482	165	9	Prospect	130								0,049					7293750	1633250	3	U-Th	24I	8g
Norrdöttern 2	ORED00191	166	9	Prospect														7298600	1634900	3	U-Th	24I	9g
Rabnaträsket	ORED04199	167	9	Mineralization														7282780	1556315	3	U-Th	24H	6b
Rävarberget	ORED04197	168	9	Prospect	40								0,15					7284600	1632400	3	U-Th	24I	6g
Gråberget	ORED00828	169	10	Prospect	390				0,5									7263000	1615780	2	Cu	24I	2d
Malådalen	ORED05253	170	10	Prospect														7245950	1624240	3	Cu	23I	9e
Mörtträsk norra	ORED00731	171	10	Mineralization														7240690	1664700	3	Fe-sulphides	23J	8c
Orrträsket	ORED05260	172	10	Mineralization														7222075	1587775	3	Fe-sulphides	23H	4h
Sandlidberget	ORED05100	173	10	Mineralization	250											30		7228650	1720460	3	Fe-sulphides	23K	5e
Skärfonäset	ORED00710	174	10	Mineralization														7263050	1555300	3	Cu-Zn	24H	2b
Ersmarksberget norra	ORED05703	175	11	Prospect	6956		8,6			1,82	0,65							7252000	1563370	1	Zn-Pb	24H	0c
Hemberget	ORED00851	176	11	Prospect	1821		5,5			2,98	0,32							7229220	1569620	2	Zn-Pb	23H	5d
Morön	ORED05072	177	11	Mineralization														7193600	1747150	3	Pb	22K	8j
Duobblonbäcken	ORED00674	178	12	Prospect														7276900	1555300	3	Au	24H	5b
Ersmarksberget	ORED04138	179	12	Prospect	895	3,7	5,2			0,75	0,23							7250500	1564100	2	Au	24H	0d
Fäbodliden	ORED15812	180	12	Mineralization														7170600	1602600	2	Au	21I	3a
Mejvankilen	ORED05214	181	12	Prospect														7193100	1591700	3	Au	22H	8i
Paubäcken	ORED00676	182	12	Mineralization														7190580	1592680	3	Au	22H	8i
Sjöliden	ORED05215	183	12	Prospect														7196700	1589900	3	Au	22H	9h
Stortjärnhobben	ORED15908	184	12	Mineralization														7203500	1586500	3	Au	23H	0h
Svartliden	ORED05702	185	12	Prospect	2500	5,4												7186630	1588500	2	Au	22H	7h
Bygdsiljum	ORED05021	186	13	Closed mine														7147350	1726400	3	Fe-Mn	21K	9f
Hindersön	ORED05038	187	13	Closed mine														7292850	1812150	3	Fe	24M	8c
Näsberget 2	ORED15770	188	13	Closed mine														7254000	1699200	3	Fe-Ni	24J	0j
Mångfallberget	ORED05073	189	14															7206140	1716360		andalusite	23K	1d
Säter	ORED00910	190	14															7217420	1628200		andalusite	23I	2f
Flarken	ORED05209	191	15	Prospect														7142000	1743600		graphite	21K	8i
Njuggträskliden	ORED00926	192	15															7195880	1664560		graphite	22J	9c
Ådammet	ORED00929	193	15															7155330	1698800		graphite	22J	1j
Bergsbyn	ORED04710	194	16															7192300	1753000		limestone	22L	8a
Björkdal	ORED04708	195	16															7211930	1727850		limestone	23K	2f
Borup	ORED04704	196	16															7216060	1669400		limestone	23J	3d
Brännbergsliden	ORED04714	197	16															7160670	1731100		limestone	22K	2g
Djupdal	ORED04733	198	16															7162380	1526950		limestone	22G	2f
Grannäs	ORED04711	199	16															7162100	1723300		limestone	22K	2e
Gravlund-göksjöliden	ORED04713	200	16															7160850	1727300		limestone	22K	2f
Gruvskogen	ORED04691	201	16															7292550	1812420		dolomite	24M	8c

Name	ID-Code	Nr	Type	Status	Tonnage	Au (ppm)	Ag (ppm)	PGE	Cu (%)	Zn (%)	Pb (%)	Ni (%)	U (%)	W (%)	As (%)	S (%)	Co(%)	N-coord	E-coord	Size	Commodity	Sheet	Square
Hannosviken	ORED04692	202	16															7291950	1812120		dolomite	24M	8c
Häbbersfors	ORED04706	203	16															7211350	1725900		limestone	23K	2f
Innansjön	ORED04712	204	16															7162000	1726300		limestone	22K	2f
Kvarnby	ORED04715	205	16															7158930	1723120		limestone	22K	1e
Lappsjöbäcken	ORED04716	206	16															7156830	1733500		limestone	22K	1g
Norrberget	ORED04707	207	16															7209700	1731600		limestone	23K	1g
Rönnberget	ORED04705	208	16	Closed mine/ quarry														7211600	1730150		limestone	23K	2g
Sandberget	ORED04709	209	16															7208500	1720300		limestone	23K	1e
Tjärn	ORED00927	210	16															7165800	1746080		graphite	22K	3j
Hedensbyn	ORED15143	211	17	Closed mine/ quarry														7191000	1751000		feldspar, quartz	22K	
Norra bergsbyn	ORED05406	212	17															7191400	1750200		feldspar	22L	8a
Storhamnsberget	ORED05461	213	17															7196200	1755500		quartz	22L	9b
Varuträsk	ORED05405	214	17															7197600	1734500		feldspar, mica, other	22K	9g
Ytterklinten	ORED05407	215	17															7132000	1733000		feldspar	21K	6h
Granlidsknösen	ORED05455	216	18															7242000	1547500		fluorite	23G	8j
Degernäset	ORED05452	217	19															7148000	1700300		diatomite	21K	9a
Gåstjärnen	ORED05451	218	19															7154550	1693825		diatomite	22J	0i

Table 4. Size classification of mineral deposits in the Skellefte District and surrounding areas (tonnage in thousand tonnes of ore).
Storleksklassificering av mineralförekomster i Skelleftefältet med omnejd. Tonnage i tusen ton malm.

Type		small (3)	medium (2)	large (1)
1	Volcanic massive sulphide deposit (VMS)	<100	100–1 000	>1 000
2	Replacement copper-zinc (Cu±Zn) deposit	<100	100–1 000	>1 000
3	Porphyry copper-gold (Cu-Au) deposit	<2 000	>2 000	—
4	Epithermal gold (Au) deposit	<100	100–1 000	>1 000
5	Ultramafic associated nickel (Ni) deposit	<100	100–1 000	>1 000
6	Mafic associated nickel (Ni) deposit	<100	>100	—
7	Orogenic gold (Au) deposit	<1 000	1 000–10 000	>10 000
8	Tin-tungsten (Sn-W) deposit	—	>100	—
9	Uranium (U) deposit	<1 000	>1 000	—
10	Unspecified copper (Cu) deposit	—	—	—
11	Unspecified zinc-lead (Zn-Pb) deposit	<1 000	1 000–5 000	>5 000
12	Unspecified gold (Au) deposit	<800	>800	—
13	Iron (Fe) deposit	—	—	—

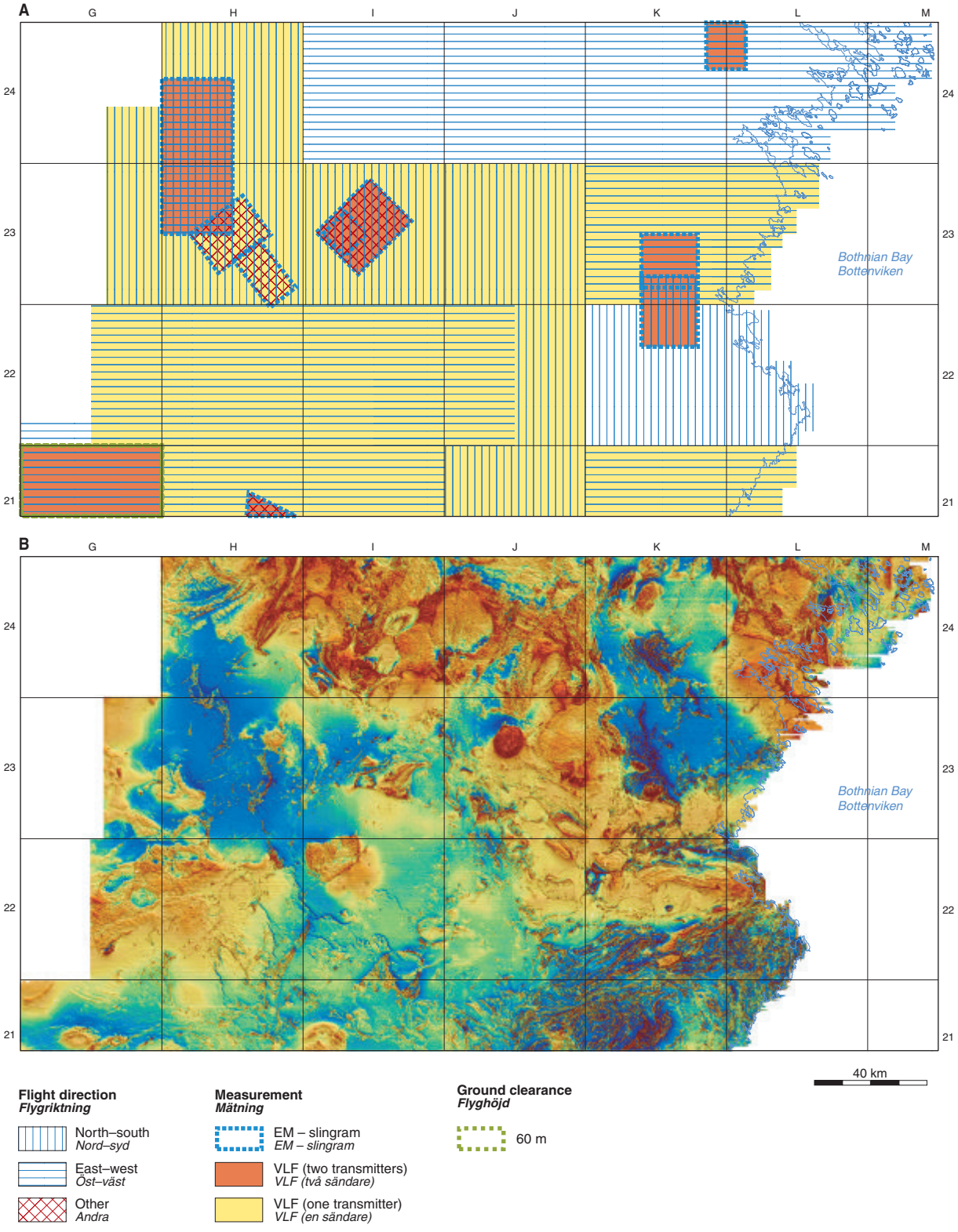


Fig. 46. **A**. Map of flight directions for airborne geophysical measurements. **B**. Magnetic anomaly map of the Skellefte District and surrounding areas. **Red: high magnetization, blue: low magnetization.**

***A**. Karta över flygriktningar för flyggeofysiska undersökningar. **B**. Magnetisk anomalikarta över Skelleftefältet med omnejd. Rött: hög magnetisering, blått: låg magnetisering.*

guer anomalies is constrained mainly by the accuracy of the determination of the elevation, differential GPS and altimeters are now used by SGU. Prior to 1995, the elevation isolines of the topographic map were used to a large extent. The mean accuracy of the older gravity measurements was approximately 0.6 mGal, but modern techniques have improved this to below 0.2 mGal.

One of the main actors in mining in the Skellefte District has been the company Boliden Mineral AB, which commenced gravity measuring as long ago as the 1940s. Data from the surveys carried out by Boliden Mineral AB have largely contributed to the gravity map of the Skellefte District presented here. The map displays the processed Bouguer anomaly with superimposed sample points. Typical sampling distances vary between 0.5 and 5 km. The lowest point density is found over the Gulf of Bothnia and the Caledonides.

The Bouguer anomaly is based upon the following:

Reference field:	IGSN71 (International Gravity Standard Network, 1971)
Normal field:	Gravity formula of 1980
Bouguer density:	2670 kg/m^3
Gravity base	9912.xyz

The data have been processed by using a grid cell size of 400 m × 400 m. Relief impression is created by illumination with solar inclination of 70° and declination of 337.5°. Operational mines and closed mines of size classification 1 and some closed mines of size classification 2 (see Table 4) have been added to the map. A Bouguer anomaly map with resolution lower than on Ba 57:5 is shown in Figure 47.

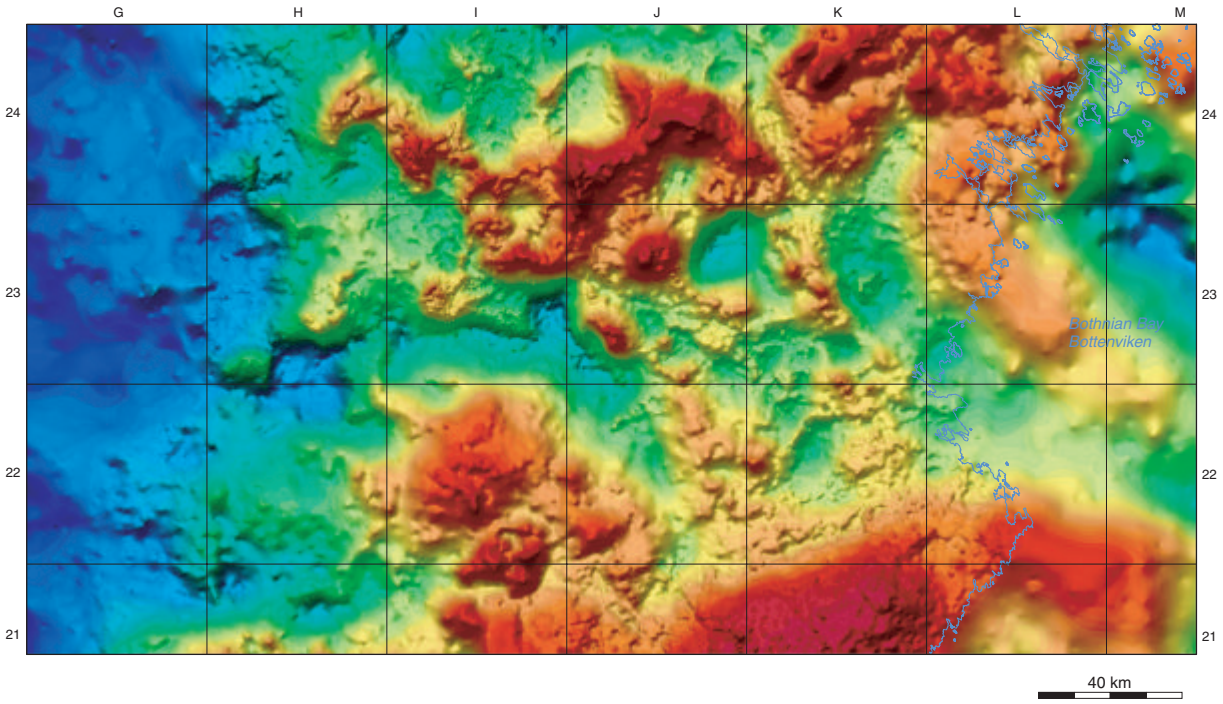


Fig. 47. Bouguer anomaly map of the Skellefte District and surrounding areas. Red: gravity high, blue: gravity low.
Bougueranomalikarta över Skelleftefältet med omnejd. Rött: tyngdkraftsöverskott, blått: tyngdkraftsunderskott.

Explanation to the Gamma radiation map, Electromagnetic map (VLF), topographic relief map and Euler solutions on gravity data

GAMMA RADIATION MAP

In the late 1960s the Geological Survey of Sweden (SGU) started airborne measurements with gamma ray spectrometry. Initially the size of the crystal was 6 litres but was changed to 16.8 litres around 1979. This significantly improved the data quality. In 1995 a 4 litre "up-looking" crystal was added, effectively monitoring variations in radon content and background radiation. These measurements were carried out concordantly with the magnetic field measurements (for details, see above). The data have been processed using a grid cell size of 200 m × 200 m.

The gamma radiation map gives information regarding the content of potassium (K), uranium (U), and thorium (Th) in the uppermost part of the ground, i.e. in the bedrock or in the Quaternary cover. As outcrops are sparse (on average, the bedrock is exposed in less than 4% of the area) the Quarternary cover significantly affects the results. When taking glacial drift into account, however, the composition of the cover reflects the bedrock composition of the region, which is why gamma ray spectrometry data can be used as an aid in bedrock mapping.

The calculations of uranium and thorium content are based on assumed radioactive equilibrium. The relative contents of the three elements in the uppermost part of the ground are presented as a colour composite. Variations in the overall intensity are displayed using shades of grey. Darker shades indicate low values and paler grey represents higher values. A small-scale version of the gamma radiation map (Ba 57:6) is shown in Figure 48.

ELECTROMAGNETIC MAP (VLF)

In 1973 the Geological Survey of Sweden (SGU) commenced airborne measuring of variations in the relative ground conductivity, using its in-house developed radiomagnetic system (RAMA). RAMA was based on the use of VLF (very low frequency) signals, commonly from the Great Britain Rugby (GBR) transmitter. The site of the transmitter largely influenced the results, as conductors more or less parallel with the direction to the transmitter (i.e. south-west) were enhanced, whereas those striking parallel with the inducing magnetic field vector (i.e. north-west) were suppressed.

The electromagnetic measurements were carried out concordantly with the magnetic field measurements (for details, see above). The electromagnetic (VLF) map gives information regarding the relative electric conductivity of the ground through the relative total intensity of the

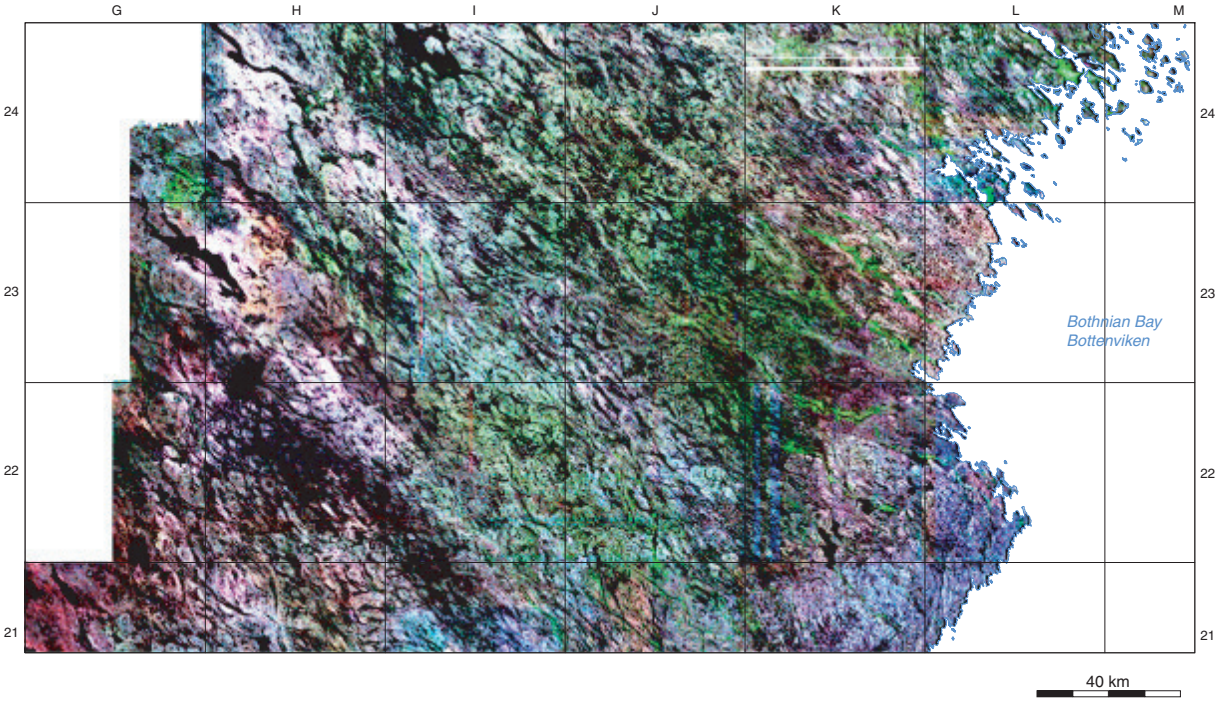


Fig. 48. Gamma radiation map of the Skellefte District and surrounding areas. Red: uranium, blue: thorium, green: potassium.
Gammastrålningskarta över Skelleftefältet med omnejd. Rött: uran, blått: torium, grönt: kalium.

induced secondary electromagnetic field. Direct information on the relative ground conductivity is disturbed by anomalies emanating from civil installations such as high tension lines, fences, railroads etc. which however in most cases are possible to identify by comparison with topographic maps.

The data have been processed using a grid cell size of 50 m × 50 m. The total intensity of the secondary induced electromagnetic field is displayed on the topographic relief of the terrain, which is based on the elevation database with the data density (50 m × 50 m) of the National Land Survey of Sweden. A small-scale version of the electromagnetic map (VLF, Ba 57:6) is shown in Figure 49.

Within the project area, another type of electromagnetic survey (horizontal loop EM or slingram) was also carried out by the Swedish Geological Company (SGAB) using a dual-frequency vertical coaxial coil system for the client NSG (The State Mining Property Commission). However, these measurements cover only small areas.

TOPOGRAPHIC RELIEF MAP

This map shows the altitude variations within the project area. They are shadowed by illumination with source inclination of 60° and source declination of 22.5°. The topographic model is based on the digital elevation database with the data density (50 m × 50 m) of the National Land Survey of Sweden. The data have been processed with a grid cell size of 50 m × 50 m.

EULER SOLUTIONS ON GRAVITY DATA

The Swiss mathematician Leonhard Euler (1707–1783), together with Joseph Louis Lagrange (1736–1813), developed modern mathematics. PC hardware and software development in recent years and the implementation of fast Fourier transform has made it possible to apply some of Euler's theoretical work for practical evaluation of potential field data. Thompson (1982) and Reid et al. (1990) described the theory and present examples of 2D and 3D modelling respectively.

The aim of processing geophysical data is to support two-dimensional geological surface maps with 3D information. Euler deconvolution is a method that provides rapid depth estimates from magnetic, gravity, and modern two-way electromagnetic (VLF) data in grid form, using Euler's homogeneity relation. This type of processing offers unique opportunities to study magnetic and gravity data to elicit objective information strictly correlated to potential fields.

Structural indices, which in this context describe certain geological features (contact/step, sill/dyke, cylinder or pipe, barrel-shaped bodies) by values ranging between 0 and 3, can be optimized in order to provide math-

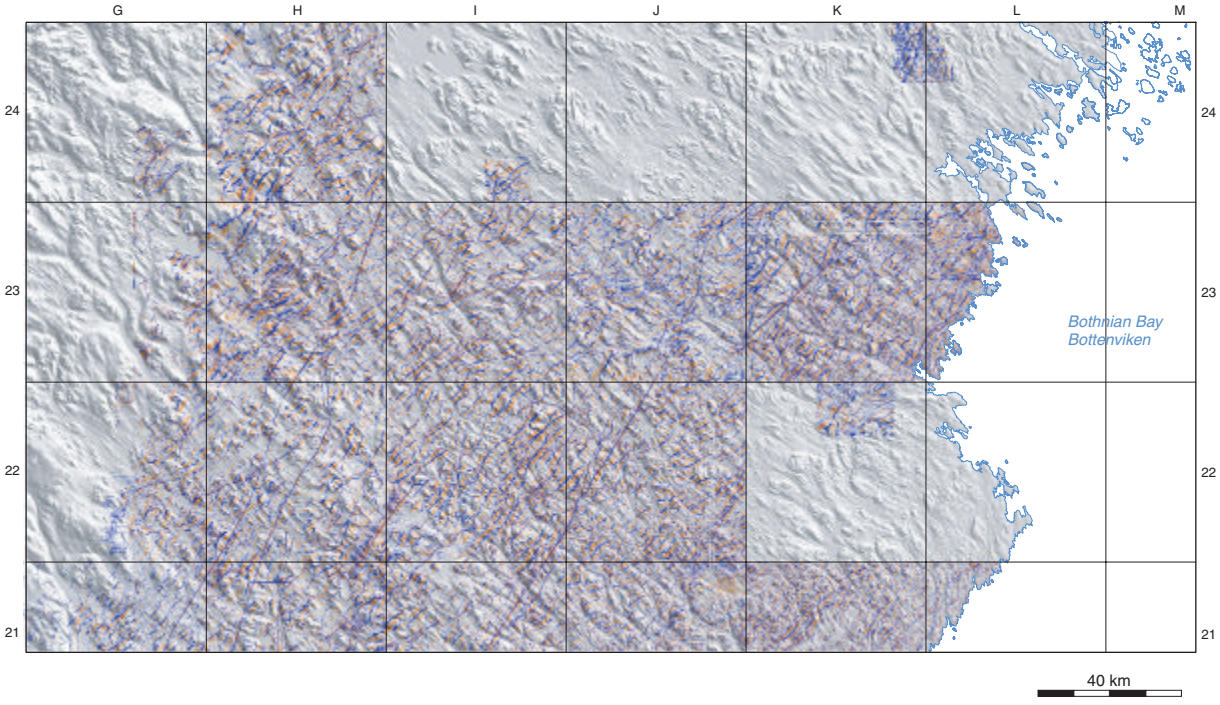


Fig. 49. Electromagnetic map (VLF) of the Skellefte District and surrounding areas. The total intensity of the secondary induced electromagnetic field is displayed on a topographic relief map. Blue: electric conductors.

Elektromagnetisk karta (VLF) över Skelleftefältet med omnejd. Det sekundära inducerade elektromagnetiska totalfältet visas på höjdreliefkartan. Blått: elektriska ledare.

ematically the best fit to various geological situations. The same geological constraints for magnetic and gravity data demand that, in the same algorithm, different structural indices are employed for magnetic and gravity data respectively. "A sill edge, dyke, or fault with a limited throw is best displayed at an index of 1.0, while a fault with large throw is best displayed at a zero index" (Reid et al. 1990). Higher indices give more precise depth estimates, but the gross structural trends can be outlined despite a poor choice of index. "Although the structural index approach to source description does not include irregular boundaries, each solution employs only data within its window, so that irregular sill-like bodies can be well delineated by the Euler method with an index of 1.0, while irregular contacts are well shown with a zero index" (Reid et al. 1990). Briefly, the gravity structural index 0 equates to the magnetic structural index 1, and so on. The indices make it possible to compare the same geological structure with both magnetic and gravity potential fields of the same area. For further information, the interested reader is referred to Reid et al. (1990).

Euler deconvolution is based solely on the geometrical shape of the potential field anomalies and thus knowledge of magnetic properties of rocks such as magnetic susceptibility and magnetic remanence is not necessary for processing. The same applies to gravity field data with respect to density properties.

The excellent magnetic and gravity datasets of the Skellefte District and surrounding areas are highly suitable for Euler deconvolution processing. In order to illustrate the major planar structures near the surface and down to a few kilometres in an objective manner, Euler deconvolution has been used on the relatively dense gravity data of the project area. From the gravity measurements as described on p. 76, a grid of 400 m × 400 m has been created. The window used is 12 × 12 grid points, to create a window of c. 4 km. The chosen limitation of the error of depth is better than 15%. The Euler solutions obtained from gravity data are presented on a map of the magnetic anomaly field. This map has been processed according to the "sandwich method" of Jacobsen (1987). It represents the signal of magnetic sources from the uppermost hundred metres of the bedrock.

Description of key areas

In order to elucidate different types of geological environments, ten areas (Fig. 50) have been chosen to be presented in the form of more detailed geological or geophysical maps and descriptions. The areas *Central Skellefte District*, *Renström–Petiknäs* and *Boliden* host some of the main VMS deposits in subaqueous metavolcanic rocks of the Skellefte Group. The *Hej–Urikberget* area is taken as an example of very well preserved subaerial volcanic rocks of the Arvidsjaur Group. The *Ledfat* area represents a sedimentary succession, related to the volcanic sequences of the Arvidsjaur Group. The bedrock of the *Knaften* area contains the oldest dated Proterozoic rocks in the map area. The *Adak* area has been chosen as an example of the setting of pyrite-dominated zinc-copper sulphide ores and copper breccia or dissemination ores in the western Skellefte District. Special rock types such as magmatic breccias from the contact zone of Archaean and Proterozoic rocks are described in the chapter "The nature of the Archaean–Proterozoic boundary in the Luleå area". The "Krukmakar discontinuity zone" is a seismic zone which is still active.

CENTRAL SKELLEFTE DISTRICT

Volcanic facies in the central part of the Skellefte District

The central part of the Skellefte District (CSD), as defined here, comprises metavolcanic rocks south and west of the Jörn granitoid complex on map sheet 23J Norsjö. In Figure 51 the geological facies of this area is presented. The facies interpretations are taken largely from Allen et al. (1996) with additional new information from the 1:50,000 bedrock mapping of map sheet 23J Norsjö (Bergström et al. 2003).

The metavolcanic rocks of the CSD are bordered to the south by amphibolite grade metagreywackes of the Bothnian Supergroup, the Karsträsk intrusion of Jörn GI type and by felsic and mafic intrusions of the Revsund suite. To the north the CSD is bordered by the Jörn granitoid complex and the Gallejaur intrusion. To the east it grades into the eastern Skellefte District whereas it narrows down to a short strip of mafic volcanic rocks in the west which is continuous into the western Skellefte District. The partly poorly exposed

areas to the west and north of the Gallejaur intrusion are not included here.

Detailed volcanological facies studies have been carried out mainly in the Maurliden, Holmtjärn, and Petikträsk areas. In Figure 52 generalized stratigraphic columns from these areas are presented, all slightly modified from Allen et al. (1996). Besides the work on volcanic facies presented by Allen et al. (1996), results from a PhD thesis by Cecilia Montelius (2005) and co-workers in the Maurliden area is partly included in this brief summary of volcanic facies and stratigraphy of the CSD.

The CSD is important for our understanding of the stratigraphic relationship between the Skellefte Group and the overlying Vargfors Group. Furthermore, the relationship between felsic volcanic centres and volcanic hosted massive sulphide deposits can be studied in detail in the Maurliden and Holmtjärn areas.

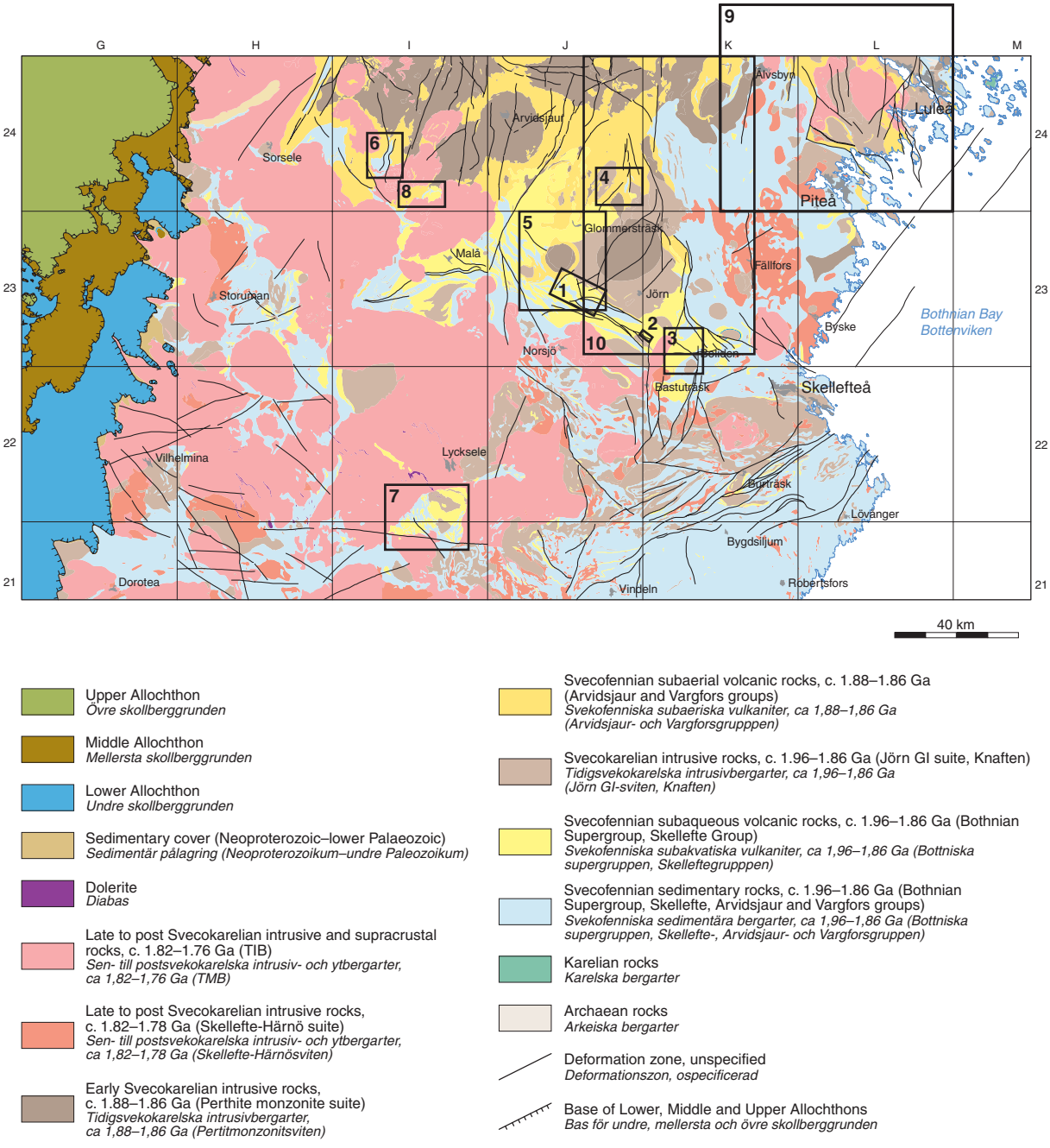
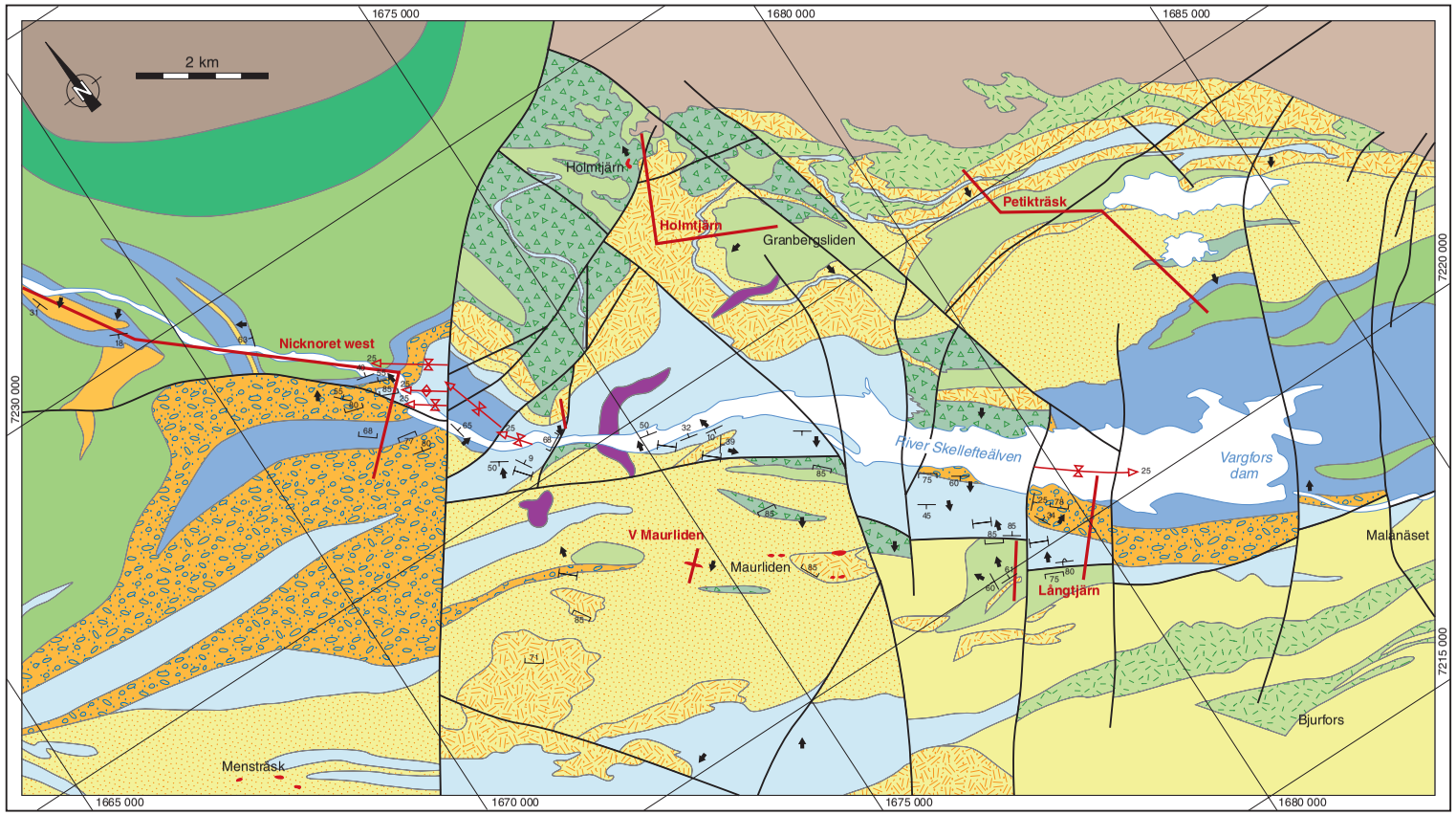


Fig. 50. Simplified bedrock map of the Skellefte District and surrounding areas with locations of key areas: 1) Central Skellefte District, 2) Renström–Petiknäs, 3) Boliden, 4) Hej–Urikberget, 5) Gallejaur–Jörn area, 6) Ledfat, 7) Knaften, 8) Adak, 9) The Archaean–Proterozoic boundary in the Luleå area, 10) The "Krukmakar"discontinuity zone.

Förenklad berggrundskarta över Skelleftefältet med omnejd med nyckelområden: 1) Centrala Skelleftefältet, 2) Renström–Petiknäs, 3) Boliden, 4) Hej–Urikberget, 5) Gallejaur–Jörnområdet, 6) Ledfat, 7) Knaften, 8) Adak, 9) Den arkeisk–proterozoiska gränsen i Luleåområdet, 10) "Krukmakardiskontinuitetszonen".



Vargfors Group, c. 1.88–1.86 Ga
Vargforsgruppen, ca 1,88–1,86 Ga

- Mudstone–turbidite units ± graphitic mudstone
  Lersten–turbiditenheter ± grafitisk lersten
- Rhyolitic–dacitic breccia–conglomerate and coarse-grained sandstone with or without granite or limestone clasts
  Ryolitisk–dacitisk breccia–konglomerat och grovkornig sandsten med eller utan granit eller kalkstensklaster
- Polymict conglomerate with abundant granite clasts
  Polymikt konglomerat med talrika granitklaster
- Basalt–dacite lavas, volcaniclastic sedimentary rocks, sills
  Basalt–dacitlavor, vulkanoklastiska sedimentbergarter, lagergångar
- Rhyolite–dacite lavas and sills
  Ryolit–dacitlavor och lagergångar
- Rhyolite ignimbrite
  Ryolitisk ignimbrit

Skellefte Group, c. 1.90–1.86 Ga
Skelleftegruppen, ca 1,90–1,86 Ga

- Extrusive basalt–andesite: lava, hyaloclastite and stratified to massive clastic units
  Extrusiva basalter–andesiter: lava, hyaloklastit och stratifierade till massiva klastiska enheter
- Basalt–andesite intrusions
  Basalt–andesitintrusioner
- Composite stratified successions of mass flow units interbedded with mudstone, sandstone: mainly syn-eruptive pumiceous, and post-eruptive (reworked) rhyolitic units
  Komplexa stratifierade lagerföljder av massflöden växellagrande med lersten, sandsten: i huvudsak syneruptiva pimpstensenheter och posteruptiva (omlagrade) ryolitiska enheter
- Undifferentiated felsic volcanics
  Odifferentierade felsiska vulkaniter
- Fine grained rhyolite lavas, intrusions and hyaloclastites
  Finkorniga ryolitiska lavor, intrusioner och hyaloklastiter
- Quartz-feldspar porphyritic rhyolitic syn-eruptive pumiceous mass flows
  Kvarts-fältspatporfyriska, ryolitiska, syneruptiva massflöden av pimsten
- Strongly quartz-feldspar and feldspar porphyritic rhyolite intrusions, lavas and hyaloclastites
  Rikligt kvarts-fältspat- och fältspatporfyriska ryolitiska intrusioner, lavor och hyaloklastiter

Intrusive rocks
Intrusivbergarter

- Ultra-mafic intrusions
  Ultramafiska intrusioner
- Syn-volcanic granitoid (Perthite monzonite suite)
  Synvulkanisk granitoid (Pertitmonzonitsviten)
- Syn-volcanic granitoid (Jörn GI suite)
  Synvulkanisk granitoid (Jörn GI-sviten)
- Gabbro, dolerite intrusions
  Gabbro, diabasintrusioner

- Way-up determination
  Uppåtbestämning
- Ore
  Malm
- Fault and shear zone
  Förkastning eller skjuvzon
- Bedding
  Lagring
- Main regional cleavage
  Huvudsaklig regional foliation
- Synform and antiform with plunge
  Synform och antiform med stupning
- Site of stratigraphic column
  Läge för stratigrafisk kolumn

Fig. 51. Bedrock map of the central Skellefte district (modified from Allen et al. 1996). For location of the area, see Fig. 50.
Berggrundskarta över centrala Skellefteområdet (modifierad efter Allen m.fl. 1996). Områdets läge framgår av fig. 50.

Over 20 different volcanic facies have been identified in the Skellefte District. In the CSD, felsic metavolcanic rocks dominate, although some areas like Granbergsliden and Bjurfors host major mafic metavolcanic sequences. The Vargfors Group conglomerates, sandstones, and mafic and felsic volcanic rocks outcrop mainly along river Skellefteälven.

Syn-volcanic, early Svecokarelian granitoids of the Jörn GI suite

The CSD is bordered to the north by the Jörn granitoid complex. The outer, oldest intrusion of this composite batholith (Jörn GI phase), dated at 1888^{+20}_{-14} Ma (Wilson et al. 1987b) and 1898±11 Ma (SGU, unpublished), is roughly coeval with the metavolcanic rocks of the Skellefte Group. The Jörn GI intrusion is heterogeneous and consists of several medium-grained, commonly porphyritic granodioritic to tonalitic intrusions. The prevailing mafic mineral is hornblende, which dominates over biotite. Within the Jörn GI metagranitoids, quartz-feldspar porphyritic high-level intrusions occur as dykes and minor intrusions. These rocks are related to porphyry copper-gold (Cu-Au) deposits (see page 138). It is still not clear whether or not the Jörn GI metagranitoids are intrusive into the Skellefte Group. However, they were exposed and eroded when the Abborrtjärn conglomerate of the Vargfors Group was deposited, c. 1875 Ma, as the latter contains clasts of Jörn GI type.

An important group of rock types in the CSD are the strongly quartz-feldspar and feldspar porphyritic rhyolitic intrusions, domes, and lavas. These rocks appear to be concentrated to proximal parts of felsic volcanic centres and are frequent in the Holmtjärn and Maurliden areas. They contain phenocrysts of quartz and feldspars with sizes from 1 mm to over 1 cm and in varying amounts from a few percent up to 30–35% of the rock volume. Many of these rocks are probably subvolcanic domes and intrusions with hyaloclastic margins. Photographs of this lithofacies are shown in Figures 53a–d.

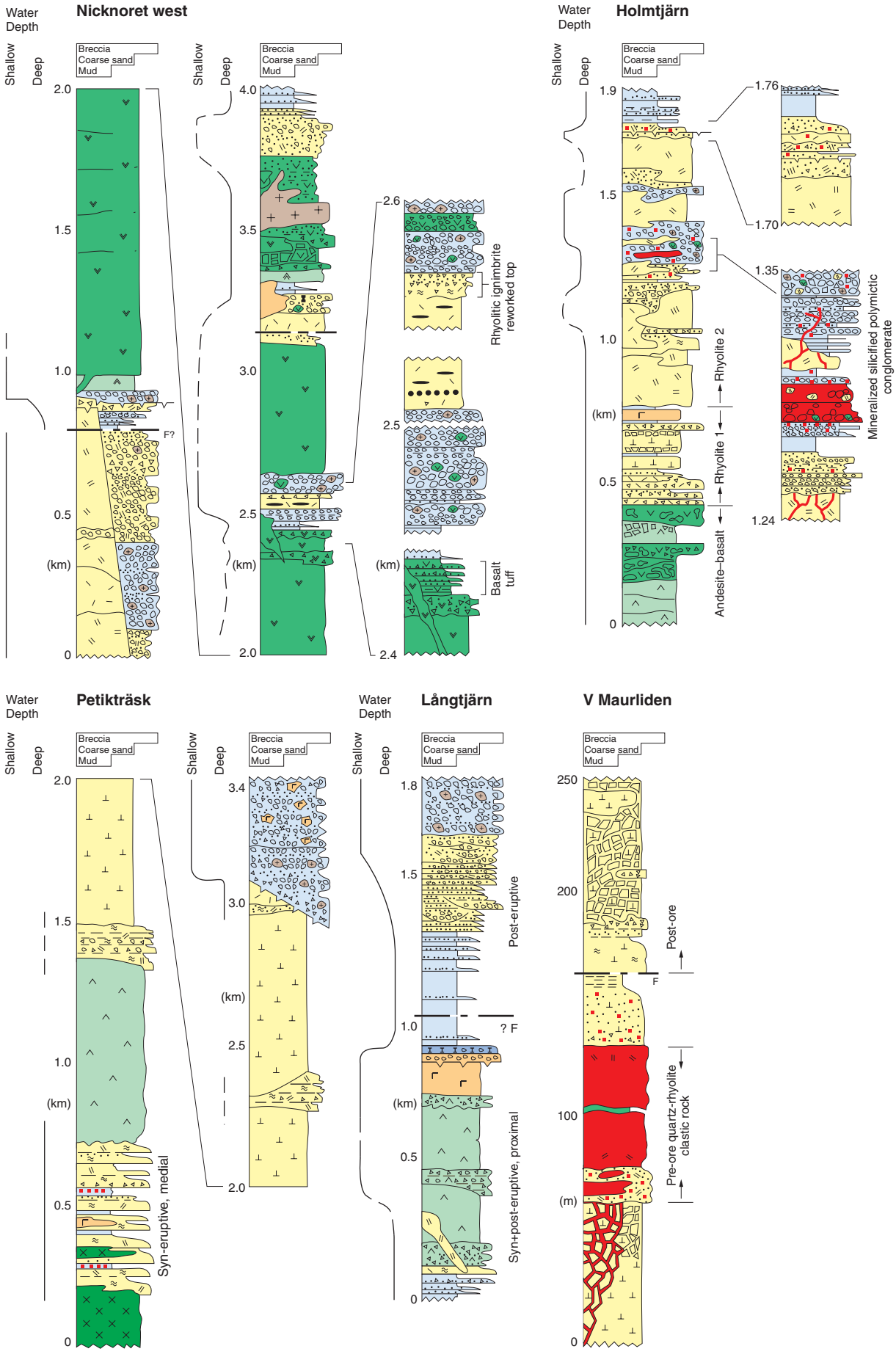
Basaltic to andesitic intrusions and associated extrusive rocks such as lava, hyaloclastite, and stratified to massive clastic units are common in the south central part of CSD in the Malånäset area and at the contact with the Jörn granitoid complex. These rocks are commonly porphyritic. The rocks at Malånäset are in many cases plagioclase porphyritic with up to 1 cm large plagioclase phenocrysts. Some rocks are also hornblende (after pyroxene?) porphyritic. Most of these rocks are interpreted as sill complexes, although contact relationships with adjacent rocks are not always exposed and partly intense deformation in this area obscures primary contact relationships.

The mafic rocks in contact with the Jörn granitoid complex are commonly uralitic hornblende porphyritic. This is a characteristic feature of the mafic rocks of the Vargfors Group, and they are therefore interpreted as belonging to this group. As with the former type, these rocks are interpreted mainly as sill complexes, although extrusive varieties exist.

Quartz-feldspar porphyritic, rhyolitic, syn-eruptive, pumiceous mass flows are associated with the more distal parts of the volcanic centres as products of reworking of the coherent lava and dome facies. Reworking of the volcanic material is common in the CSD. After primary deposition, the hyaloclastic, fragmented parts of the quartz-feldspar-bearing coherent rocks were reworked and emplaced as different types of mass flow deposits. These mass flows are sporadically interbedded with mudstones and sandstones, indicating a more distal source and less volcanic activity in the area of deposition. This facies grades into composite stratified successions of mass flow units interbedded with mudstones and sandstones. Syn-eruptive pumiceous and post-eruptive (reworked) rhyolitic units are found for example in the Holmtjärn area where they form part of the ore-bearing horizon, indicating a different mode of emplacement for the Holmtjärn massive sulphide ore (see below), compared with many other VMS deposits in the Skellefte District. This latter facies is also transitional into the Vargfors Group. A fairly similar facies is common south of Nicknoret towards Mensträsk and comprises rhyolitic to dacitic breccias, conglomerates, and coarse-grained sandstones with or without granitoid or limestone clasts. This unit is important as it manifests the transition from submarine to shallow marine and subaerial conditions in the Skellefte arc at the time of deposition. Within this facies the existence of erratic Jörn GI metagranitoid clasts also indicates that parts of the arc had been emergent and eroded for some time. This facies is also transitional into the Vargfors Group.

Many of the felsic metavolcanic rocks within the Skellefte Group are fine-grained rhyolitic lavas, intrusions, and hyaloclastites. These rocks are aphyric, fine-grained to aphanitic and weather into white for which reason they are sometimes named in the literature as felsite. The composition of these rocks is mainly the same as for the coarse varieties.

Minor units of rhyolitic to dacitic lavas and sills and ignimbritic rhyolites occur in the Vargfors Group. These are fine-grained, locally feldspar porphyritic, pale red to brown. They are distinguished from the Skellefte Group by the red colour and the higher content of potassium (K-feldspar). These rocks were probably deposited either subaerially or in shallow water. The


Nicknoret west
Water Depth
Shallow
Deep
Breccia
Coarse sand
Mud
2.0
1.5
1.0
0.5
(km)
0
F?
4.0
3.5
3.0
2.5
2.0
2.6
2.5
2.4
Rhyolitic ignimbrite reworked top
Basalt tuff
Holmtjärn
1.9
1.5
1.0
0.5
0
1.76
1.70
1.35
1.24
Rhyolite 2
Rhyolite 1
Andesite–basalt
Mineralized silicified polymictic conglomerate
Petikträsk
3.4
3.0
2.5
2.0
Syn-eruptive, medial
Långtjärn
1.8
1.5
1.0
0.5
? F
Post-eruptive
Syn+post-eruptive, proximal
V Maurliden
250
200
100
(m)
F
Post-ore
Pre-ore quartz-rhyolite clastic rock

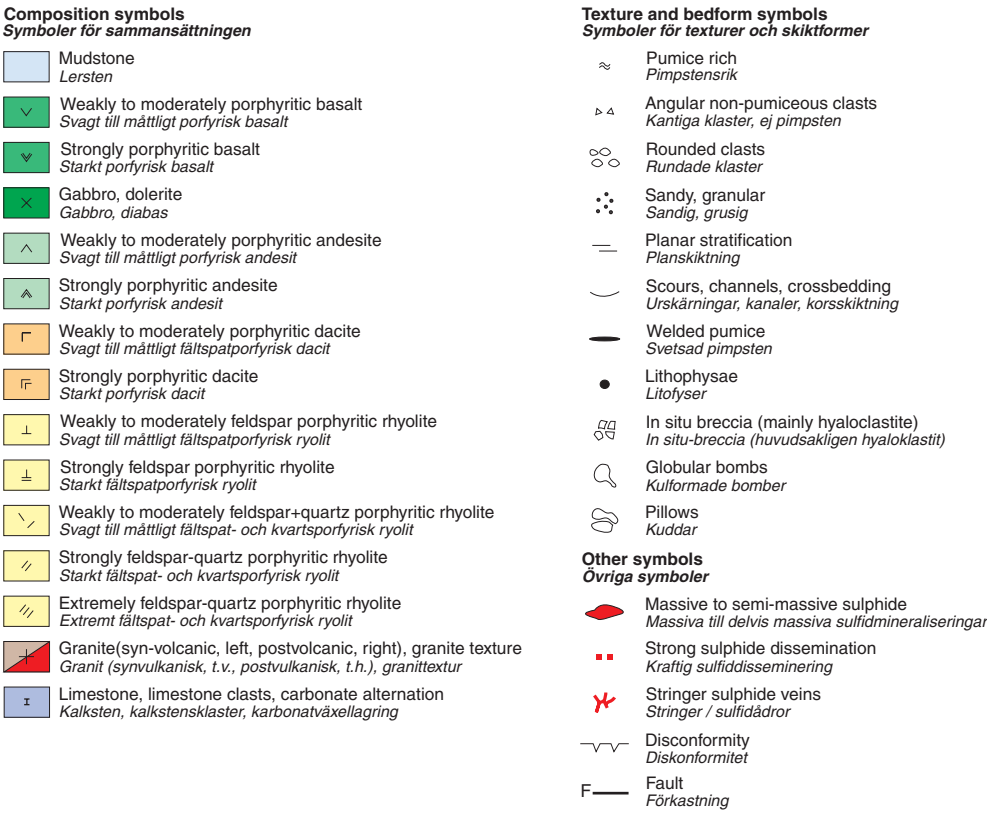


Fig. 52. Generalized stratigraphic columns from Nicknoret, Holmtjärn, W Maurliden, Petikträsk, and Långtjärn. The position of each profile is shown on the map in Fig. 51 (modified from Allen et al. 1996).

Förenklade stratigrafiska kolumner för Nicknoret, Holmtjärn, V. Maurliden, Petikträsk och Långtjärn. Profilernas position visas på kartan i fig. 51 (modifierad efter Allen m.fl. 1996).

depositional environment is interpreted mainly from the rock association of welded ignimbrites and clast-supported granitoid boulder conglomerates. Within the Vargfors Group south of the Gallejaur structure and within the conglomerates below the Vargfors dam, the dominant volcanic rock type is composed of basaltic to dacitic lavas, sills, and volcaniclastic sedimentary rocks. This facies is dominated by coherent uralitic hornblende porphyritic basalts with abundant flow breccias and hyaloclastites. Intercalated polymict conglomerates with abundant metagranitoid clasts (Abborrtjärn type) and clasts of the Arvidsjaur Group volcanic rocks (Dödmanberget type) are a characteristic facies of the Vargfors Group. The metagranitoid clast-bearing conglomerates lie generally stratigraphically below the conglomerates with Arvidsjaur Group clasts and both are exposed in extensive areas east of the Vargfors dam. The Abborrtjärn type is also intercalated with the basaltic lavas along the river Skellefteälven north-west of Nicknoret whereas a few isolated occurrences of the Dödmanberget type occur south of the river Skellefteälven north of lake Mensträsket (7223870/1669270). These conglomerates have been interpreted as deltaic and fluviatile and are again recording the uplift of the arc at the time of their emplacement, c. 1875 Ma.

Gabbroic to dioritic intrusions occur as a marginal facies of the Gallejaur structure. These rocks are probably also largely high-level intrusions. Extrusive varieties occur along the northern contact of the Gallejaur structure. These mafic rocks are related to the Vargfors Group extrusive mafic rocks and, as an intrusive facies, they belong to the Perthite monzonite suite.

Thick units of argillitic turbidite beds, with or without, graphitic mudstone overlie the Skellefte Group metavolcanic rocks and are lateral facies varieties of the coarse epiclastic rocks in the central parts of the CSD. These units show the typical appearance of turbidites with well developed grading, scouring, and load casts. Bouma sequences are commonly discernible. Similar rocks are found at lower stratigraphic levels and were deposited during periods of low volcanic activity. In the CSD, the units overlying the metavolcanic units of the Skellefte Group are incorporated into the Vargfors Group, as they are lateral facies equivalents of the coarse clastic rocks of the Vargfors Group and also continuous with the turbidite facies of the Bothnian



Fig. 53. **A**. Volcanic breccia from the Maurliden area with clasts of coherent feldspar porphyry. **B**. Coherent quartz feldspar porphyry north-west of Önusberget. **C**. Peperitic contact between intrusive quartz-feldspar porphyry and siltstone, from the Finnliden area. **D**. Extremely crystal-rich (quartz and feldspar) volcanic sandstone from the Bjurträsk area. Photo Pär Weihed.

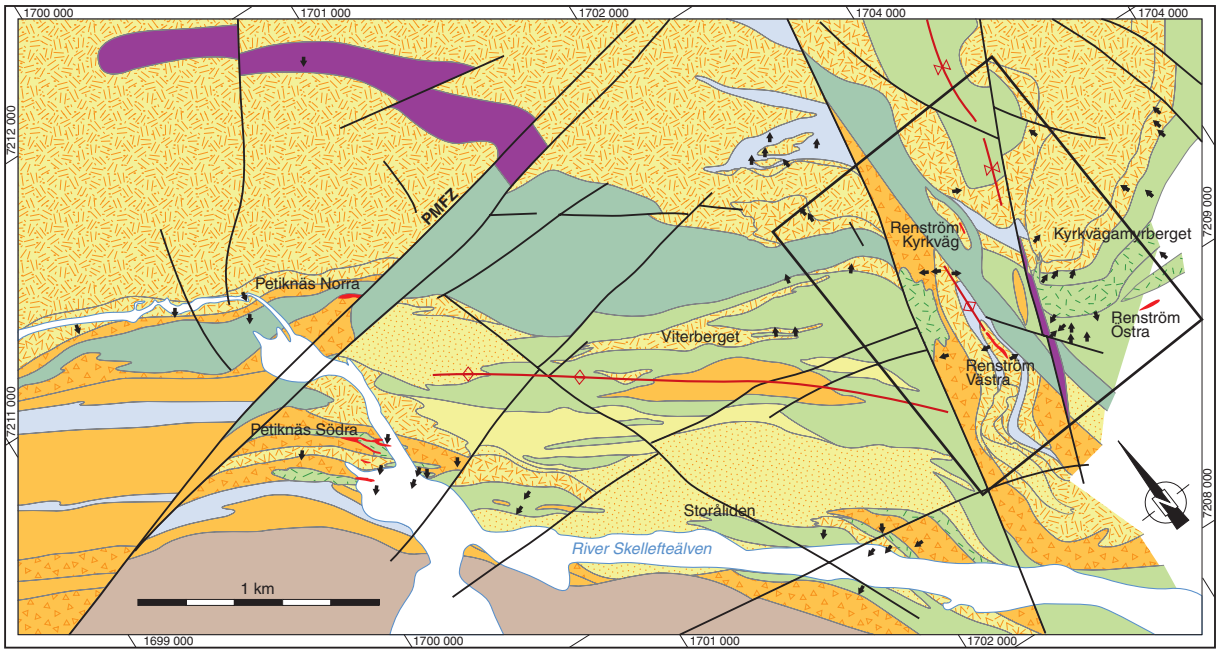
***A**. Vulkanisk breccia från Maurliden med fragment av koherent fältspatporfyr. **B**. Koherent kvarts-fältspatporfyr nordväst om Önusberget. **C**. Peperitisk kontakt mellan intrusiv kvarts-fältspatporfyr och siltsten, från Finnliden. **D**. Mycket kristallrik (kvarts, fältspat) vulkanisk sandsten från Bjurträskområdet.*

Supergroup to the south. However, the units intercalated with the Skellefte Group metavolcanic rocks are assigned to the Skellefte Group as they merely record interruptions in the volcanic activity.

Three separate minor ultramafic intrusions occur east of Nicknoret. They seem to crosscut most units and are therefore interpreted as a young intrusive phase although no age determination is available for these rocks. Minor high magnesium ultramafic sill complexes occur in the turbiditic rocks south of the river Skellefteälven between the Vargfors dam and Maurliden. The relationship between these and the intrusions is obscure.

RENSTRÖM–PETIKNÄS

The bedrock of the Renström–Petiknäs area consists of an extremely variable sequence of supracrustal, predominantly metavolcanic rocks (Fig. 54). Depositional units have a very limited lateral extension and the local stratigraphy is complicated and laterally variable. The depositional sequence is furthermore disrupted by numerous shear zones and faults. The rocks probably represent a low stratigraphic level of the Skellefte Group and were mostly emplaced in a subaqueous, proximal volcanic environment (cf. Allen et al. 1996). Duckworth (1991) and Duckworth & Rickard (1993) stated that the area has undergone amphibolite facies metamorphism and then been retrogressed to greenschist facies assemblages. Despite this alleged medium-grade metamorphic overprint, primary textures are locally very well preserved and allowed Allen et al. (1996) to perform surprisingly detailed volcanological and sedimentological interpretations, even in hydrothermally altered rocks.



Skellefte Group, c. 1.90–1.86 Ga
Skelleftegruppen, ca 1,90–1,86 Ga

- Mudstone–turbidite units ± graphitic mudstone
  Lersten–turbiditenheter ± grafitisk lersten
- Younger dacite–andesite intrusions
  Yngre dacit–andesitintrusioner
- Moderately to strongly feldspar porphyritic, older dacite intrusions
  Medel- till rikligt fältspatporfyriska äldre intrusioner
- Extrusive basalt–andesite: lava, hyaloclastite and stratified to massive clastic units
  Extrusiva basalter–andesiter: lava, hyaloklastit och stratifierade till massiva klastiska enheter
- Basalt–andesite intrusions
  Basalt–andesitintrusioner
- Mainly syn-eruptive pumiceous and post-eruptive (reworked) rhyolitic mass flow units
  Dominerande syneruptiva pimpstens- och posteruptiva (omlagrade) ryolitiska massflödesenheter
- Feldspar-porphyritic dacitic (±low silica rhyolite, silicic andesite) syn-eruptive pumiceous mass flows ± reworked volcaniclastic rocks
  Fältspatporfyriska, dacitiska (±lågkiselryolit, kiselrik andesit) syneruptiva pimpstensmassflöden ± omlagrade vulkanoklastiter
- Fine-grained rhyolite lavas, intrusions and hyaloclastites
  Finkorniga ryolitiska lavor, intrusioner och hyaloklastiter
- Quartz-feldspar porphyritic rhyolitic syn-eruptive pumiceous mass flows
  Kvarts-fältspatporfyriska, ryolitiska, syneruptiva massflöden av pimsten
- Strongly quartz-feldspar and feldspar porphyritic rhyolite intrusions, lavas and hyaloclastites
  Rikligt kvarts-fältspat- och fältspatporfyriska ryolitiska intrusioner, lavor och hyaloklastiter

Intrusive rocks
Intrusivbergarter

- Ultramafic intrusions
  Ultramafiska intrusioner
- Syn-volcanic granitoid (Jörn GI suite)
  Synvulkanisk granitoid (Jörn GI-sviten)
- Way-up determination
  Uppåtbestämning
- Ore
  Malm
- Fault and shear zone
  Förkastning eller skjuvzon
- Synform and antiform
  Synform och antiform

Fig. 54. Bedrock map of the Petiknäs–Renström area (modifed from Allen et al. 1996). For location of the area, see Fig. 50. Detailed map of the Renström area, shown in Fig. 80B, is indicated.

Berggrundskarta över Petiknäs–Renströmområdets (modifierad från Allen m.fl. 1996). Områdets läge framgår av fig. 50. Detaljkarta över Renström som visas i fig. 80B är markerad.

The presentation below is based on results of the bedrock mapping programme in the area conducted by SGU (Lundström & Antal 2000) and a compilation of publications by Helfrich (1971), Duckworth (1991), Duckworth & Rickard (1993), Allen et al. (1996), Bergman Weihed (1997), and Nordin et al. (1997).

General geology

In the western part of the area, the main rock units and local foliation strike west-northwest–east-southeast and dip subvertically, probably due to an overall transposition into a major shear zone along the river Skellefteälven. Just east of the Renström mine (Renström Västra), this regional trend is abruptly cut by a north–south striking, more brittle shear zone, east of which the same rock units and foliations strike north–south. Folding is evident only on the mesoscopic scale and the fold axes are parallel to a system of subvertical stretching lineations and boudin axes (Duckworth 1991).

The main rock types in the area are:

(1) Mostly quartz porphyritic rhyolitic lavas, intrusions, and hyaloclastites. These make up most of the Storåliden hill and become successively more sheared towards the river Skellefteälven. Along the Petiknäs road and on the bank of the river Skellefteälven, the

Storåliden quartz porphyry shows a patchy sericite-biotite alteration, grading into a jigsaw fit pattern, suggesting hydrothermal brecciation.

(2) Basaltic–andesitic extrusive rocks, mostly lavas and hyaloclastites, but also stratified clastic units. These units are poorly exposed, but thought by Nordin et al. (1997) to form the footwall sequence of the Renström and Kyrkväg ore bodies.

(3) Dacitic shallow intrusive, homogeneous rock with euhedral plagioclase phenocrysts between Petiknäs and Renström. This unit also extends east of the Renström shear zone, where it was recorded by Nordin et al. (1997) as post-dating the folding.

(4) Quartz-feldspar porphyritic rhyolitic coherent and hyaloclastic rocks north-west of Renström and north of Petiknäs. At Viterberget hill, this rock is beautifully flow-banded and associated with a subaqueous mass flow unit containing clasts of the rhyolite and rip-up clasts of metasedimentary rocks, deposited during ambient sedimentation (see Fig. 19a). A similar, coherent, rhyolitic unit occurs also east of the shear zone, at Kyrkvägamyrberget hill.

These rock types are thus dominated by dacitic to rhyolitic, mostly coherent, and consequently proximal metavolcanic rocks. According to Duckworth (1991), welding, ripples, and accretionary lapilli have been found, indicating rather shallow-water deposition and even subaerial eruptions. However, Allen et al. (1996) suggested a predominance of deep-water depositional environments, probably due to a predominance of graded, planar bedding. Apparently, the depositional environments changed very quickly, probably in response to local horst and graben tectonics in a volcanic landscape.

Structural geology

Folding is not evident in the area, probably due to an overprint by later, penetrative shearing movements, which transposed earlier folds in the direction of the vertical stretching lineations.

Strain increases from north to south, i.e. towards the river Skellefteälven, and the river valley follows a west-northwest–east-southeast striking, steeply dipping high-strain zone, which can be observed both on the slopes of the Storåliden hill north of the river and underground in the Renström Västra and Petiknäs Norra and Södra mines. Vertical stretching lineations are ubiquitous and kinematic indicators show northern side up at least north of the river. Thus, dip-slip movements seem to have predominated, but Bergman Weihed (1997) also reported sinistral sense of movement on dip-slip surfaces south of Kusfors (7210670/1697870). This southward strain increase apparently fits into a regional pattern, demonstrated by Bergman Weihed (1997) and Lundström & Antal (2000). South of the river, however, kinematic indicators show southern side up movements.

The north–south striking shear zone or fault, which separates the Renström mine area from the western part of the area, is steep and weak c-s fabrics indicate eastern side up movements according to Wanhainen (1997). From regional geologic evidence, Bergman Weihed (1997) concluded that this zone is younger than the above-mentioned west-northwest–east-southeast striking zone along the river Skellefteälven.

A third, topographically well marked deformation zone, the Petiknäs Main Fracture Zone (PMFZ), strikes east-northeast–west-southwest north of Petiknäs. It disrupts the rock units very abruptly and most probably dips moderately to the south. According to Bergman Weihed (1997), it is associated with a sharply bounded clay zone in the Petiknäs Norra mine, indicating that the deformation is brittle, at least in part.

BOLIDEN

The Boliden area is built up of rocks belonging to the Skellefte and Bothnian Groups which are folded into an anticline with a north-east–south-west striking axial trace (Fig. 55). A coarse quartz-feldspar porphyritic, rhyodacitic subvolcanic rock from the core of the anticline was dated at 1884±6 Ma (Billström & Weihed 1996), which is one of the oldest ages found so far among Skellefte Group rocks. The host rock of the Boliden ore is a feldspar porphyritic subvolcanic dacite at the stratigraphic top of the Skellefte Group, which was found to have an age of 1869±15 Ma with the Kober technique (Bergman Weihed et al. 1996). As this is the youngest age recorded so far for the Skellefte Group, the Boliden area seems to contain a rather complete stratigraphic section through the Skellefte Group. On the limbs of the anticline, the Skellefte Group metavolcanic rocks are overlain by volcanic sandstones and sedimentary rocks belonging to the Bothnian Supergroup. The anticline is truncated towards the north-east by a north-west striking, probably ductile deformation zone and by a rather more brittle, north–south striking deformation zone in the west (see Fig. 55, Lundström & Antal 2000). The south-eastern part of the area, shown in Figure 55, has been metamorphosed to lower amphibolite facies whereas the remainder has been altered to greenschist facies.

The description of the Boliden area presented here is based mainly on the results from bedrock mapping by SGU (Lundström & Antal 2000) and on publications by Allen et al. (1996), Bergman Weihed et al. (1996), and Billström & Weihed (1996). These papers also con-

tain many further references regarding the Boliden ore deposit (see also page 131).

General geology

In the Boliden area, the rocks of the Skellefte Group are clearly dominated by dacitic compositions, whereas rhyolites are less common (Allen et al. 1996). Bergman Weihed et al. (1996) stated that they are typically calc-alkaline rocks. Coherent, probably subvolcanic units dominate, locally showing peperitic contacts towards surrounding metavolcaniclastic or metasedimentary rocks. The volcaniclastic rocks are partly pumiceous, pyroclastic massflow deposits, partly volcanic breccias and more or less resedimented, polymict, but mostly rather juvenile volcanic conglomerates. The pumiceous clasts indicate shallow-water eruptive environments and the volcanic debris of the volcaniclastic rocks suggests that the volcanic rocks were in a position to be eroded already during the emplacement of the Skellefte Group. However, there are planar bedded mudstone interlayers, indicating that calm basin environments also persisted.

Basaltic–andesitic rocks that have intruded the felsic volcanic rocks close to Boliden mine are associated with rare extrusive equivalents. Furthermore, a number of narrow mafic sills have intruded all metavolcanic rock types close to the Boliden mine area.

The sedimentary rocks of the Bothnian Supergroup clearly superpose the Skellefte Group rocks on the limbs of the anticline. Due to numerous exploration drill holes from the Boliden mine, the contact relations are particularly well known around the mine area and are well demonstrated by stratigraphic columns in Allen et al. (1996). Because volcanic debris (see Fig. 18) is common in the lower parts of the Bothnian Supergroup, volcanic rocks must have been in a position to be eroded or to produce volcanic debris when deposition of the Bothnian Supergroup started in this area. Allen et al. (1996) therefore concluded that the contact between the Vargfors and Skellefte Groups is disconformable. However, the intrusive dacite hosting the Boliden ore was also said by Bergman Weihed et al. (1996) to show peperitic contacts against the Bothnian Supergroup rocks. Consequently, the disconformity cannot represent a very long period of time.

The base of the Bothnian Supergroup sedimentary rocks in the Boliden area consists of a graphitic mudstone, which is overlain by fine-grained sand- and mudstones with local interbeds of volcaniclastic mass flow deposits. The overlying, major part of the Bothnian Supergroup consists of turbiditic greywackes with local interbeds of graphitic mudstones.

Two massifs of intrusive rock occur in the Boliden area (see Fig. 55). South of Boliden mine, a coarsely feldspar porphyritic granite occurs south of Bjurliden (7201710/1716740). Macroscopically, it is very similar to the late to post Svecokarelian Revsund granites, but its composition is more similar to what is common among early Svecokarelian calc-alkaline, Jörn GI type metagranitoids. Another coarsely feldspar porphyritic granite is situated in the westernmost part of the area (Fig. 55). On its western side, it clearly crosscuts ductile deformation and therefore most probably belongs to the Revsund suite.

Structural geology, metamorphism

The anticlinal structure is dominated by a steeply dipping, east-northeast striking axial planar cleavage (see Fig. 19c) and the corresponding fold axis plunges moderately to the east. Greenschist facies minerals are commonly associated with this cleavage which, in the Boliden mine, bends into a sinistral shear zone with an east-plunging stretching lineation. This shear zone is consequently younger than the anticline and indicates that the northern side has moved obliquely upwards and to the west. In the mine area, these structures and greenschist facies parageneses are locally overprinted by lower amphibolite facies minerals such as epidote, calcite-actinolite and andalusite, which are, however, retrogressed to greenschist facies assemblages in some places (Bergman Weihed et al. 1996). A monazite from the alteration zone of the Boliden ore was dated at 1852±3.5 Ma by Bergman Weihed et al. (1996). As the monazite occurred together with andalusite, this may well be the age of the amphibolite facies metamorphism. The amphibolite facies parageneses are constricted to the area south-east of lakes Bjurvattnet, Gillervattnet, and Bastuträsket (Lundström & Antal 2000) and are locally overprinted by a north-east striking axial planar crenulation cleavage.

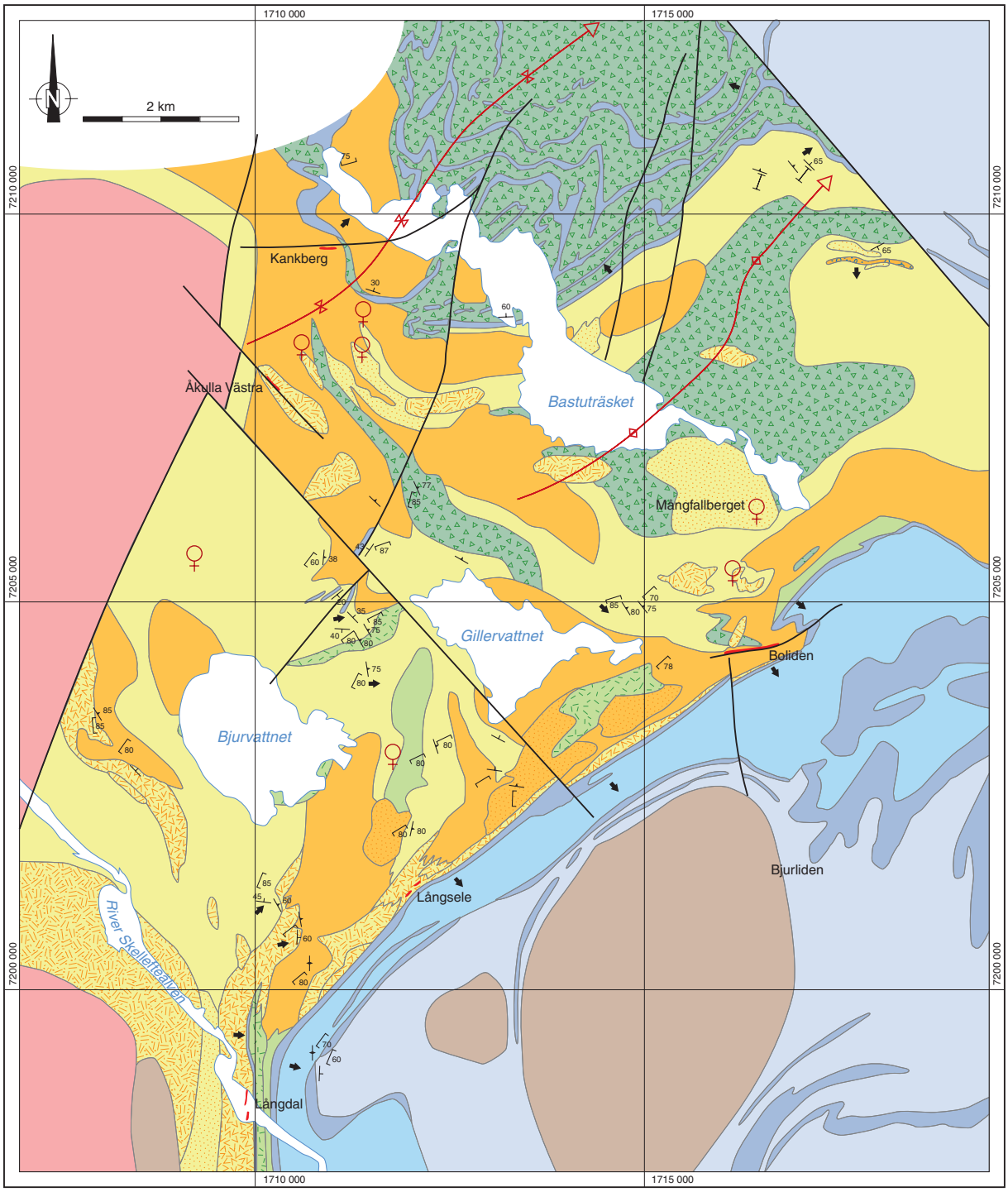
Synvolcanic alteration and ores

Chlorite and sericite alterations are common in restricted zones, particularly close to major ore bodies (Ödman 1941, Nilsson 1968) and actinolite locally occurs in small patches and veins (Lundström & Antal 2000). Locally, these alterations clearly overprint the precursor rocks in a jigsaw fit pattern.

In the Boliden mine, the ore zone with an outer chlorite aureole and an inner, andalusite-rich sericite aureole follows the sinistral shear zone, mentioned above. This shear zone also cross-cuts the local, ore-hosting rock. Outside the shear zone, the host rocks

are commonly recognizable as coherent, feldspar porphyritic dacite, which is intruded by basalts and rhyolites. Both the character of the host rocks and the cross-cutting behaviour of the ore zone thus demonstrate that the ore must have been formed by epigenetic processes before c. 1852 Ma (Bergman Weihed et al. 1996).

The Långsele ore body is also present at a high stratigraphic level within the Skellefte Group rocks. This ore body is, however, hosted by a pumiceous pyroclastic mass flow deposit. As this unit must have been emplaced too rapidly to allow syngenetic ore formation, this ore was also interpreted by Allen et al. (1996) to have formed by subsurface replacement or infiltration. The Åkulla Västra and Kankberg ore bodies are not described in the literature, but occur in an area with abundant subvolcanic dacitic and rhyolitic intrusions. At Mångfallberget a small occurrence of pyrite, tetrahedrite, and gold is found within an andalusite-rich sericite-chlorite alteration aureole, similar to the alteration aureoles around the



Boliden ore. The Mångfallberget occurrence is described by Grip & Ödman (1942).

HEJ–URIKBERGET

The bedrock in the Hej area in northern Västerbotten County consists mainly of felsic and subordinate mafic volcanic rocks, here called the Hej volcanic rocks, and some intraformational epiclastic units (Fig. 56). These rocks belong to the Arvidsjaur Group and occur in a synform with north-northeast striking axial surface. This is situated close to the transition zone between the subaqueous and the subaerial volcanic successions of the Skellefte and Arvidsjaur Groups, respectively. The synform is underlain and flanked by metagranitoids of the Jörn GI suite and volcanic rocks of the Skellefte Group. The Jörn GI suite was dated (U-Pb, zircon) about 30 km south-southwest of the Hej area at 1888^{+20}_{-14} Ma (Wilson 1987b) and 1898±11 Ma (SGU, unpublished).

The Hej volcanic rocks comprise rhyolitic to dacitic, quartz or feldspar porphyritic lavas and volcaniclastic rocks, including a rhyolitic crystal tuff, intermediate plagioclase porphyritic rocks and volcanic breccias (Fig. 57a), rhyolitic ash-fall tuffs (Fig. 57b), and non-welded and welded, typically purple ignimbrites (Fig. 57c). The ash-fall tuffs and the ignimbrites are considered to form a 400–500 m thick compound cooling unit, emplaced in an intra-caldera setting (Rapp 1996).

Intercalations of epiclastic sedimentary rocks, mainly polymict conglomerates and subordinate impure sandstones, occur at several stratigraphic levels within the volcanic succession. The most extensive of these conglomerate lenses, here referred to as the Urikberget conglomerate, has a north–south extension of more than 5 km and a thickness of 200–400 m. It is composed of several, steeply dipping and westerly younging, unstratified and poorly sorted beds on the one hand and distinctly layered beds on the other hand.

The clasts range from 1 to 50 cm in size and are mostly well rounded to rounded, with marked sphericity. They consist of metagranodiorites and metatonalites of the Jörn GI suite and of lavas and lithified volcaniclastic rocks, mainly of the Arvidsjaur Group. A metagranodiorite clast of Jörn GI type from the Urikberget con-

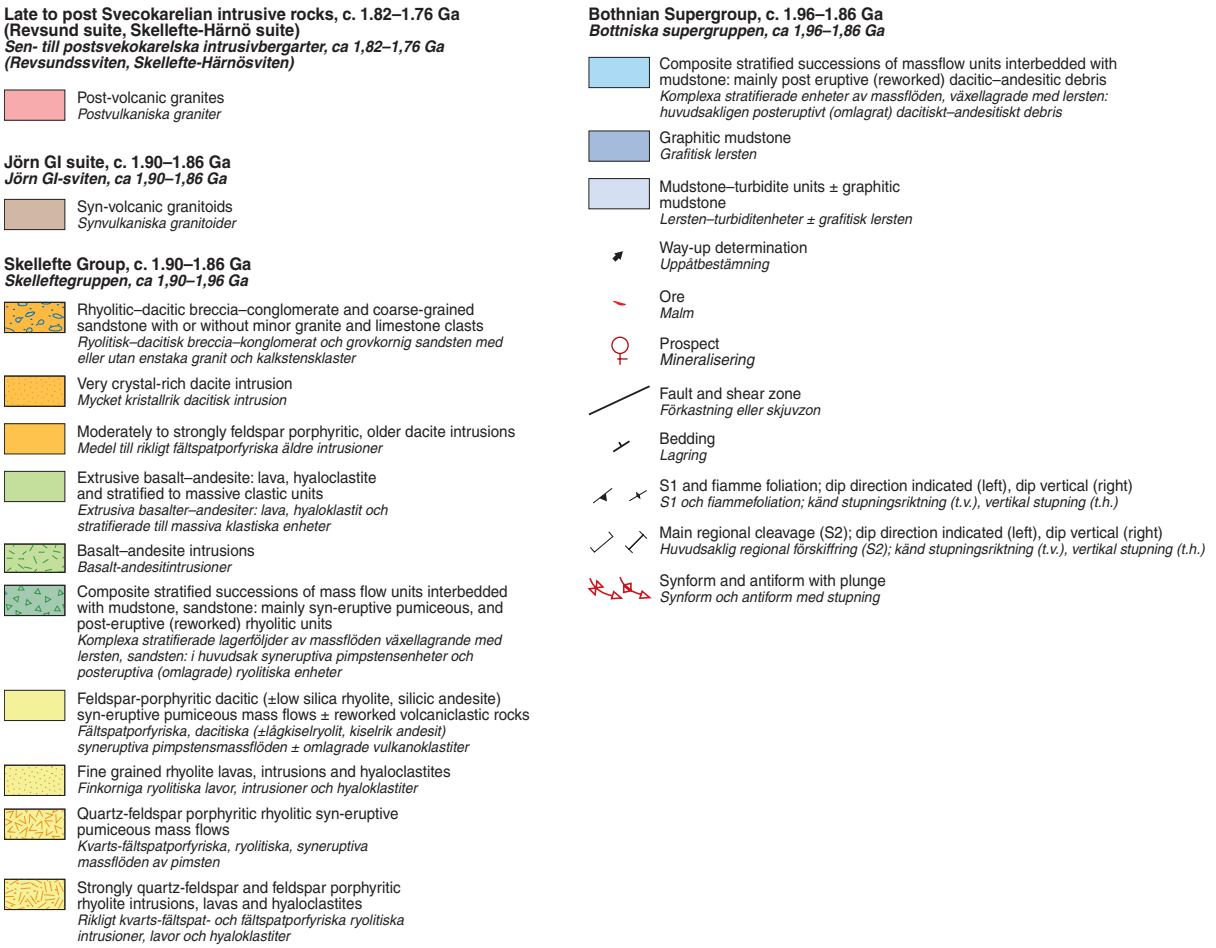


Fig. 55. Bedrock map of the Boliden area (modified from Allen et al. 1996). For location of the area, see Fig. 50.
Berggrundskarta över Bolidenområdet (modifierad efter Allen m.fl. 1996). Områdets läge framgår av fig. 50.

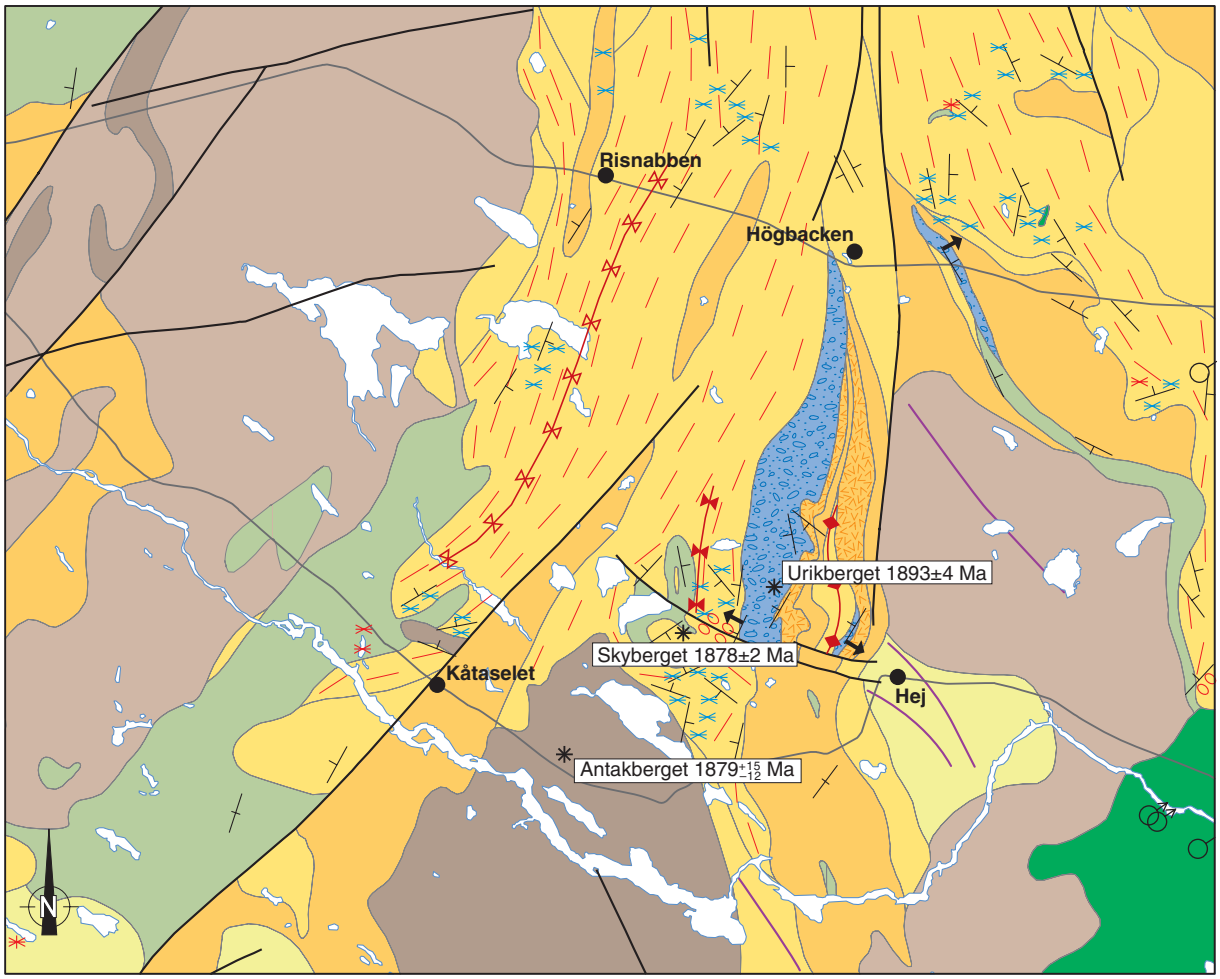


Fig. 56. Bedrock map of the Hej–Urikberget area. For location of the area, see Fig. 50.

Berggrundskarta över Hej–Urikbergsområdet. Områdets läge framgår av fig. 50.

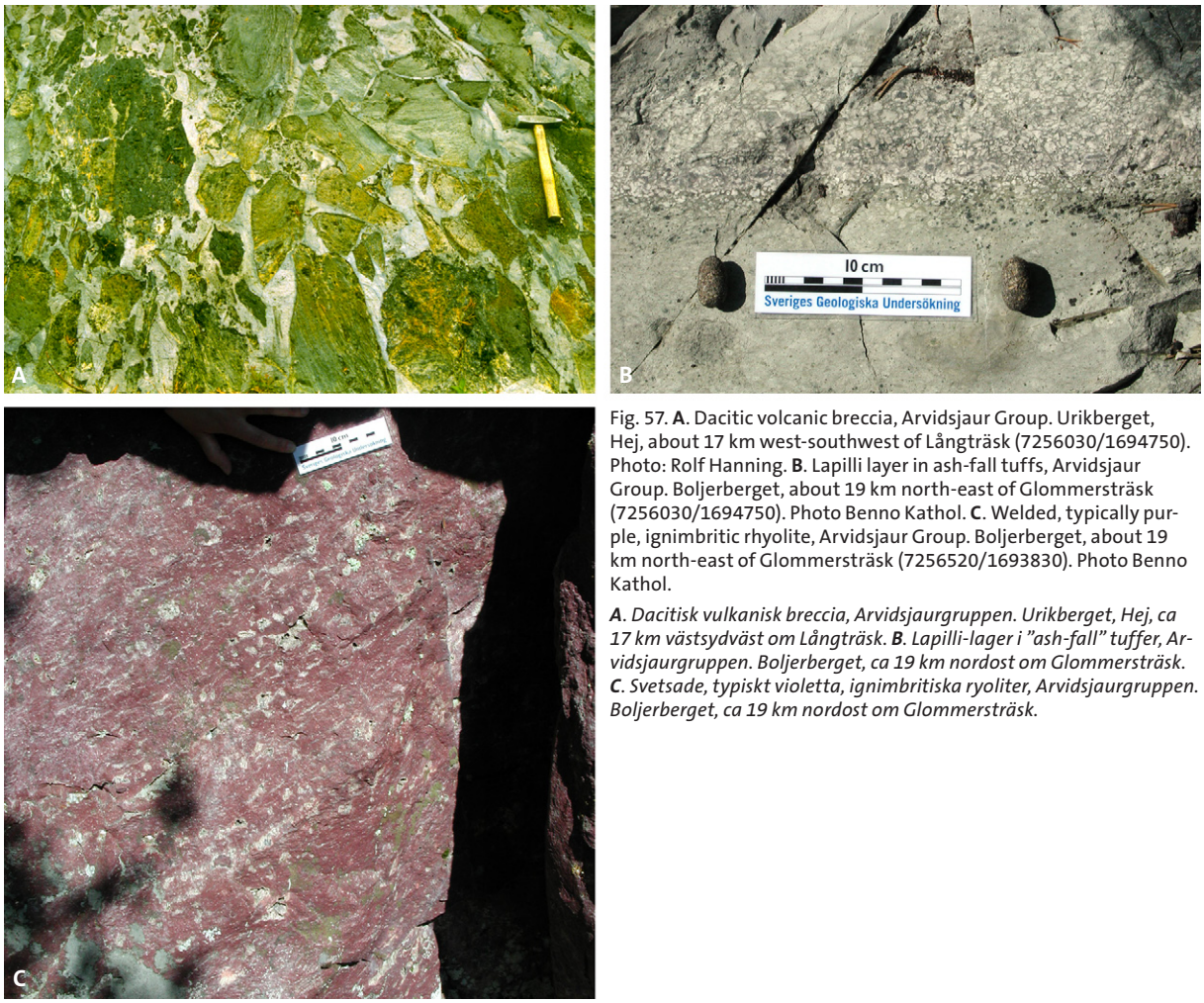


Fig. 57. **A**. Dacitic volcanic breccia, Arvidsjaur Group. Urikberget, Hej, about 17 km west-southwest of Långträsk (7256030/1694750). Photo: Rolf Hanning. **B**. Lapilli layer in ash-fall tuffs, Arvidsjaur Group. Boljerberget, about 19 km north-east of Glommersträsk (7256030/1694750). Photo Benno Kathol. **C**. Welded, typically purple, ignimbritic rhyolite, Arvidsjaur Group. Boljerberget, about 19 km north-east of Glommersträsk (7256520/1693830). Photo Benno Kathol.

***A**. Dacitisk vulkanisk breccia, Arvidsjaurgruppen. Urikberget, Hej, ca 17 km västsydväst om Långträsk. **B**. Lapilli-lager i "ash-fall" tuffer, Arvidsjaurgruppen. Boljerberget, ca 19 km nordost om Glommersträsk. **C**. Svetsade, typiskt violetta, ignimbritiska ryoliter, Arvidsjaurgruppen. Boljerberget, ca 19 km nordost om Glommersträsk.*

glomerate has been dated at 1893±4 Ma (U-Pb zircon, SGU unpublished). The metagranodiorite clasts show a weak penetrative foliation, which pre-dates the deposition of the conglomerate.

Due to the lack of argillaceous material in the matrix, the occurrence of thick, unstratified units, and its inner framework, this conglomerate is considered to represent the result of mass flows initiated by slope wasting in alluvial areas, with relatively high relief and unweathered volcanic rocks.

Emplacement of the Hej volcanic rocks in a subaerial environment is indicated by the occurrence of eutaxitic textures, lithophysae, fiamme, and welding within the rhyolitic ignimbrites, as well as by the red colours of most of the felsic rocks. Further indirect evidence of the subaerial nature of the Hej volcanic rocks is given by the occurrence of drying cracks within an intercalated sandstone lens in the ash-fall tuffs and the intraformational occurrence of the Urikberget conglomerate.

The metamorphic grade within the Hej volcanic rocks does not exceed lower greenschist facies and therefore primary textures are well preserved, apart from epidote alteration of feldspar phenocrysts and epidote growth within lithophysae.

In the eastern part of the Hej area, the volcanic rocks dip at moderate angles to the west and north-west, and minor overturned limbs indicate a deformation style with tight to isoclinal folds with vergence to the east and south-east. However, no foliation related to these folds has been observed. In the western part, the Hej volcanic rocks dip steeply to the east and south-east. In general, the Hej volcanic rocks lie right-way-up with the purple, welded ignimbrite at the top of the succession, occupying the core of the major synform.

The Hej volcanic rocks are intruded by the even-grained, fine- to medium-grained, light red to red Antak granite in the south-central parts. By geophysical modelling, the thickness of the elliptical Antak intrusion (c. 5 × 8 km) is estimated to be between 200 and 700 metres at the present erosion level. The intrusive contact relationship between the Antak granite and the volcanic rocks has only been observed directly in one locality, but on a map scale the granite contact cuts the bedding trends within the Hej volcanic rocks, confirming

the intrusive relationship. Furthermore, a granitic dyke, which is cogenetic with the Antak intrusion, based on REE and trace element composition, cuts the bedding perpendicularly in the Urikberget conglomerate.

A comagmatic origin of the Antak granite and the ignimbrites and rhyolites of the Hej area is indicated by REE and the trace element patterns of these rocks (Kathol & Rapp 1996). Their coeval origin is also supported by a zircon U-Pb dating of the Antak granite which yielded an age of 1879^{+15}_{-12} Ma (Kathol & Persson 1997) which is comparable to the 1878±2 Ma age of the rhyolitic ignimbrites at Skyberget (Skiöld et al. 1993). The Antak granite is therefore considered to have crystallized at a shallow level within comagmatic extrusive phases. The granite itself probably represents the position of the eruptive centre of the rhyolitic parts of the Hej volcanic rocks.

The above cited radiometric datings and field relationships constrain the time interval for intrusion, deformation and uplift, as well as the erosion of metagranitoids of the Jörn GI suite and the deposition of the Hej volcanic rocks and the Urikberget conglomerate to the interval 1893 to 1878 Ma or, taking the errors into account, 1897 to 1876 Ma.

THE GALLEJAUR AND JÖRN INTRUSIVE COMPLEXES

The Gallejaur intrusive complex

The Gallejaur intrusive complex (Fig. 58) in the Skellefte District is the southernmost known plutonic rock of the Perthite monzonite suite (cf. Skiöld 1987) of the early Svecokarelian intrusive rocks. This suite, found predominantly north of the Skellefte District, has been dated at c. 1.88 to 1.86 Ga (cf. Skiöld 1987, Skiöld 1988, Skiöld et al. 1993, Öhlander et al. 1993, and Kathol & Persson 1997). The Gallejaur gabbro was dated at 1876±4 Ma (Skiöld et al. 1993) and the monzonite at 1873±10 Ma (Skiöld 1988). The Perthite monzonite suite has been considered to post-date Svecokarelian deformation and metamorphism north of the Skellefte District in the Norrbotten County (cf. Skiöld 1987) and is as such critical for discussions on the timing of both deformation and metamorphism. The Gallejaur intrusive rocks, however, are related to the Vargfors Group volcanic rocks. The latter are dated at 1875±4 Ma (Billström & Weihed 1996), which pre-dates peak metamorphism and deformation in the Skellefte District, thus indicating that the peak metamorphism here post-dates the intrusions of the Perthite monzonite suite.

The close genetic relationship between the Gallejaur intrusive complex and the surrounding, mainly mafic volcanic rocks has long been known (cf. Lundberg 1980). The circular Gallejaur structure is interpreted as a volcanic centre and the mafic volcanic rocks are considered to be comagmatic with the Gallejaur mafic intrusive rocks. The central monzonite was interpreted as a thin, sheet-like unit by Enmark & Nisca (1984), and recently Lilljequist (2000) interpreted the structure as the result of a meteorite impact. Winnes et al. (2000) emphasized the close relationship between the mafic and felsic intrusive components, indicated by the common occurrence of mafic enclaves in the felsic parts, i.e. mingling between the two magmas. This has also produced hybrid rocks, which are interpreted as a result of mixing processes.

As mentioned above, the intrusive rocks of the Gallejaur structure are bimodal in composition. The felsic part is classified by modal analysis as monzonite to quartz monzonite. However, the only available chemical analysis plots as granodiorite in a Q-P diagram (Fig. 59c) of Debon & LeFort (1983), whereas the mafic samples plot as quartz diorite to gabbro in the same diagram. The monzonite is medium-grained and light red in colour. The main minerals are alkali-feldspar, albite–oligoclase, quartz, chloritized amphibole, biotite, opaque phases, muscovite, and apatite. Quartz and alkali-feldspar show granophyric intergrowth. The mafic rocks are dominated by amphibole, pyroxene, and plagioclase. Compared with other felsic rocks of the c. 1.88–1.86 Ga old Perthite monzonite suite, the Gallejaur monzonite displays a more sodium- and calcium-rich composition. It is clearly metaluminous and shows a within-plate character in a ternary Rb-Hf-Ta and Rb vs Y+Nb diagram (Figs. 59e,b). In a modified R1-R2 diagram, the felsic Gallejaur intrusion plots as late orogenic within the trend displayed by other rocks of the Perthite monzonite suite (Fig. 59a). The REE pattern does not display the negative europium anomaly typical of most Perthite monzonite suite rocks.

Depth estimation of the Gallejaur structure with upward continuation as a separation filter for potential-field maps

The circular Gallejaur structure is 10–12 km in diameter and gives rise to positive anomalies on both the magnetic and the Bouguer anomaly maps. The gravity high indicates that the structure consists mostly of mafic rocks.

A borehole was drilled at the Gallejaur structure in the 1980s by the Swedish Nuclear Fuel and Waste Management Company (SKB) in order to identify the position of the sub-horizontal contact between the surface-near monzonite and the buried gabbro as pro-

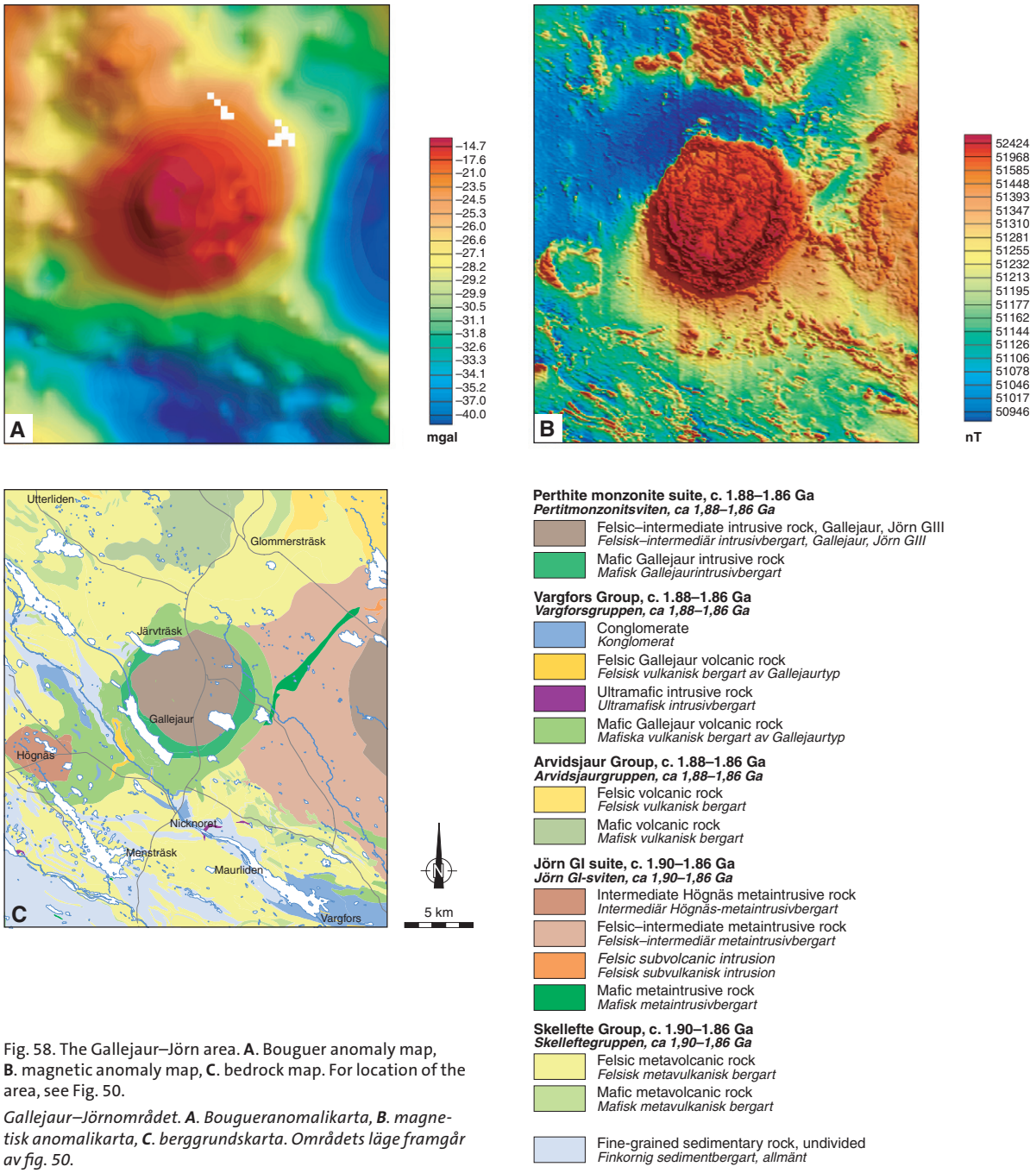


Fig. 58. The Gallejaur–Jörn area. **A**. Bouguer anomaly map, **B**. magnetic anomaly map, **C**. bedrock map. For location of the area, see Fig. 50.

*Gallejaur–Jörnområdet. **A**. Bougueranomalikarta, **B**. magnetisk anomalikarta, **C**. berggrundskarta. Områdets läge framgår av fig. 50.*

posed in the model by Enmark & Nisca (1984). The 400 metre deep borehole only intersected monzonite. Recent mapping of the area has yielded new information, showing outcrops of gabbro in the central part of the structure. This indicates a more complex situation than what was known from geological studies preceding the geophysical modelling by Enmark & Nisca (1984). A more complex geometry in the rock distribution could be explained by the observations reported by Lilljequist (2000) where the highly magnetic ring structure is described as an impact melt body with varying amounts of more or less absorbed clasts of different rock types.

As indicated by Enmark & Nisca (1984) the lower surface of the monzonite undulates. According to them, the calculated gravity anomaly lies slightly above the measured one, suggesting that a slightly thicker monzonite with a more undulating lower surface would give an even better correspondence between measured and modelled data. However, the intention of the authors was probably to give a general description of the main features, rather than an exact fit.

To define the Gallejaur structure further, an upward continuation filter was applied on the magnetic total field grid and on the Bouguer gravity grid. To avoid lat-

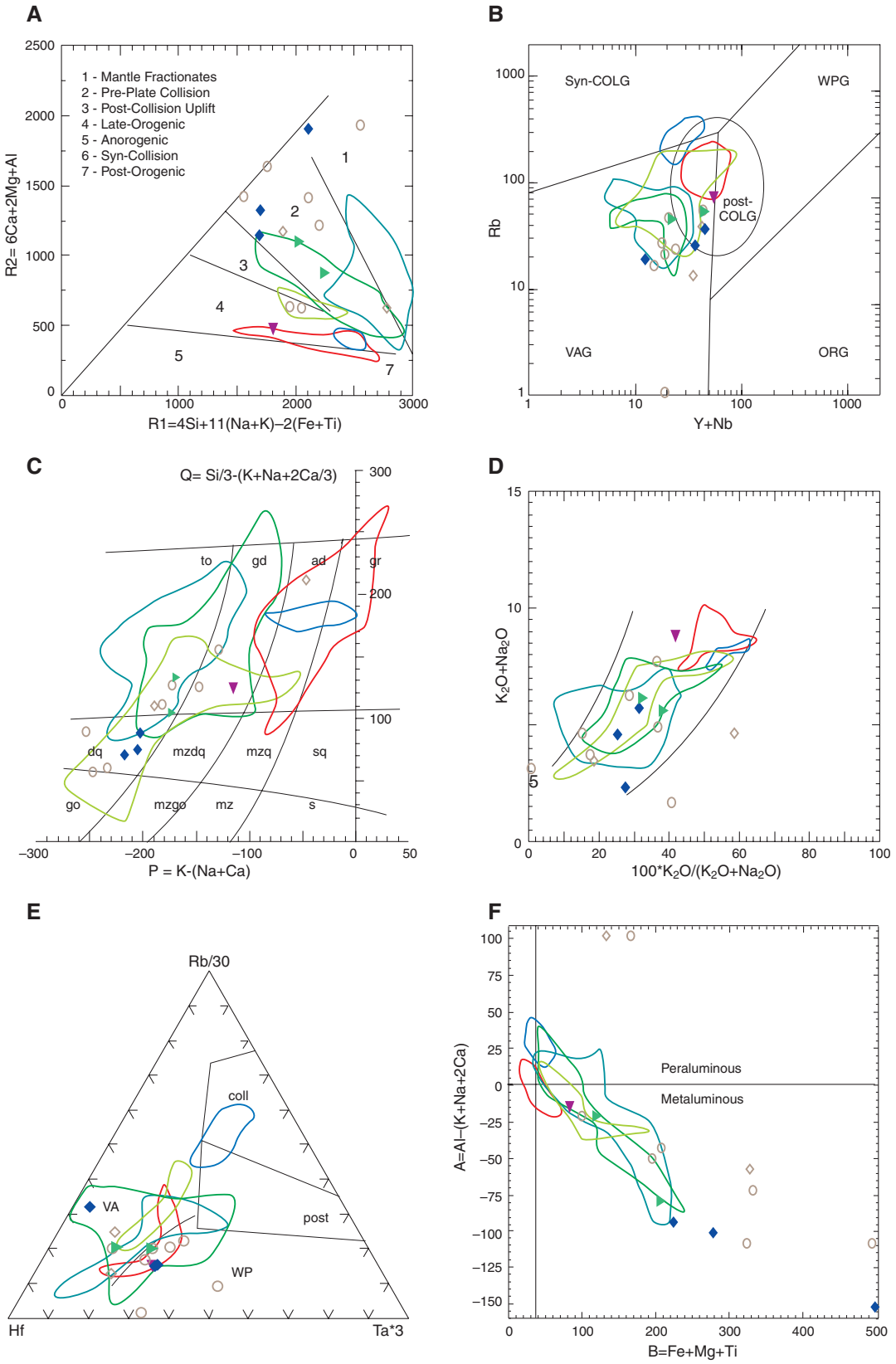
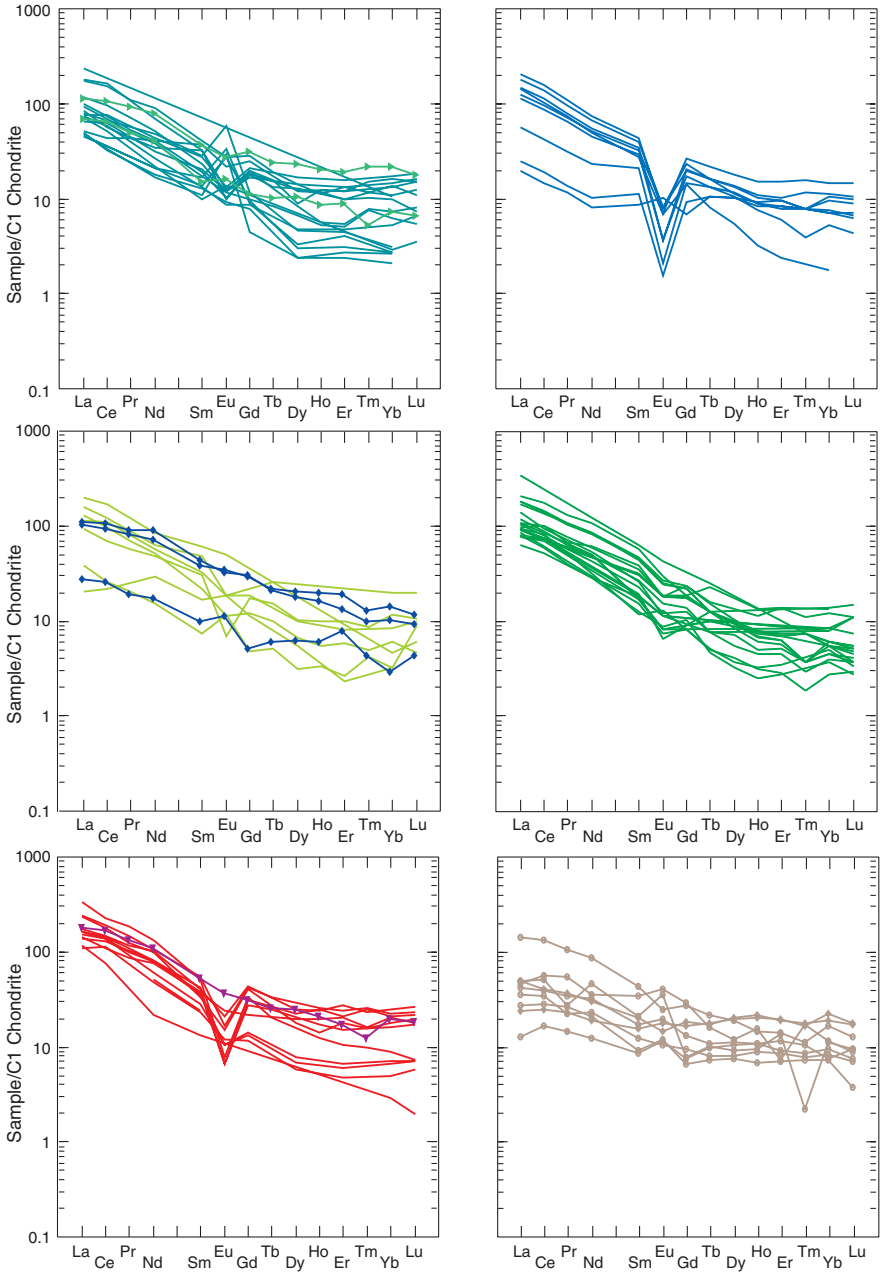


Fig. 59. Geochemical diagrams of Gallejaur and Jörn intrusive complexes and related volcanic rocks. **A**. Modified R1-R2 diagram after Batchelor & Bowden (1995). **B**. Tectonic discrimination of granitoids after Pearce (1996). Abbreviations: Syn-COLG= syn-collision granites, WPG = within-plate granites, VAG = volcanic arc granites, post-COLG = post-collision granites, ORG = ocean ridge granites. **C**. P-Q diagram after Debon & Le Fort (1983). Abbreviations: gr = granite, ad = adamellite, gd = granodiorite, to = tonalite, sq = quartz syenite, mzq = quartz monzonite, mzdq = quartz monzodiorite, dq = quartz diorite, s = syenite, mz = monzonite, mzgo = monzogabbro, go = gabbro. **D**. Igneous spectrum after Hughes (1973). **E**. Tectonic discrimination after Harris et al. (1986), abbreviations as in B. **F**. A-B diagram after Debon & Le Fort (1983); **G**. REE diagrams.

G



Analyses from the Gallejaur–Jörn area
Analyser från Gallejaur–Jörnområdet

- Mafic volcanic rocks, Vargfors Group
  Mafiska vulkaniter, Vargforsgruppen
- Mafic dykes, Vargfors Group
  Mafiska gångar, Vargforsgruppen
- Felsic intrusive rock, Gallejaur type, Perthite monzonite suite
  Felsisk intrusivbergart, Gallejaurtyp, pertitmonzonitsviten
- Mafic intrusive rocks, Gallejaur type, Perthite monzonite suite
  Mafiska intrusivbergarter, Gallejaurtyp, pertitmonzonitsviten
- Högnäs intrusion, early Svecokarelian calc-alkaline granitoids, 1.90–1.88 Ga
  Högnäsintrusionen, tidigsvekokarelska kalk-alkalina granitoider, 1,90–1,88 Ga

Analyses from the project area (for comparison)
Analyser från projektområdet (som jämförelse)

- Late to post Svecokarelian granites
  Sen- till postsvekokarelska graniter
- Perthite monzonite suite
  Pertitmonzonitsviten
- Early Svecokarelian calk-alkaline granitoids, 1.87–1.83 Ga
  Tidigsvekokarelska kalk-alkalina granitoider, 1,87–1,83 Ga
- Early Svecokarelian calk-alkaline granitoids, 1.90–1.88 Ga
  Tidigsvekokarelska kalk-alkalina granitoider, 1,90–1,88 Ga
- Early Svecokarelian calk-alkaline granitoids, 1.95–1.90 Ga
  Tidigsvekokarelska kalk-alkalina granitoider, 1,95–1,90 Ga

Geokemisk sammansättning av intrusivkomplexen i Gallejaur och Jörn och relaterade vulkaniska bergarter. ***A****. Modifierat R1-R2-diagram efter Bachelor & Bowden (1995).* ***B****. Tektonisk diskriminering av graniter efter Pearce (1996). Förkortningar: Syn-COLG= syn-kollisionsgraniter, WPG = kontinentalplattegraniter, VAG = öbågegraniter, post-COLG = post-kollisionsgraniter, ORG = graniter, relaterade till oceaniska ryggar.* ***C****. P-Q-diagram efter Debon & Le Fort (1983) Förkortningar: gr = granit, ad = adamellit, gd = granodiorit, to = tonalit, sq = kvartssyenit, mzq = kvarts-monzonit, mzdq = kvartsmonzodiorit, dq = kvartsdiorit, s = syenit, mz = monzonit, mzgo = monzogabbro, go = gabbro.* ***D****. "Igneous spectrum" efter Hughes (1973).* ***E****. tektonisk diskriminering efter Harris m.fl. (1986), förkortningar som i B.* ***F****. A-B-diagram efter Debon & Le Fort (1983).* ***G****. REE-diagram.*

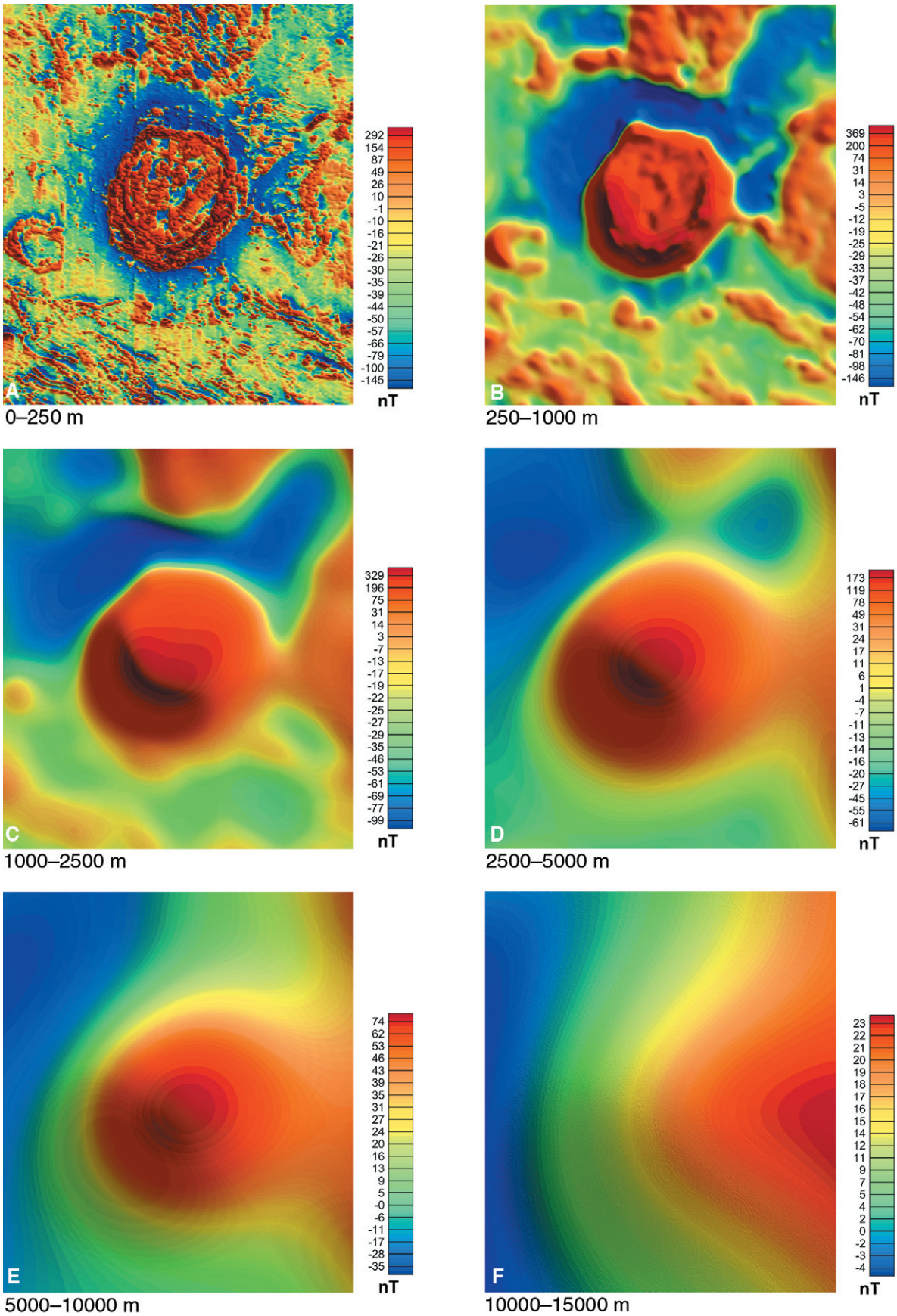


Fig. 60. Magnetic anomaly maps obtained by upward continuation for different depths over the Gallejaur structure.
Magnetiska anomalikartor beräknade för olika djup över Gallejaurstrukturen.

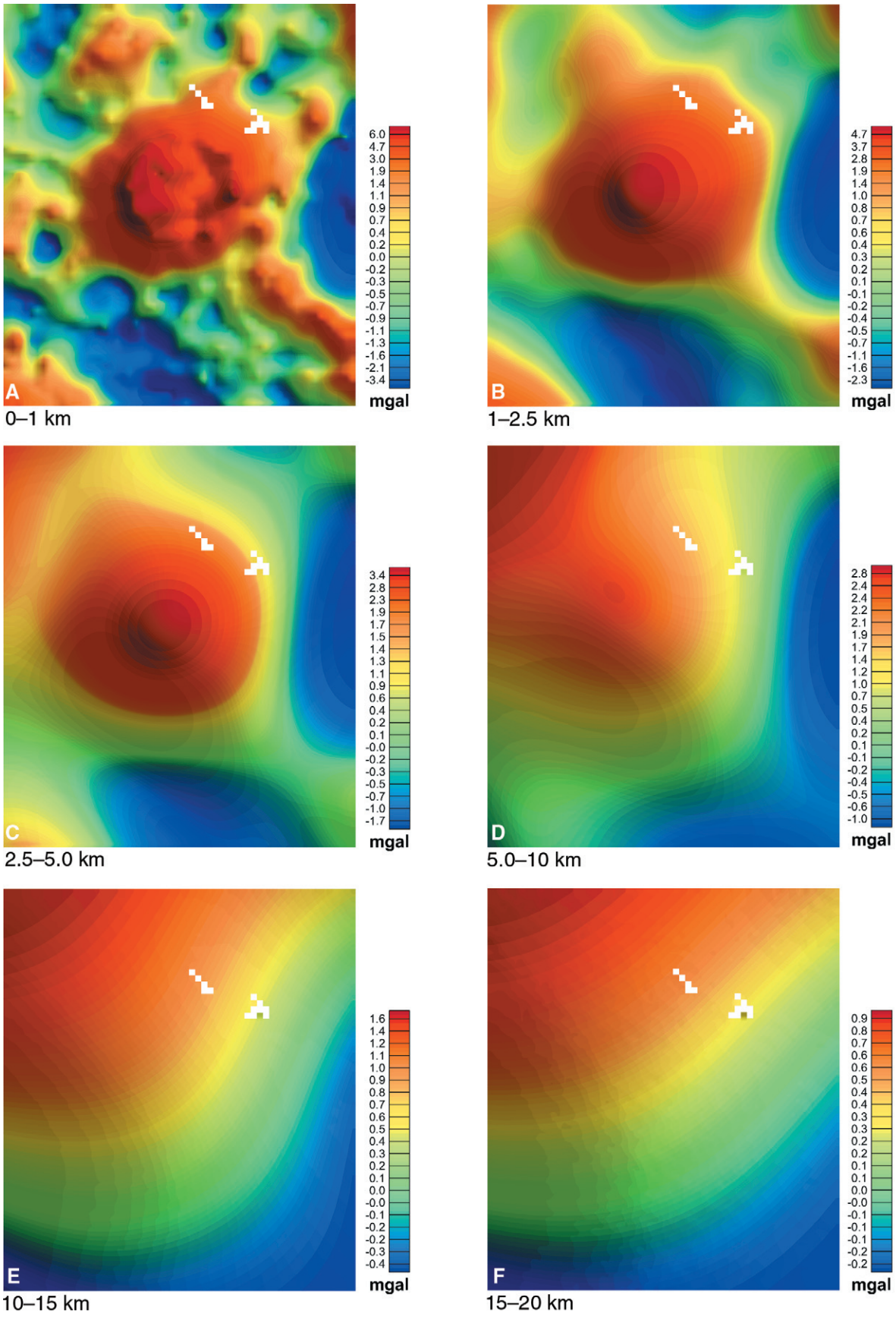


Fig. 61. Gravity maps obtained by upward continuation for different depths over the Gallejaur structure.
Tyngdkraftskartor beräknade för olika djup över Gallejaurstrukturen.

eral effects the upward continuation covered an area of 15,000 km^2 including the entire Gallejaur structure.

The upward continuation was done for different levels for both grids. To obtain the "sandwich" source distribution, the methods described by Jacobsen (1987) and Pedersen (1991) were applied. The "sandwich" source distribution for the magnetic anomaly field and the Bouguer gravity field are illustrated for the Gallejaur structure in Figures 60 and 61 respectively.

The magnetic anomalies from the Gallejaur structure are clearly visible in all "sheets" down to a depth of 10 km (Figs. 60a–e). The magnetic anomaly from the structure is dislocated in the "sheet" between 10 and 15 km (Fig. 60f). The situation is almost the same for the gravity field (Fig. 61) with the difference that the anomaly from the Gallejaur structure becomes unclear already at a depth greater than 5 km (Fig. 61d).

To obtain more information regarding the internal structure of the Gallejaur intrusion, it is necessary to study the shallow source distribution. In Figure 60a, the magnetic anomalies from the uppermost level between 0 and 250 metres are shown. The ring structures as well as some low magnetic patterns are clearly seen on the map.

The residual gravity field between the surface and 1000 m (Fig. 61a) shows a positive anomaly at the western side of the Gallejaur structure and a gravity low on the eastern side. This indicates that the monzonite body observed in outcrops on the surface is somewhat thicker on the eastern side.

The conclusion is that the model presented by Enmark & Nisca (1984) gives a realistic explanation for the geophysical anomalies, based on a sound geological model, though the details in the actual geological situation are too complex to be exactly modelled on a regional scale. Their prediction of a rather thin monzonite layer above a thicker gabbroic layer is probably an appropriate model. The applied "sandwich" source distribution technique indicates a somewhat deeper lower surface of the gabbroic body, probably around 5–10 km compared to the 4 km postulated by Enmark & Nisca (1984). The correctness of the prognoses when using the "sandwich" technique is, however, dependent on the quality of base data.

The Jörn granitoid complex (Jörn batholith)

The Jörn granitoid complex (Wilson et al. 1987b) has since mining commenced, and geological evolutionary models were first suggested for the Skellefte District, played a fundamental role as a marker in the stratigraphic schemes suggested for the area (cf. Fig. 58 and the section on development of stratigraphic schemes). The Jörn granitoid complex, between 1.90 and 1.87 Ga old (Wilson et al. 1987b), consists of four distinct intrusive phases (GI to GIV). The GI phase, which is the type intrusion of early Svecokarelian, calc-alkaline intrusions in the Skellefte District, is a heterogeneous, medium-grained metatonalite to subordinate metagranodiorite, commonly with large blue quartz phenocrysts. GII is an even- and medium-grained metagranodiorite to metatonalite. GIII is a reddish, medium- to coarse-grained granite, now interpreted as belonging to the early Svecokarelian Perthite monzonite suite, whereas GIV is a medium-grained, grey-red granite. The GI phase contains porphyry copper-gold (Cu-Au) deposits (cf. Weihed et al. 1987, Weihed 1992a, Weihed & Fallick 1994) like the Tallberg deposit (7221870/1690630).

Deformed bodies of Jörn GI metagranitoids occur in several places in the Skellefte District and these rocks have long been regarded as comagmatic with the Skellefte Group volcanic rocks. This relationship is, however, not confirmed more than as an overlap in age of the two rock types. Intrusive porphyries within the Jörn GI phase of the Jörn granitoid complex texturally resemble the coarser varieties of subvolcanic intrusions within the Skellefte Group metavolcanic rocks. The intrusive porphyries have been dated at 1886^{+15}_{-9} Ma (Weihed & Schöberg 1991), which is (within error) the same age as the Skellefte Group metavolcanic rocks. However, the relationship between the subvolcanic intrusions in the Skellefte Group and the high-level porphyritic intrusions within the Jörn GI phase is still an open question. The subvolcanic intrusions are generally more felsic in character and preliminary results (Weihed unpublished) indicate that they are distinctly different in REE-composition from the high-level intrusions, and thus are not genetically related.

The outer phase of the Jörn granitoid complex (GI) is, according to the classification of Debon & Le Fort (1983) and De La Roche et al. (1980), tonalitic (Fig. 59c) and metaluminous (Fig. 59f). The GI metatonalite typically has low contents of yttrium and niobium, shows a LREE fractionated pattern with a HREE depletion and displays a weak but significant negative europium anomaly, Eu/Eu*=0.64–0.84 with a La_N/Yb_N ratio of 4. The HREE depletion, and low ytterbium, may be attributed to garnet, hornblende, pyroxene or accessories in the residue from partial melting, or result from fractionation of hornblende and plagioclase during crystallization. The REE pattern of the metatonalites could be consistent with partial melting of metasomatized LREE-enriched spinel lherzolite mantle with plagioclase fractionation (Weihed 1992a).

Geophysical characteristics

The Jörn granitoid complex is clearly visible on the magnetic anomaly map and the Bouguer anomaly map (Ba 57:4 and Ba 57:5) as described in detail by Wilson et al. (1987b). Differences in the petrophysical properties of the different intrusive phases (Table 5, see also Figs. 43:1–20) are, as expected, reflected in their anomaly patterns.

The GI phase is characterized by comparatively high densities with wide variations in magnetic susceptibility. Based on gamma ray spectrometry on outcrops, Lundström et al. (1997) and Weihed & Antal (1999) showed that the GI phase (as compared with the GIII phase) has a low content of potassium and thorium (Figs. 43:3 and 43:15). Results from the GII phase are not shown in Figure 43:1–4; however, gamma ray spectrometry and chemical analyses indicate concentrations of potassium and thorium between the levels found in the GI and GIII phases. A similar pattern is known from the GIV phase. The chemical analyses of Wilson et al. (1987b) gave the same variation patterns. The Hobergsliden intrusion (7247380/1706760) south of Långträsk (cf. Lundström & Antal 2000) is similar to the GIII phase, though with a significantly higher thorium content.

The GII phase appears as an appendix at the southern border of the GIII phase. Adjacent to the GII phase, and partly surrounding it, a rock volume with increased magnetization and density is indicated. The anomaly source was modelled by Antal (unpublished) to have a density of at least 2800 kg/m^3. Weihed (1992a) reported mafic dykes in the Tallberg area (7221870/1690630), which are interpreted as a part of the anomaly source.

The densities in the GIII phase vary from the lowest in the whole complex, around 2580 kg/m^3, up to around 2650 kg/m^3, with magnetic susceptibilities above 100×10^{-5} SI. The GIII phase is manifested as a well-defined gravity low with a depth of around 4–8 km (Enmark & Parasnis 1980). Modelling by Antal (unpublished) gave similar results.

The GIV phase appears as a semicircular magnetic low with a diameter of around 5 km in the central part of the GIII phase. The susceptibilities are in general lower than for the other intrusive phases.

LEDFAT

In a number of places, restricted areas with sedimentary units younger than the Arvidsjaur Group volcanic rocks are encountered. The largest of these units is the Ledfat series (Offerberg 1959), situated by the river Skellefteälven about 35 km east of Sorsele (Fig. 62). The Ledfat rocks were investigated briefly by Högbom (1937) and Gavelin (1955), and a detailed map and description were presented by Offerberg (1959). More recent work in the area has focused on the Gråberget copper mineralization (Claesson 1979).

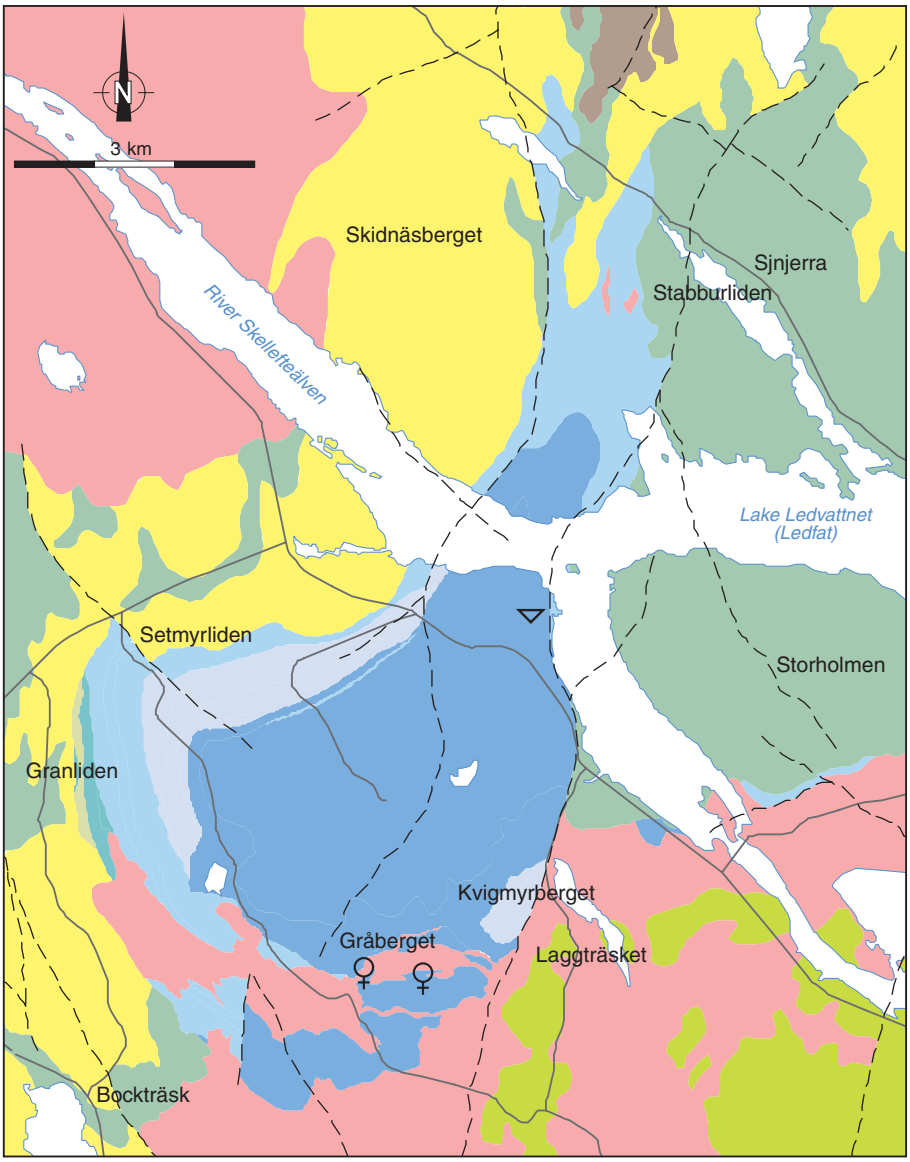
The Ledfat series was deposited on a heterogeneous basement of Arvidsjaur Group volcanic rocks. West of the Ledfat rocks, a north–south trending belt of dacitic and andesitic lavas is exposed, grading into predominantly rhyolitic ignimbrites farther north. East of the Ledfat rocks, in the Storholmen and Sjnjerra areas, there is a thick section of porphyritic basalts and andesites. The volcanic rocks of the Arvidsjaur Group are intruded by roughly coeval granites of the Perthite monzonite suite, but nowhere does a granitoid from that suite form the basement for the Ledfat rocks. It is a matter of debate whether or not the deposition of the Ledfat series was initiated by the time the Perthite monzonite suite rocks were in an erosional position.

Offerberg (1959) divided the series into four formations, where the three lowest are dominated by sandstones and partly volcanogenic rocks, whereas the uppermost, areally most exposed formation consists of conglomerates.

The lowermost unit, the Andesite Formation, is exposed in a few outcrops on the western slope of Granliden hill. It is composed of several beds of plagioclase porphyritic andesite lavas with abundant vesicles, interstratified by thin interflow ash beds. Conglomerate beds are found both stratigraphically below and on top of the andesite lavas. The clast material consists almost exclusively of volcanic rocks from the Arvidsjaur Group. The uppermost member is a laminated tuffitic sandstone with a high volcanic component.

Table 5. Petrophysical properties of the different phases of the Jörn granitoid complex.
Petrofysiska egenskaper för de olika intrusiva faserna av Jörn-granitoidkomplexet.

Intrusive phase	Magnetic susceptibility (x10^{-5} SI)	Density (kg/m^3)	K_2O (%)	Th (ppm)
GI	30–5000	2660–2800	0.5–3.5	1–12
GII	1100–4000	2660–2700	3.4–3.6	10–11
GIII	150–3500	2580–2650 (2700)	2.5–4.5	7–18
GIV	30–800	2600–2660	2.3–2.5	7–8



Cu-mineralisation
Cu-mineralisering

Quarry
Stenbrott

Deformation zone
Deformationszon

Late to post Svecokarelian intrusive rocks, c. 1.82–1.76 Ga
Sen- till postsvekokarelska intrusivbergarter, ca 1,82–1,76 Ga

Granitoids, Revsund suite (TIB)
Granitoider, Revsundssviten (TMB)

Mafic rocks, Revsund suite (TIB)
Mafiska bergarter, Revsundssviten (TMB)

Perthite monzonite suite, c. 1.88–1.86 Ga
Pertitmonzonitsviten, ca 1,88–1,86 Ga

Alkali feldspar granite
Alkalifältspatgranit

Arvidsjaur Group, c. 1.88–1.86 Ga
Arvidsjaurgruppen, ca 1,88–1,86 Ga

LEDFAT SERIES
LEDFATSERIEN

Conglomerate Formation
Konglomeratformationen

Upper and lower conglomerate
Övre och undre kongomerat

Tuffite Formation
Tuffitformationen

Sandstone, tuffite, conglomerate
Sandsten, tuffit, konglomerat

Sandstone Formation
Sandstensformationen

Arkose or feldspar-quartz sandstones, conglomerate, sandstone
Arkos och fältspat-kvartssandsten, konglomerat, sandsten

Andesite Formation
Andesitformationen

Tuff and tuffite, conglomerate
Tuff och tuffit, konglomerat

Andesite lava
Andesitlava

Underlying volcanic rocks
Underliggande vulkaniter

Felsic volcanic rock
Felsisk vulkanit

Mafic volcanic rock
Mafisk vulkanit

Fig. 62. Bedrock map of the Ledfat area, modified from Offerberg (1959). For location of the area, see Fig. 50.

Berggrundskarta över Ledfatområdet, modiferad efter Offerberg (1959). Områdets läge framgår av fig. 50.

The Andesite Formation is overlain by the Sandstone Formation, exposed on Granliden hill and farther to the south. The northernmost exposed Ledfat rocks, on Stabburliden hill north of lake Ledvattnet, probably belong to the Sandstone Formation (Offerberg 1959). The Sandstone Formation consists of grey and brownish violet sandstones in lower sections and reddish grey arkose and feldspathic quartz sandstones in the upper part. These sandstones are separated by a conglomerate, characterized by the almost monomict composition of clasts from the lower parts of the Ledfat series. The lower grey sandstones are commonly more fine-grained and laminated, with abundant structures such as cross-bedding. The upper, reddish quartz-rich sandstones show considerable recrystallization.

The next unit, the Tuffite Formation, is well exposed in the Setmyrliden area in the north-western part of the exposed Ledfat rocks. It consists of reddish, volcanogenic tuffites and sandstones with abundant lamination. It is generally more fine-grained than the underlying Sandstone Formation, with beds of silt- and mudstones and relatively insignificant conglomerate intercalations (Offerberg 1959). Cross-bedding is frequently observed. The tuffites contain varying amounts of devitrified pyroclastic rocks.

The upper Conglomerate Formation was originally compared with and named after the Vargfors conglomerates in the central Skellefte District (Offerberg 1959). It is divided into a lower unit, commonly reddish in colour and including 60% sandstone clasts from lower parts of the Ledfat series and 40% Arvidsjaur Group volcanic rocks (Offerberg 1959), and an upper, greenish grey unit, with 40% lower Ledfat series clasts, about 10% granitoid clasts, and the remainder Arvidsjaur Group volcanic rocks. The latter show a strong predominance of mafic compositions. The upper conglomerate generally has a more pronounced polymict clast distribution. Offerberg (1959) defines the border between the two units by the appearance of granitoid clasts. Sandstone intercalations and bedding are locally encountered in the conglomerates.

The different units in the Ledfat series have been deposited more or less continuously, but show considerable unconformities in some places. Erosion of lower units is also proven by the wealth of clasts from the lower units in the upper Conglomerate Formation. The rocks of the Ledfat series form a synclinal structure with steeply dipping lower units in the outer parts and flat-lying upper conglomerate units in the inner parts. Repeatedly active north–south striking faults probably formed a depression, which initiated deposition. The total thickness of the Ledfat series was estimated by Offerberg (1959) to be around 2000 m at its thickest.

Mainly in the southern part of the area, the Ledfat series is intruded by late to post Svecokarelian intrusive rocks. These are mainly even-grained, medium-grained, reddish granites, which break up the Ledfat structure, and the sedimentary rocks form large megaxenoliths in the intrusive bodies. Narrow granite and granite porphyry dykes intrude the conglomerates in the Kvigmyrberget hill area. On Gråberget hill, the granite is altered and contains a weak dissemination of chalcopyrite (see page 143). Mineralized fissures with chalcopyrite, chalcocite, and haematite may also extend into the conglomerates. Small granite intrusions are also found on Stabburliden hill in the northern part of the area.

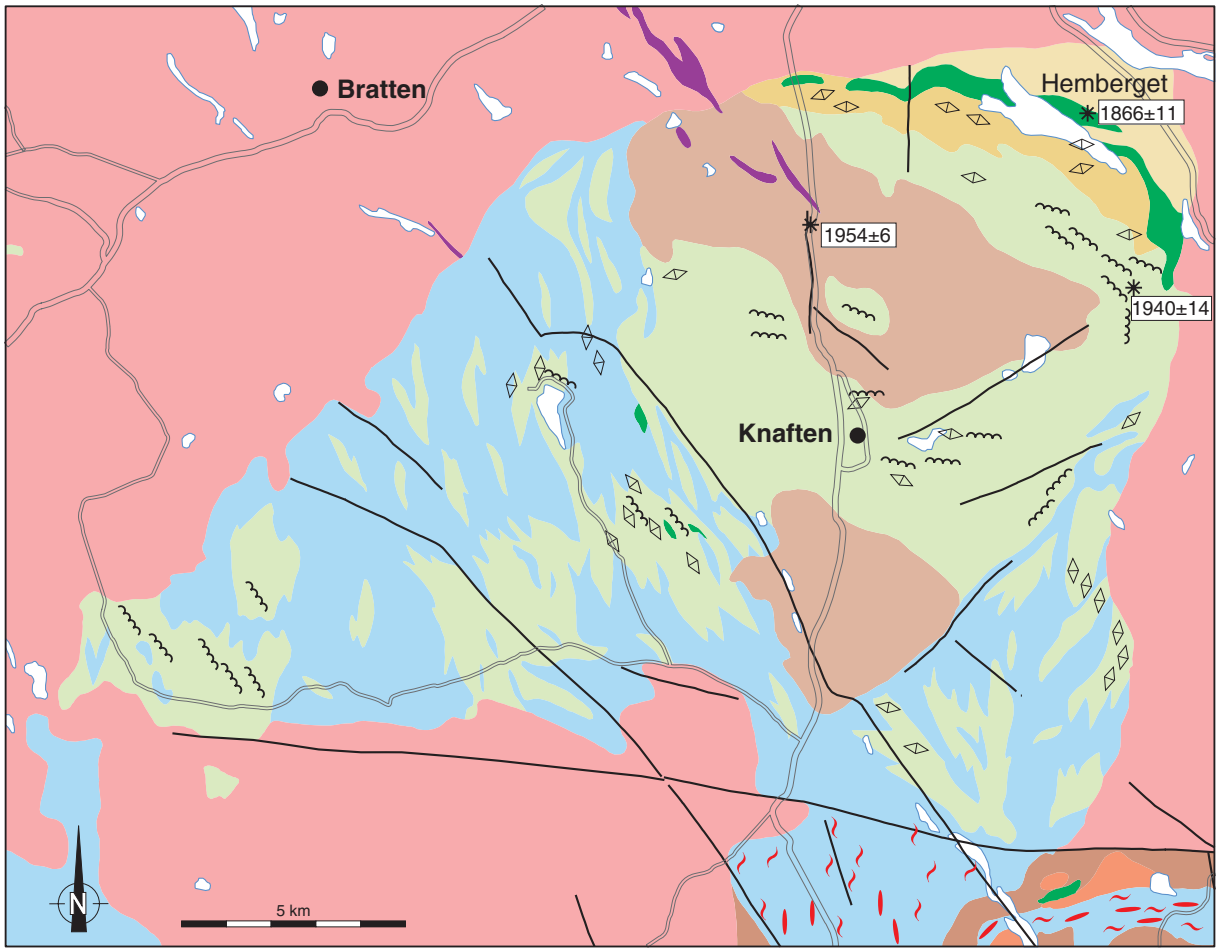
The late to post Svecokarelian intrusive rocks also include numerous gabbroic bodies, especially in the Laggträsket area, where they form part of the Ljungby gabbro complex (7262070/1622870). Mafic dykes, possibly apophyses from the gabbro complex, are common in the Ledfat series, especially in the south-eastern part. Geophysical investigations suggest gabbroic rocks about 1 km below the Ledfat series.

KNAFTEN

The Knaften area (Fig. 63) is situated south of Lycksele. It is dominated by metavolcanic and metasedimentary rocks, intruded by early Svecokarelian metagranitoids and metagabbro. The area is surrounded by granites of the Revsund suite, except in the south-east, where metasedimentary rocks of greenschist to lower amphibolite facies are separated by a major deformation zone from migmatized sedimentary rocks outside the Knaften area.

The area was mapped during 1986 and 1987 in connection with the ongoing bedrock mapping programme of the Geological Survey of Sweden (SGU) in the region and the results were presented in an unpublished M.Sc. thesis (Wasström 1990). These results have been incorporated in a slightly modified fashion in the bedrock maps 21I Fredrika NV and NO (Björk & Kero 1988) and 22I Lycksele SV and SO (Björk & Kero 2002).

The metavolcanic rocks comprise mafic massive flows, pillow lavas, and volcaniclastic rocks, and display a MORB to island-arc type affinity. They are intercalated with metagreywackes and meta-argillites. Locally, graphite- or sulphide-bearing horizons occur in the meta-argillites. This volcanic–sedimentary succession is part of the Bothnian Supergroup. Previously, the felsic and mafic metavolcanic rocks of the Knaften area have been gathered under the term "Knaften group" (Kousa & Lundqvist 2000), whereas the intercalating metasedimentary rocks have been assigned to the "Härnö Formation" or "Härnö Group" (Lundqvist 2000).



Dolerite, Mesoproterozoic
Diabas, mesoproterozoisk

Late to post Svecokarelian intrusive rocks, c. 1.82–1.76 Ga
Sen- till postsvekokarelska intrusivbergarter, ca 1,82–1,76 Ga

Granite, Revsund suite, TIB
Granit, Revsundssviten, TMB

Granite, Skelllefte-Härnö suite
Granit, Skellefte-Härnösviten

Early Svecokarelian calc-alkaline intrusive rocks, c. 1.96–1.86 Ga
Tidigsvekokarelska kalk-alkalina intrusivbergarter, ca 1,96–1,86 Ga

Metagranitoid, Jörn GI suite
Metagranitoid, Jörn GI-sviten

Mafic or ultramafic rock, Jörn GI suite
Mafit eller ultramafit, Jörn GI-sviten

Metagranitoid, calc-alkaline, c. 1950 Ma
Metagranitoid, kalkalkalin, ca 1950 Ma

Bothnian Supergroup, c. 1.96–1.86 Ga
Bottniska supergruppen, ca 1,96–1,86 Ga

Metadacite to metarhyolite
Metadacit till metaryolit

Metadacite
Metadacit

Mafic metavolcanic rock
Mafisk metavulkanit

Metagreywacke, meta-argillite
Metagråvacka, metaargillit

Deformation zone, unspecified
Deformationszon, ospecificerad

Sample site for radiometric dating, age in million years
Provpunkt för radiometrisk datering, ålder i miljoner år

Altered to veined gneiss
Ådergnejsomvandlad

Migmatized
Migmatitisk

Pillow structure
Kuddlavestruktur

Fragment, unspecified
Inneslutning, ospecifierad

Fig. 63. Bedrock map of the Knaften area. For location of the area, see Fig. 50.

Berggrundskarta över Knaftenområdet. Områdets läge framgår av fig. 50.

The supracrustal rocks in the Knaften area are intruded by the Knaften granitoids (1954±6 Ma, Wasström 1993), quartz-feldspar porphyritic dykes (1940±14 Ma, Wasström 1996) and ultramafic–mafic sills, amongst which the Hemberget gabbro–ultramafic layered intrusion (1866±11 Ma, Billström et al. 2002) is the most prominent. The geochemistry of the Knaften metagranitoids, the quartz-feldspar porphyritic dykes and the felsic metavolcanic rocks suggest to a common magma source for these rocks (Wasström 1994).

Titanite in the Knaften metagranitoids has also been dated. Two generations were found, one the same age

as the zircons, 1954±6 Ma, and one distinctly younger with a $^{207}Pb/^{206}Pb$ age of 1715 Ma (Björk & Kero 2002). This younger age may indicate a thermal episode accompanied by fluid circulation, an event perhaps connected with major faulting in the region.

The surrounding Revsund granites (1805±8 Ma, Eliasson et al. 2001; c. 1806 Ma, Björk & Kero 2002) are approximately 150 Ma younger than the Knaften metagranitoids. North-west striking dolerite dykes, dated with palaeomagnetic methods at c. 1270 Ma (Elming & Mattsson 2001,) are the youngest rocks in the area.

The east–west striking deformation zone in the southern part, separating the Knaften area from the migmatized sedimentary rocks, clearly post-dates the Revsund granites, but its age in relation to the dolerite dykes is uncertain.

The petrophysical properties of the different rocks are quite similar, which causes difficulties in interpreting and compiling both maps and profiles. The petrophysical data used in the calculations are listed in Table 6. According to the results from interpretations of the gravity and magnetic fields, the mafic metavolcanic rocks reach a depth of c. 10 km. Although no magnetic high-density rock seems to be present beneath the Knaften metagranitoids, these metagranitoids are probably less than 2 km thick, which would confirm earlier interpretations by L. Kero and G. Nordmark (see Wasström 1990). The metagranitoids and the central part of the mafic metavolcanic rocks are inferred to rest on rocks with gravity and magnetic characteristics corresponding to granites of the Revsund suite or metagreywackes of the Bothnian Supergroup, or both. However, based on the depth of the mafic metavolcanic rocks and their regional co-existence with metasedimentary rocks, the bedrock beneath the Knaften metagranitoids is inferred to consist of migmatized sedimentary rocks similar to the rocks in the uplifted block south of the Knaften area.

ADAK

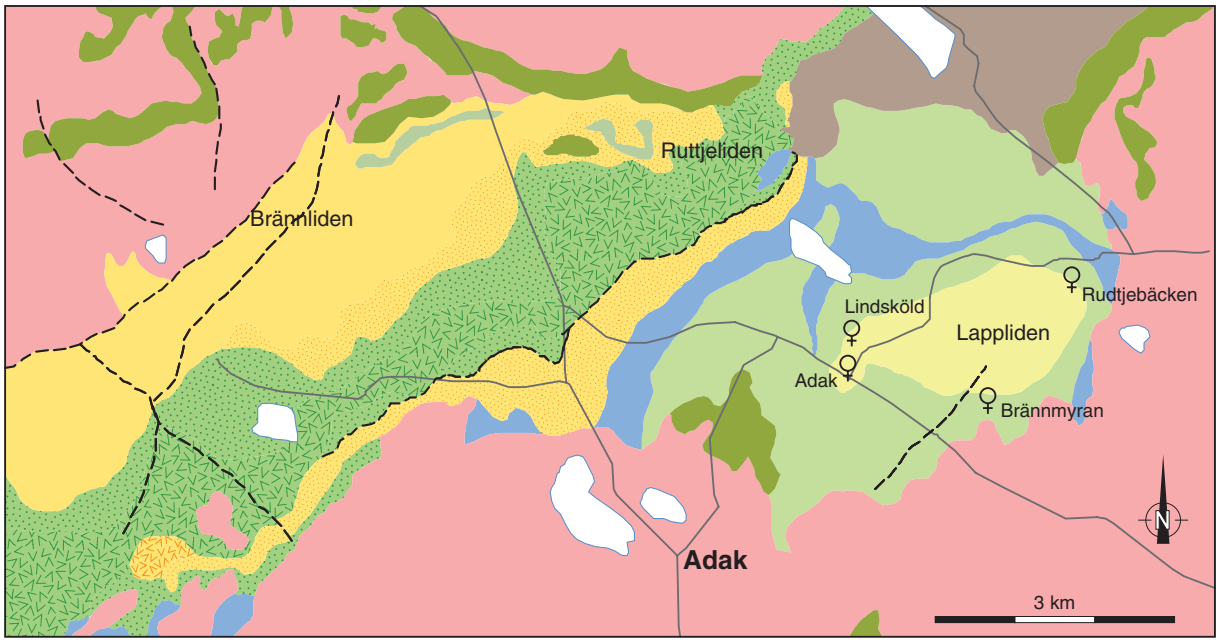
The Adak area (Fig. 64) is situated in the north-westernmost part of the Skellefte District. It is a key stratigraphic area, because the three major stratigraphic units – the Skellefte, Vargfors, and Arvidsjaur Groups – meet within a reasonably small area and their relationships can be studied.

Hydrothermally altered, metamorphosed and deformed volcanic rocks of the Skellefte Group are exposed in the Adak dome structure, which is surrounded by younger sedimentary and volcanic rocks. All rocks of the dome structure show gentle dips away from the core of the dome. The oldest rock unit, exposed on Lappliden hill, is situated in the core of the dome. It consists of grey, fine-grained, quartz-muscovite-biotite-cordierite-plagioclase-bearing dacitic and rhyolitic metavolcanic rocks which have been exposed to large-scale alteration processes and subsequent medium grade metamorphism. A number of sulphide occurrences, including the massive pyrite-dominated zinc-copper sulphide ore Rudtjebäcken and the copper breccia and dissemination ores Adak, Brännmyran, and Lindsköld are situated in the upper part of this altered unit. The ores are hosted in zones with stronger chlorite-antophyllite-skarn alteration. Minor occurrences of dark grey mudstones are found as intercalations in the uppermost parts of the unit (Gavelin 1948).

This altered felsic metavolcanic unit is structurally overlain by a unit of mafic volcanic rocks which are texturally better preserved and are hydrothemally not as strongly altered as the former. This mafic unit consists of dark greenish grey, fine-grained rocks, dominated by plagioclase and hornblende. The major constituents are laminated volcanic sandstones–siltstones (banded tuffites, according to Gavelin, 1948, and Lindberg, 1970), which locally show graded units with strati-

Table 6. Petrophysical data from the Knaften area.
Petrofysiska data från Knaftenområdet.

Type of rock	**Petrophysical properties**				
	Density kg/m³	Susceptibility x10⁻⁵ SI	Königsberger ratio	Inclination of remanent magnetisation degrees	Declination of remanent magnetisation degrees
Dolerite	3000	3000	1	–30	45
Gabbro, ultramafic layered intrusion	3035	2300 to 5500	0,56 to 1	47 to 90	0
Metagranitoid	2630	30	0,3	90	0
Metasedimentary rock	2720	20 to 700	1 to 5	90	0
Felsic metavolcanic rock	2621	10	0,3	90	0
Mafic metavolcanic rock	2970 to 3011	50 to 2300	0,4 to 1	90	0
Revsund granite	2730	40	1	90	0
Background value, Revsund granite or metasedimentary rocks	2730	40			



Late to post Svecokarelian intrusive rocks, c. 1.82–1.76 Ga
Sen- till postsvekokarelska intrusivbergarter, ca 1,82–1,76 Ga

- Granitoid, Revsund and Adak suites
  Granitoid, Revsunds- och Adaksviterna
- Mafic rock, Revsund and Adak suites
  Mafisk bergart, Revsunds- och Adaksviterna

Perthite monzonite suite, c. 1.88–1.86 Ga
Pertitmonzonitsviten, ca 1,88–1,86 Ga

- Alkali feldspar granite
  Alkalifältspatgranit

Arvidsjaur Group, c. 1.88–1.86 Ga
Arvidsjaurgruppen, ca 1,88–1,86 Ga

- Rhyolite
  Ryolit
- Andesite
  Andesit
- Dacite, lava
  Dacit, lava
- Dacite, volcaniclastic
  Dacit, vulkanoklastisk

Vargfors Group, c. 1.88–1.86 Ga
Vargforsgruppen, ca 1,88–1,86 Ga

- Magnesium basalt, volcaniclastic
  Magnesiumbasalt, vulkanoklastisk
- Magnesium basalt, lava
  Magnesiumbasalt, lava
- Sedimentary rock
  Sedimentär bergart

Skellefte Group, c. 1.90–1.86 Ga
Skelleftegruppen, ca 1,90–1,86 Ga

- Mafic volcanic rock
  Mafisk vulkanit
- Altered felsic volcanic rock
  Omvandlad felsisk vulkanit
- Closed mine
  Stängd gruva
- Deformation zone
  Deformationszon

Fig. 64. Bedrock map of the Adak area. For location of the area, see Fig. 50.

Berggrundskarta över Adakområdet. Områdets läge framgår av fig. 50.

graphic younging away from the core of the dome. Massive lavas with rare preserved plagioclase phenocrysts are found at some stratigraphic levels and coarse volcanic breccias have also been noted.

Granitoids belonging to the Adak suite of the Transscandinavian Igneous Belt (TIB) separate the Adak area from the main Skellefte District. The eastern side of the Adak dome structure is intruded by the Adak pluton, which forms an areally extensive (but thin) sheet east and south of the Adak area. Deep drilling has shown that the rocks of the Adak dome structure continue at depth east of the exposed dome below the granite sheet. Gabbroic sills, probably related to the late to post Svecokarelian intrusive rocks of the Revsund and Adak suites, intrude the rocks of the dome structure.

Fine-grained, dark grey greywackes and siltstones of the Vargfors Group stratigraphically overlie the mafic volcanic unit. These sedimentary rocks are not well exposed and are known mainly from drillcores. They contain sills of magnesium basalt with characteristic amphibole pseudomorphs of original augite phenocrysts.

West of the Adak dome, moderately west-dipping rocks of the Vargfors and Arvidsjaur Groups are exposed in a north-east trending belt. Magnesium basalts form the core of an antiformal structure, where an approximately 500 m thick package of lavas and overlying volcaniclastic rocks occur. The magnesium basalt lavas, locally with pillow structures, are mainly amygdaloidal. They contain amphibole pseudomorphs after augite, similarly to the sills in the hanging wall of the Adak dome. The volcaniclastic rocks are generally more plagioclase- and magnetite-enriched and rich in lithic fragments. Greywackes are found in places, both as inter-flow sediments and stratigraphically overlying the clastic magnesium basalts.

The magnesium basalts are overlain by grey dacitic lava domes (in the south-west) and dacitic volcaniclastic rocks with well preserved plagioclase phenocrysts,

which occur on both sides of the magnesium basalt antiform. A major thrust is interpreted on the south-eastern side of the antiform. The dacitic lava domes are interpreted as the lowermost stratigraphic unit of the Arvidsjaur Group in this area. The volcaniclastic rocks are mainly massive sandstones, displaying lamination in places. Units with coarse breccias occur as intercalations within these rocks. There is a lava dome of a similar composition in the southern part of the exposed dacite unit. Coherent (probably intrusive) plagioclase porphyritic andesites are found in the dacitic sandstones.

The dacites are overlain by massive ignimbrites of rhyolitic composition. They are purplish red and grey, variably porphyritic and strongly welded to non-welded. North-east of this area, an intrusive rock of the Perthite monzonite suite outcrops. The rock is a red, massive, medium-grained, even-grained alkali feldspar granite, which is rich in xenoliths close to the contact with the magnesium basalts and dacite unit.

The rocks of the Adak area are folded around north-east trending axes. The Adak dome structure is probably a later feature. Ljung (1974) suggested that granite, found in a deep drillcore at 750 m depth, caused the doming by diapirism. This granite is surrounded by a zone of migmatites, and the rocks of the dome structure are generally of a higher metamorphic grade than the surrounding greenschist facies rocks.

NATURE OF THE ARCHAEAN–PROTEROZOIC BOUNDARY IN THE LULEÅ AREA

The north-eastern part of the project area, occupying map sheets 24L Luleå, has recently been mapped at a scale of 1:50,000 (Wikström & Söderman 2000). The following text is a summary of results obtained during that work. The subdivision of the bedrock into different units, as presented in Figure 65, is preliminary and mainly tentative.

The Archaean unit

The oldest rocks within the project area are Archaean (c. 2700 Ma) metagranitoids and metagabbro. These rocks are found in larger blocks (several square kilometres), mainly with tectonic boundaries towards younger rocks, or intruded by granitoids of the c. 1.90–1.88 Ga Haparanda suite. Two main Archaean rock types have been identified. One is a porphyritic, gneissic metagranodiorite with feldspar phenocrysts around 2 cm in size. In some earlier investigations (e.g. Åhman 1953, Ödman 1957) it has been described as "Revsund granite". The other type is an assemblage of metatonalite, metatrondhjemite, and metagabbro, found mainly near Alhamn about 20 km south-southwest of Luleå and on the island Mannön. Rocks from this association have a similar field appearance to the Haparanda suite intrusive rocks.

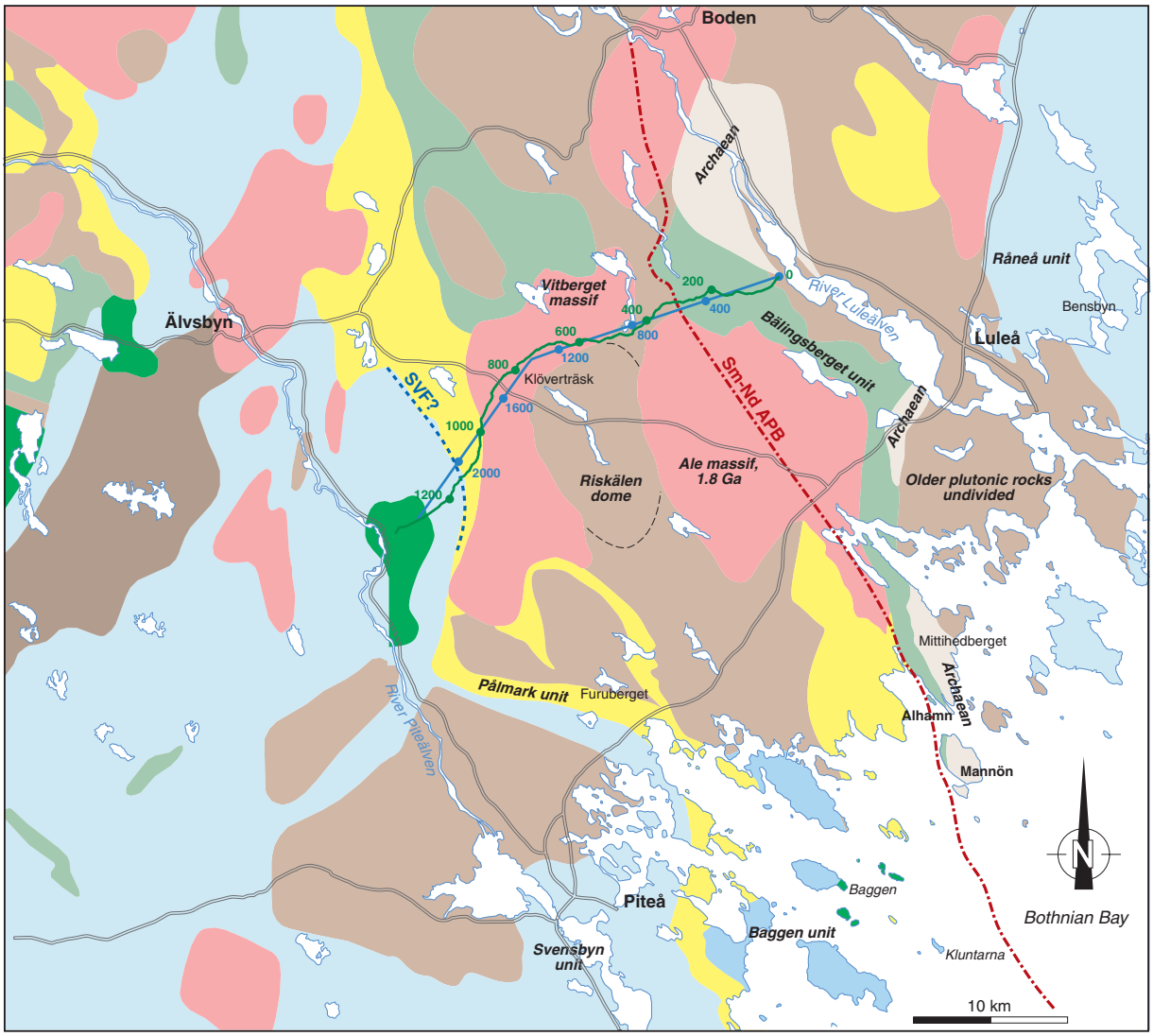
At Mittihedberget hill, the Archaean rocks are in close contact with Proterozoic supracrustal rocks. The basement–cover relationship described by Åhman (1953) at this locality has not been verified, however. The conglomerate units of Åhman (1953) have been interpreted mainly as subvolcanic magmatic breccias (Fig. 66) as described below (cf. Wikström & Söderman 2000). A unit dominated by steeply dipping westwards facing mafic metavolcanic rocks occur on the southern slopes of the hill. A wealth of younger, cross-cutting granites in this area has prevented a definite answer regarding the basement–cover relationship.

In the Björsbyn–Bensbyn area north of Luleå, another Archaean complex was identified by its very low initial $\varepsilon_{Nd\,(t=2.7)}$ values (Billström, unpublished). During the mapping programme it was noted to have a much more complicated deformation style than surrounding rocks. Radiometric results for these rocks are so far published by Lundqvist et al. (1996b, 2000) and Wikström et al. (1996a).

A special investigation of the $\varepsilon_{Nd\,(t=1.9)}$ values of the Haparanda suite metagranitoids has been made in the area (Mellqvist et al. 1999, 2003). One result of that investigation showed a very narrow boundary between rocks to the north-east, with a pronounced Archaean input during the magma generation, and rocks in the south-west, with almost no influence. This boundary also roughly follows the outcropping Archaean rocks.

The results of the BABEL seismic profile performed in the Bothnian Bay have been interpreted as demonstrating an old collision zone between a volcanic arc and continental crust (e.g. Öhlander et al. 1993, Lindsey & Snyder 1994) with north-eastwards moving thrusts. These interpretations are based mainly on south-dipping reflectors in the seismic profiles. Some north-dipping reflectors prograding into the mantle have also been interpreted as remnants of a subduction zone. The sharp change in ε_{Nd} values found by Mellqvist et al. (1999, 2003) also supports such a model.

A short complementary seismic profile was made in 1999 between the valleys of river Piteälven and river Luleälven and an interpretation of these data has been presented by Juhlin et al. (2002). At the moment very little in the surface structures can be used to support the suggested tectonic processes, however. One explanation for this could be that extensive magmatism around 1800 Ma, as well as large late shear zones, may be ob-



Late to post Svecokarelian intrusive rocks, c. 1.82–1.76 Ga
Sen- till postsvekokarelska intrusivbergarter, ca 1,82–1,76 Ga

Granite
Granit

Perthite monzonite suite, c. 1.88–1.86 Ga
Pertitmonzonitsviten, ca 1,88–1,86 Ga

Alkali feldspar granite
Alkalifältspatgranit

Early Svecokarelian calc-alkaline intrusive rocks, c. 1.90–1.86 Ga
Tidigsvekokarelska kalkalkalina intrusivbergarter, ca 1,90–1,86 Ga

Mainly mafic intrusive rock
Huvudsakligen mafisk intrusivbergart

Granitoid
Granitoid

Svecofennian supracrustal rocks, c. 1.96–1.86 Ga
Svekofenniska ytbergarter, ca 1,96–1,86 Ga

Felsic volcanic rock
Felsisk vulkanit

Mafic volcanic rock
Mafisk vulkanit

Coarse clastic rock
Grovklastisk bergart

Greywacke
Gråvacka

Archaean rocks, c. 2.7 Ga
Arkeiska bergarter, ca 2,7 Ga

Granodioritic to tonalitic gneiss
Granodioritisk till tonalitisk gnejs

SVF? Possible near-vertical fault interpreted from the seismic data
Brant förkastning, tolkad från seismiska data

Sm-Nd APB Archaean–Proterozoic boundary, Sm-Nd defined
Arkeisk–proterozoiska gränsen, Sm-Nd-definierad

1200 Seismic profile with station numbers
Seismisk profil med stationspunktnumren

2000 Processed CDP (common depth point) line
Processerad CDP ("common depth point") linje

Fig. 65. Bedrock map of the Luleå area. Modified from Juhlin et al. (2002). For location of the area, see Fig. 50. The Archaean–Proterozoic boundary as defined by the shift in the ε_{Nd} values is indicated. The reflection seismic profile by Juhlin et al. (2002) is outlined. Geological units are informal and discussed further in the text.

Geologisk karta över Luleåområdet. Modifierad från Juhlin m.fl. (2002). Områdets läge framgår av fig. 50. Den arkeiska–proterozoiska gränsen, definierad som förändring från positiva (proterozoikum) till negativa (arkeikum) ε_{Nd}-värden, är utmärkt. Den reflektionsseismiska profilen utförd av Juhlin m.fl. (2002) är markerad. Geologiska enheter är informella och diskuteras vidare i texten.



Fig. 66. Subvolcanic magmatic breccia with Archaean clasts. Mittihedberget, about 18 km south-west of Luleå (7275250/1784600). Photo Claes Mellqvist.

Subvulkanisk magmatisk breccia med arkeiska klaster. Mittihedberget, ca 18 km sydväst om Luleå.

scuring many of the earlier structures. A preliminary interpretation is that the western limit of the Bälingsberget unit, described below, is a terrane boundary and that the Ale granite is a "stitching pluton".

The Bälingsberget unit

A very specific type of violent magmatic activity has taken place near the boundary of the Archaean rocks. The conglomerate previously classified as "Bälinge conglomerate" (Åhman & Ödman 1952) west of Luleå has now been reinterpreted as a subvolcanic magmatic hydraulic breccia (Fig. 66) partly grading into volcanic extrusive rocks (Mellqvist 1993, Wikström et al. 1996b). Similar fragment-rich volcanic rocks have been observed in the vicinity of the outcropping Archaean rocks, and they dominate the volcanic rocks in the Luleå area.

The Råneå unit

In the area north-east of Luleå (with a probable Archaean basement) there are signs of a somewhat older Svecokarelian metamorphic and structural development than farther to the south. This is based on radiometric datings of the Degerberg granite (age c. 1885 Ma) as well as the Bläsberget dyke swarm with an age of c. 1880 Ma (Wikström et al. 1996c) both of which cross-cut migmatite structures in metasedimentary rocks. No further confirmation in terms of field observations for these findings have been made, however. In regional syntheses, like those of Lundqvist et al. (1996a), these rocks have been classified as Kalevian assemblages within the Karelian domain. On the "Bedrock map of the Skellefte District and surrounding areas" (Ba 57:1), these rocks are included within the Svecofennian Bothnian Supergroup (see also the chapter "Explanation to the bedrock map").

The Pålmark unit

This unit is dominated by rhyolitic and dacitic to andesitic, mainly fragment-rich pyroclastic rocks. It has been intruded by older plutonic rocks which have "juvenile" ε_{Nd}-values (Mellqvist et al. 1999, 2003) compared with corresponding rocks towards the north-east. No Archaean fragments, which are common in the Bälingsberget unit, have been observed. According to the model by Mellqvist et al. (1999, 2003), this unit has been thrust upon the Archaean continent in the north.

The boundary with the Svensbyn unit in the south and west is displayed as a regionally prominent structural feature on the magnetic anomaly maps. It has also been marked as a tectonic boundary on the Mid-Norden map (Lundqvist et al. 1996a). The fieldwork has not produced a definite answer about the nature of this zone. No tectonic boundary has been observed in the seismic investigation by Juhlin et al. (2002), possibly due to the fact that steep structures cannot be observed with that technique.

The Riskälen dome

Within and north of the Pålmark unit the older plutonic rocks are present as gneiss domes where e.g. the Riskälen dome is extremely deformed. In its marginal areas, the structures are similar to those recognized in extensional core complexes.

The Svensbyn unit

The marine sedimentary rocks of the Bothnian Supergroup north-east of Boliden continue to the north into the Piteå–Älvsbyn area where they are described as the Svensbyn unit. In general, they are strongly migmatized, rather monotonous metagreywackes with very little of primary structures preserved. They are poorly exposed.

The Baggen unit

Pillow lavas on the islands of Baggen and Kluntarna have previously been described by Åhman (1957). He suggested that they could have the same age as the lavas in the Kalix region, which now are regarded as being around 2200 Ma old. This stratigraphic position was also assigned to them on the Mid-Norden map (Lundqvist et al. 1996a). The lavas are surrounded by marine

sedimentary rocks, which have been deposited in an environment with high relief. Mass flow deposits are common. A granodiorite boulder within the Pite conglomerate, which is regarded here as belonging to the Baggen unit, has been dated at 1868±13 Ma (Persson & Lundqvist 1997) indicating a young stratigraphic position, comparable to that of the Vargfors conglomerates, for this low-grade unit.

THE "KRUKMAKAR" DISCONTINUITY ZONE

The existence of a tectonic discontinuity was postulated more than 20 years ago in what now is referred to as the "Krukmakar" discontinuity zone (Fig. 67). It was based on observations of discontinuities in geophysical anomaly patterns over a prospect of disseminated copper in a deformed granite, south of Krukmakarberget hill (7290990/1704600) to the west of Vistheden (Sjöstrand et al. 1979). Local minima in ground magnetic measurements and indications of coinciding weak electrical conductors from a horizontal loop EM (slingram) survey were considered to indicate deformation zones which were named the "Krukmakar line". Later these north–south trending zones were analysed in a regional tectonic perspective and were renamed the "Krukmakar fault zone" (Nisca 1995).

Due to its obscure character, we prefer to call this structure the "Krukmakar" discontinuity zone. It is divided into a northern and a southern part, where the northern part can be observed most easily in the datasets. The southernmost tip of the northern part is situated approximately 10 km south of Långträsk. From there it continues in an almost northerly direction for at least 50 km through the valley of the Småträsken lakes (7299490/1707310). A continuation of the same feature toward the south appears less clear. Other dis-

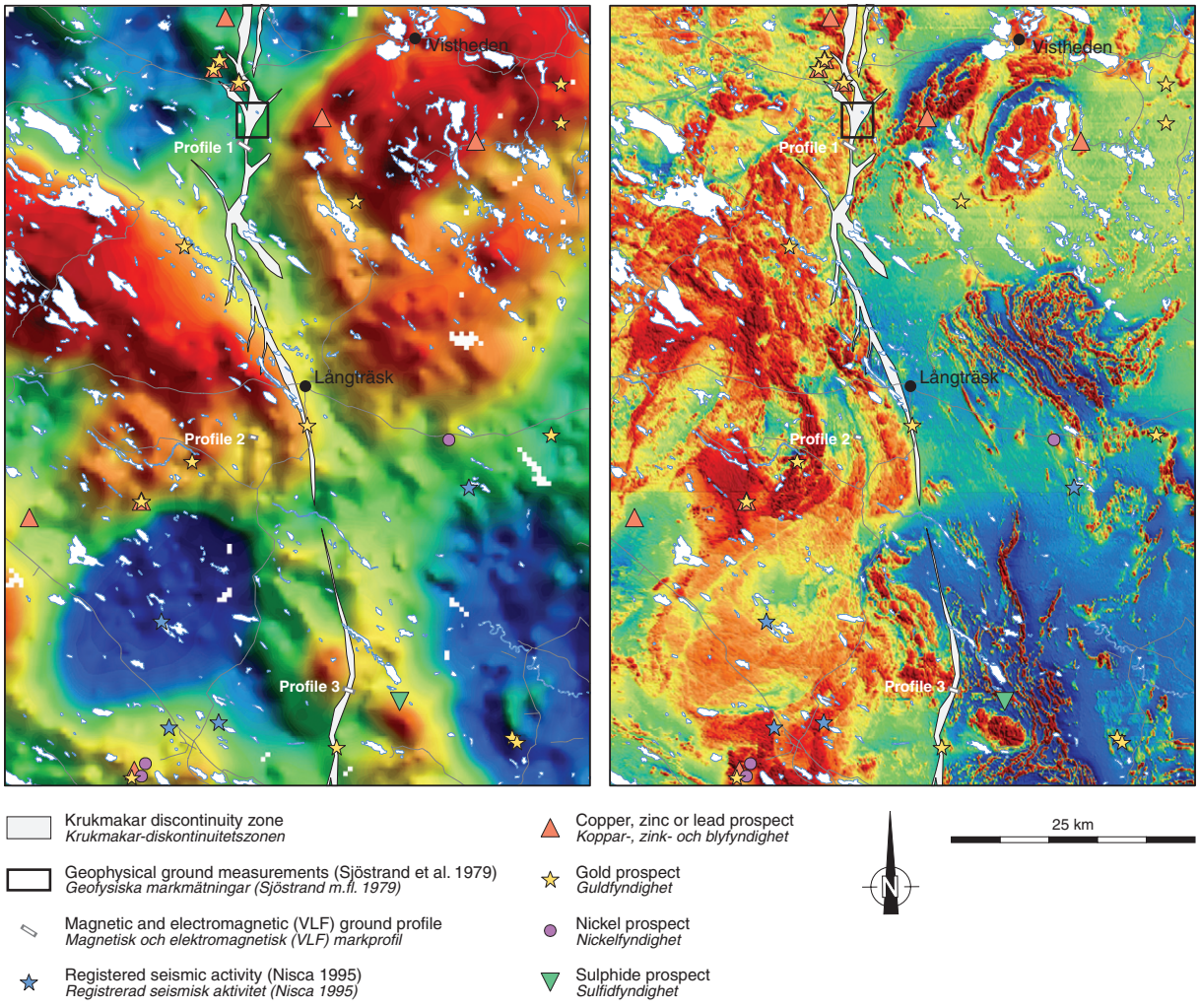


Fig. 67. Magnetic anomaly map and Bouguer anomaly map of the Krukmakar discontinuity zone. Location of profiles 1–3 are outlined. For location of the area, see Fig. 50.

Magnetisk anomalikarta och Bougueranomalikarta över Krukmakardiskontinuitetszonen. Lägena för profilerna 1–3 är angivna. Områdets läge framgår av fig. 50.

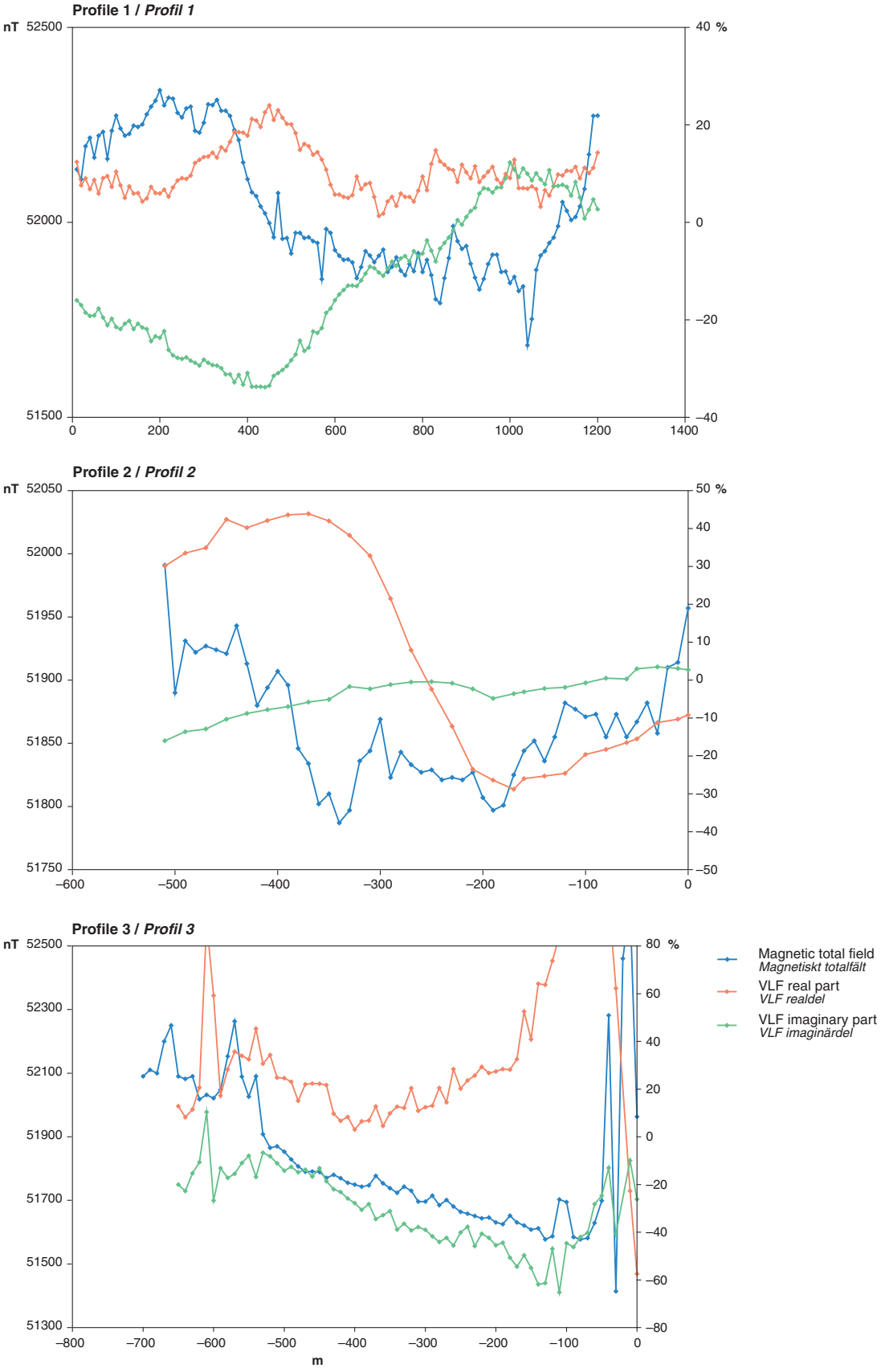


Fig. 68. Profiles 1–3 with measured magnetic total field and electromagnetic field (VLF; real and imaginary part) over the Krukmakar discontinuity zone. For location of profiles, see Fig. 67.

Profiler med mätningar av det magnetiska totalfältet och det elektromagnetiska fältet (VLF; real- och imaginärdel) över Krukmakardiskontinuitetszonen. Profilernas lägen framgår av fig. 67.

continuity zones are observed farther south, however, but their relations to the Krukmakar discontinuity zone are less clear.

In some parts within the project area, the Krukmakar discontinuity zone is interpreted to consist of one or several semi-parallel lineaments, probably indicating lithological discontinuities, with or without locally increased fracturing. In other areas, where the rock appears to be more uniform, the discontinuities are probably associated with increased fracturing only. On Krukmakarberget hill, where the Krukmakar discontinuity zone is exposed in a section of about 1 km, minor slickesides and increased fracturing (microbrecciation) of the rocks have been observed.

Within the project, electromagnetic (VLF) and magnetometer measurements have been carried out at a number of locations. A few kilometres south of the copper prospect south of Krukmakarberget hill (Sjöstrand et al. 1979), magnetic total field data show a marked magnetic minimum with a total width of more than 600 m (Fig. 68, profile 1). Within the low magnetic parts of the profile, the electromagnetic (VLF) measurements indicate more conductive zones, which are interpreted to reflect a deformation zone with mainly brittle deformation. It cannot be excluded that the broad low-magnetic zone (Fig. 68, profile 1) partly reflects ductile deformation. The total width of the discontinuity zone, including lenses of less deformed rock, is difficult to estimate. Where splaying appears to occur or where other discontinuity zones interfere, its overall width probably exceeds 1 km.

Post and late glacial faults were observed approximately 40–50 km farther south, indicating neotectonic seismic activity in the area (Rodhe et al. 1990). These post and late glacial faults, however, do not directly appear to belong to the same discontinuity zone discussed here. The source to the seismic events could be attributed to other semi-parallel fault zones of similar origin and history.

In the prospecting community, the "Krukmakar line" is regarded as an important feature governing mineralizations. As indicated by mineralogical studies, the prospect of disseminated copper reported by Sjöstrand et al. (1979) is most certainly genetically associated with tectonic events. In the area where copper-bearing boulders were found, several other tectonic features are also prevalent, as can be observed on the magnetic anomaly map. The gold occurrence south of Långträsk coincides with the discontinuity zone. However, gold occurrences in the region are also present in areas having no direct spatial correlation with the Krukmakar discontinuity zone. Farther south, the Björkdal gold deposit could possibly be related, at least spatially, to a southern continuation of this zone (cf. Weihed et al. 2003).

Observations of approximately north–south trending tectonic features are frequent in the northern part of the project area (cf. Bergman Weihed 1997, 2001). The Krukmakar discontinuity zone is one of the more easily recognizable, whereas others are less obvious, though known to exist. The importance of deformation in the formation and concentration of metals is well established and the Krukmakar discontinuity zone is one of several such zones within the project area that should be evaluated in that perspective.

Ores and mineralizations

In this chapter, mineral deposits in the Skellefte District and surrounding areas are described, grouped according to their lithotectonic setting, geographic position, metal content, alteration characteristics, and genesis. The presentation below follows the division into 19 different types of metallic and industrial mineral deposits used on the "Map of mineral and bedrock resources and hydrothermal alterations" (Ba 57:3) and also presented above in Table 4.

VOLCANIC ARC RELATED DEPOSITS

The Skellefte District *sensu stricto* has been interpreted as a Proterozoic analogue of a volcanic arc (cf. Weihed et al. 1992, Allen et al. 1996). It is defined by the presence of rocks of the Skellefte Group, characterized by subaqueous, mainly felsic volcanic rocks, deposited in the time interval 1.90–1.86 Ga with radiometric ages around 1.89–1.88 Ga. The Skellefte Group is spatially and temporally associated with metagranitoid plutons of the Jörn GI suite. The Skellefte Group hosts a large number of volcanogenic massive sulphide deposits (VMS, type 1), which form by far the most important economic deposit type in the mining history of the Skellefte District. The Jörn GI metagranitoids host non-economic porphyry copper deposits (type 3). Volcanic rocks of the Arvidsjaur Group and coeval intrusive rocks of the Perthite monzonite suite dominate

the bedrock in the area north of the Skellefte District. Small copper mineralizations of the disseminated type are known to exist in these intrusive rocks, but all are so insignificant that they have been omitted from Table 3. The replacement copper-zinc (Cu±Zn) ores (type 2) of the Adak mining camp, the Storliden mine, and the Svartliden mineralization are all probably related to the early evolution of the volcanic arc. These deposits share several characteristics with type 1 deposits but are characterized by stringer zone copper mineralization instead of massive sulphide deposits. In the description below, some replacement copper deposits are presented in the massive sulphide section. A few deposits, interpreted to have been formed by epithermal processes (i.e. the Boliden ore, Bergman Weihed et al. 1996), are known in the Skellefte District (type 4). These deposits may have been formed under subaerial or shallow-water conditions.

1. Volcanogenic massive sulphide deposits (VMS)

Volcanogenic massive sulphide (VMS) deposits are generally regarded as formed on the sea floor from hot metal-bearing sulphur-rich fluids in deep-water environments (Ohmoto & Skinner 1983). They are therefore regarded as syngenetic, exhalative sulphide deposits. Recent investigations in the Skellefte District and elsewhere have indicated that in many deposits, substantial amounts of the metals were precipitated below the sea floor as replacement mineralization (cf. Allen et al. 1996, Allen et al. 2002)

Volcanogenic massive sulphide deposits are the most common and the economically most important ore type in the Skellefte District. In Figure 69 the in situ value in Swedish kronor (SEK) is shown for the major deposits. Since 1924, about twenty larger ore bodies have been mined and another hundred have been discovered. Ongoing exploration work is still directed towards massive sulphide ores, mainly at deeper levels. In Table 3 (page 77–81) the 80 most important VMS deposits in the Skellefte District are listed. These have been divided into copper (Cu), zinc-copper (Zn-Cu), and zinc-copper-lead (Zn-Cu-Pb) deposits, according to Large (1992), see Figure 70. Some deposits, for example Svansele and Åliden, consist mainly of iron sulphides with low base metal content, and are therefore included

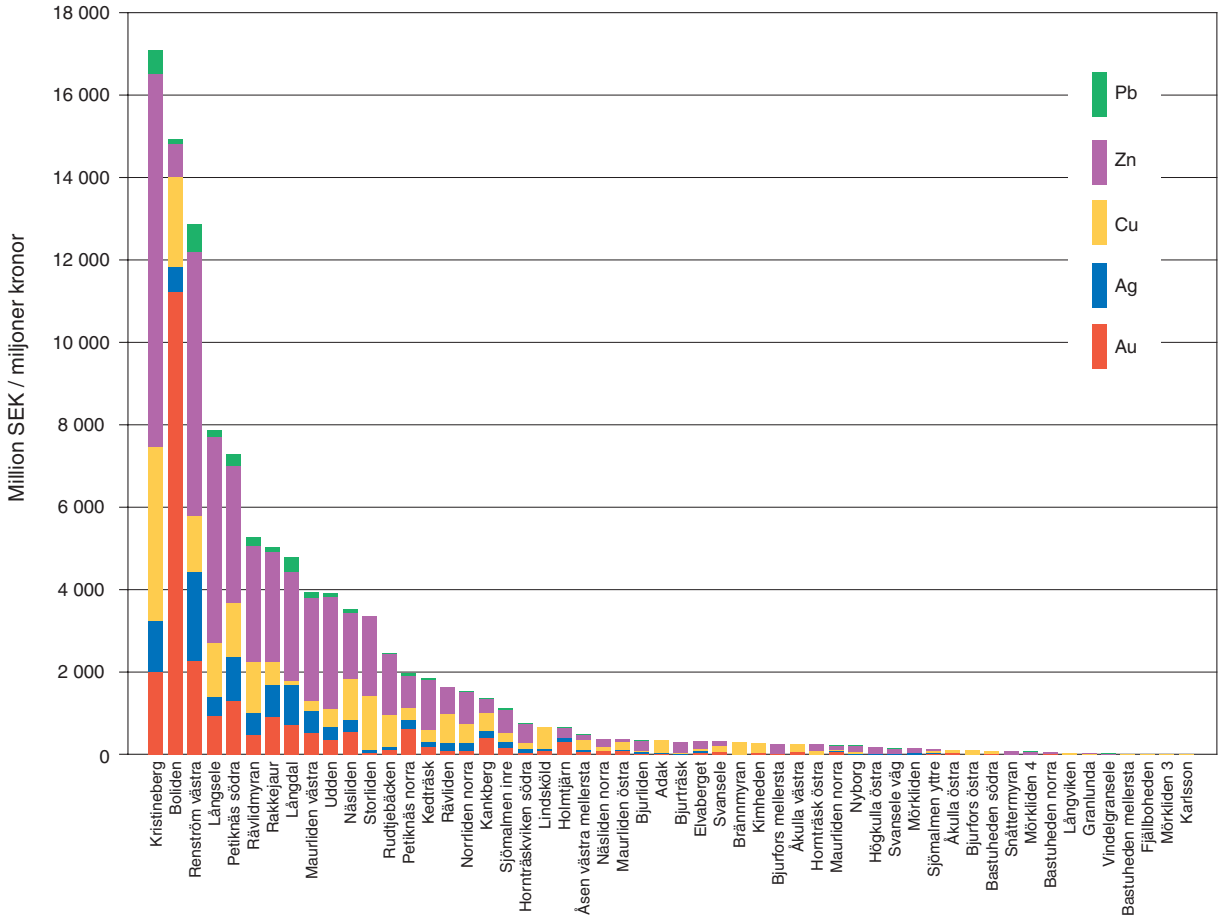


Fig. 69. In situ values of VMS ores in the Skellefte district. Metal price in year 2000.
In situ-värde för VMS-malmer. Metallpriser år 2000.

as iron sulphides in Table 3. It is evident that a few deposits (Kristineberg, Rakkejaur, Långsele, Kedträsk, Maurliden Västra, and Boliden) dominate the total tonnage of this ore type and they are all pyrite-dominated deposits with relatively low base metal grade (Figs. 71 and 73). High-grade base metal deposits (Cu+Zn+Pb >10%) are rare (Fig. 72), and the lead content is generally very low in the deposits of the Skellefte District. Precious metals contribute strongly to the economic potential of the massive sulphide deposits in the Skellefte District (Fig. 73), and many deposits have been mined due to their high content of precious metals. Three deposits – Boliden, Holmtjärn, and Petiknäs Norra – stand out as exceptionally gold-rich (>5 g/t). Many VMS deposits in the Skellefte District have a high arsenic content, and the correlation between arsenic and gold is sometimes strong, for example the high gold content in the massive arsenopyrite bodies in the Boliden deposit.

Many deposits show metal zoning within the ore body, whereas in some deposits copper- and zinc-rich ores are developed in separate ore zones forming adjacent lenses. Prominent copper-rich stringer zones occur in a number of the ores, and may form a substantial part of the total ore tonnage (cf. Allen et al. 1996). The Skellefte District can be divided into a number of domains (cf. Allen et al. 1996), each with a unique volcanic stratigraphy. A similar division is made here with some simplifications.

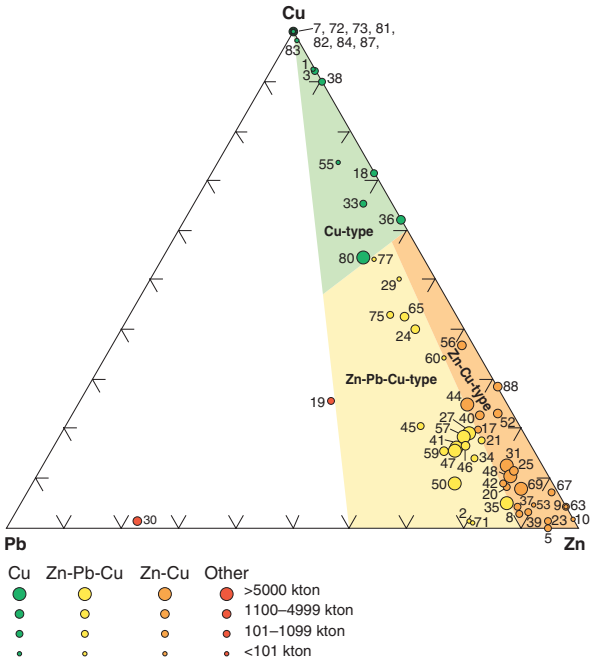


Fig. 70. Ternary Pb-Zn-Cu diagram of VMS ores. Subdivision of ore types after Large (1992). Numbers refer to deposit numbers in Table 3.

Triangeldiagram över Pb-Zn-Cu-innehåll i VMS-malmer. Underindelning av malmtyperna efter Large (1992). Siffrorna hänvisar till fyndighetsnummer i Tabell 3.

The Kristineberg domain

The Kristineberg domain, constituting the western part of the Skellefte District, is shown as the western Skellefte District in Ba 57:3. It is characterized by intense deformation of the metavolcanic rocks of the Skellefte Group and the sedimentary rocks of the Vargfors Group. The deformation intensity is partly a result of the original mica-rich rock, formed by large-scale alteration processes, and partly depending on the distance to the important deformation zones separating the bedrock of the Kristineberg area from less deformed rocks to the north-west and north. The Skellefte Group volcanic rocks form two antiformal structures or domes, where the core of the eastern, larger antiform is occupied by the 1907±13 Ma old (Bergström et al. 1999) Kristineberg

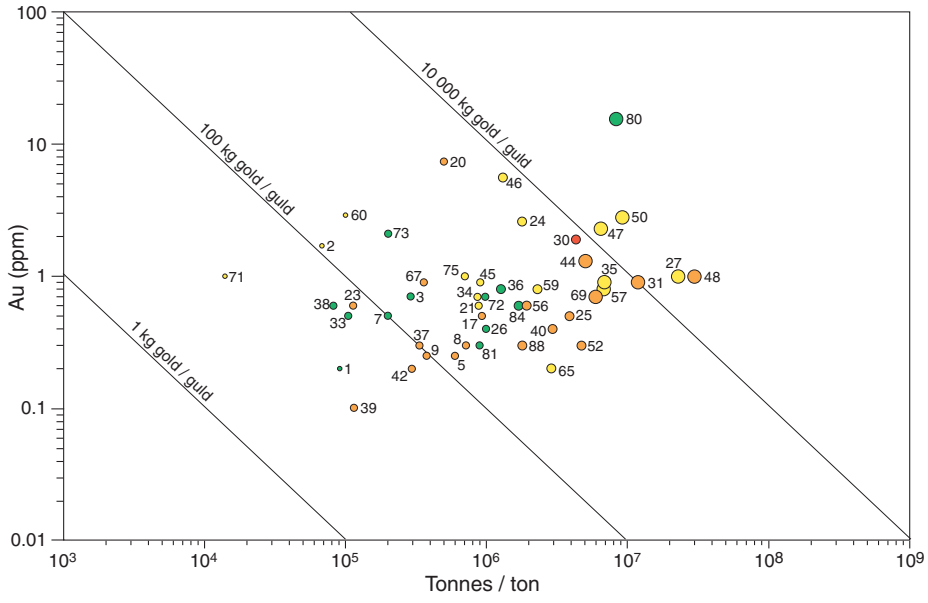


Fig. 71. Gold versus tonnage diagram for VMS ores. Numbers refer to deposit numbers in Table 3.

Guld mot tonnagediagram för VMS-malmer. Siffrorna hänvisar till fyndighetsnummer i Tabell 3.

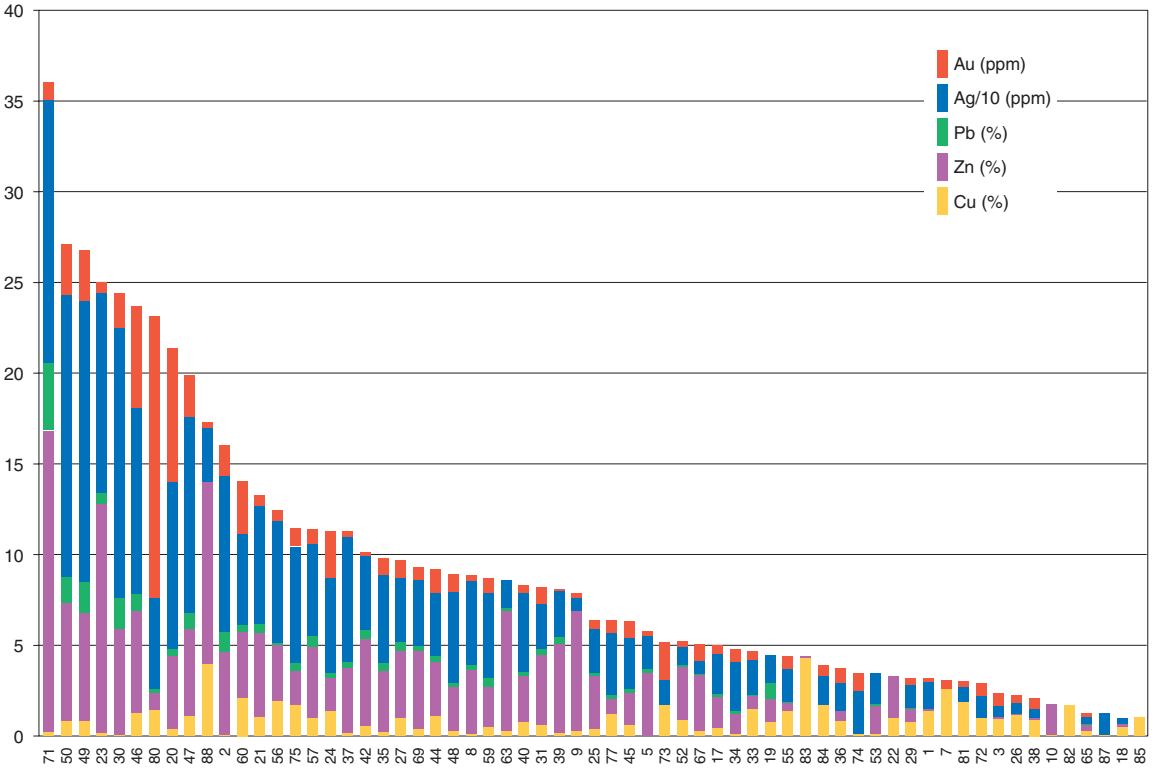


Fig. 72. Metal content of VMS ores. Numbers refer to deposit numbers in Table 3.

Metallinnehåll i VMS-malmer. Siffrorna hänvisar till fyndighetsnummer i Tabell 3.

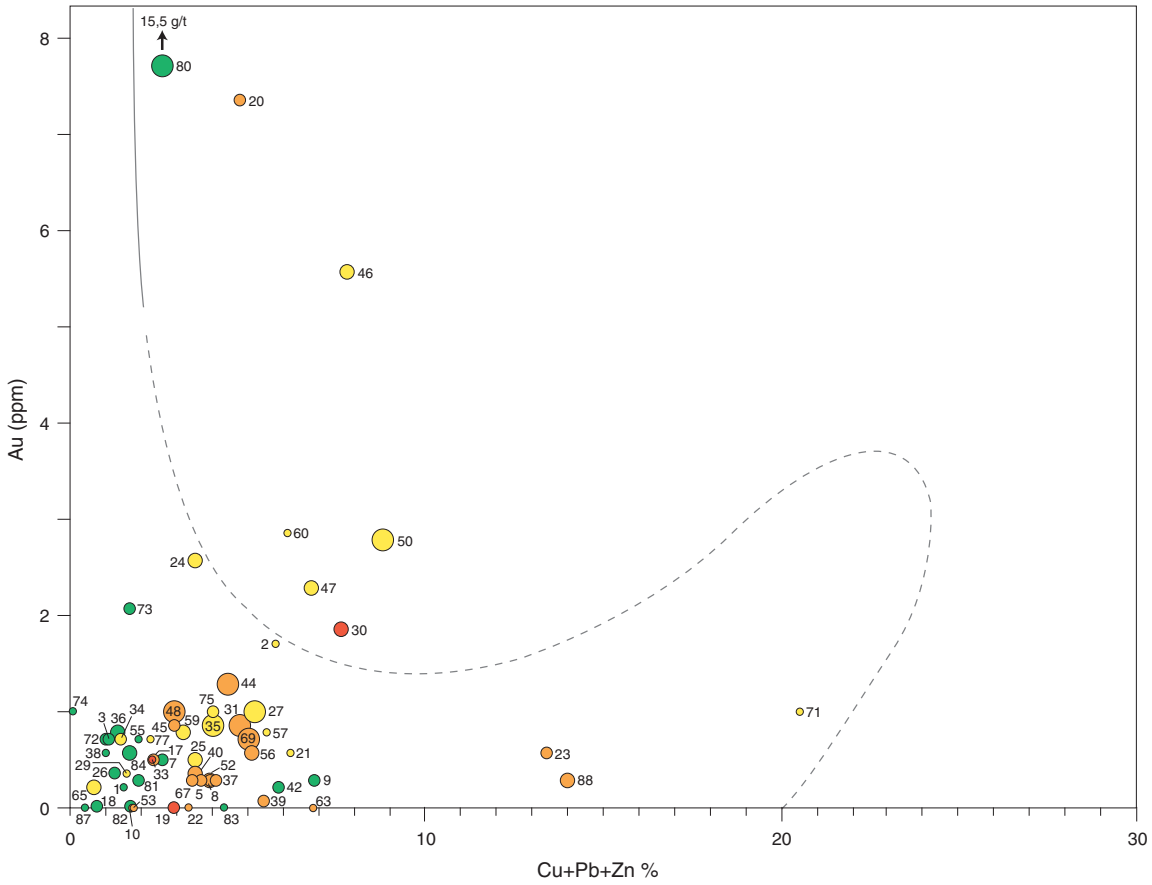


Fig. 73. Gold versus base metal content of VMS ores. Numbers refer to deposit numbers in Table 3. Dashed line indicates field for Australian VMS deposits after Large (1992).

Guld- och basmetallinnehåll i VMS-malmer. Siffrorna hänvisar till fyndighetsnummer i Tabell 3. Streckad linje indikerar fält för australiensiska VMS-malmer efter Large (1992).

metatonalite, belonging to the early Svecokarelian calc-alkaline granitoids, whereas the western antiform is cored by the late to post Svecokarelian Släppträsket pluton at approximately the same structural position. A synform with greywackes and intercalated ultramafic sills separates the two antiforms in the west.

The Skellefte Group metavolcanic rocks are mainly rhyolitic subvolcanic intrusions or lava domes and probably coherent volcaniclastic rocks. Willdén (1986) suggested that the volcaniclastic rocks occupied longitudinal synvolcanic depressions or rifts, formed during extensional phases of Skellefte Group volcanism. The depressions also focused later mafic volcanism, mainly emplaced as subvolcanic sills, and hydrothermal activity. The sericite and chlorite alteration processes affected large volumes of rocks, where original textures can only very rarely be observed. To the south, higher grade metamorphism formed andalusite-cordierite-bearing assemblages in analogous rocks. Magnetite is another important alteration mineral and alteration zones are generally outlined by their magnetic patterns.

A number of ore types are present in the Kristineberg area. The large Kristineberg deposit was originally a large, massive pyrite ore body with zinc-copper-gold-silver, transformed by deformation into a number of ore lenses. A fine-grained, late intrusive facies of the Kristineberg metatonalite, the Viterliden porphyry, intrudes the ore-bearing volcanic rocks close to the ore. The Kristineberg deposit was described by Du Rietz (1953), Edelman (1963), Willdén (1986), and Vivallo & Willdén (1988).

Farther to the north, at the same structural level as the Kristineberg deposit, the massive to disseminated Kimheden pyrite-chalcopyrite deposit occurs. Kimheden is hosted by strongly deformed and chlorite-altered volcanic rocks.

The stratigraphic position is somewhat different for the VMS deposits of the Rävliden area farther to the west. There, the ores are strongly stratigraphically controlled and occur along the contact with the overlying sedimentary rocks of the Vargfors Group. The favourable ore horizon in the Rävliden area is characterized by small sedimentary intercalations hosted by felsic volcaniclastic rocks. The Rävlidmyran deposit consists of one large pyrite-chalcopyrite ore body, the Sture ore, and a number of smaller, zinc-lead-bearing lenses, commonly associated with strongly deformed argillitic intercalations. In the Hornträskviken deposit, lenses of zinc-lead ore are restricted mainly to small carbonate occurrences. The Rävliden deposit includes one copper-rich ore lens and one zinc-rich lens, situated adjacent to each other.

Farther to the south, the small, low-grade Mörkliden ore bodies occur along the same stratigraphic horizon. They are mainly sphalerite-chalcopyrite disseminations with very little ferric oxide. The Nyborg deposit to the north is another example of the similar sphalerite disseminated type. The Vindelgransele area hosts only small VMS mineralizations, for example the high-grade Vindelgransele deposit.

Geology of the Kristineberg VMS deposit

The Kristineberg deposit is one of the largest polymetallic volcanogenic massive sulphide (VMS) occurrences in the Skellefte District. Exploitation of the deposit by Boliden Mineral AB started in 1941. By the end of 2001, 21.1 million tons, grading 1.05 g/t gold, 36 g/t silver, 1.04% copper, 3.64% zinc, 0.24% lead, and 25.9% sulphur, had been mined from surface down to approximately 1100 m depth.

The bedrock of the Kristineberg area comprises a thick pile of Palaeoproterozoic felsic and minor mafic metavolcanic rocks (Skellefte Group, cf. Allen et al. 1996) overlain by fine-grained turbiditic sedimentary rocks (Vargfors Group, cf. Allen et al. 1996). The Kristineberg deposit and the nearby Kimheden deposit to the north represent an ore horizon which seems to be developed rather deep in the volcanic stratigraphy, compared with many other similar deposits in the Skellefte District. The Rävliden horizon is developed in the upper part of the volcanic pile and occurs about 3 km west of Kristineberg (Fig. 74a; Table 7). In the latter, abundant calc-silicate assemblages and some marble associations occur which are only locally observed in the Kristineberg–Kimheden horizon.

The metavolcanic rocks at Kristineberg occur around and adjacent to the composite Kristineberg metatonalite massif, previously called the Viterliden intrusion (Du Rietz 1953, Edelman 1963, Rickard & Zweifel 1975, Willdén 1986). A marginal and late phase (called mine porphyry or Viterliden porphyry) of the Kristineberg massif has intruded the altered volcanic footwall rocks of the Kristineberg orebody and therefore post-dates the age of the Kristineberg deposit. The Kristineberg massif has been considered cogenetic with other synvolcanic metagranitoids in the Skellefte District (1.90–1.86 Ga).

Fig. 74. Bedrock of the Kristineberg area, **A**. simplified bedrock map; profile 1900Y indicated, **B**. profile 1900Y, generalized geology and ore lenses indicated.

*Kristinebergsområdets berggrund, **A**. förenklad berggrundskarta, sträckningen för profil 1900Y är markerad, **B**. profil 1900Y, generaliserad berggrundskarta med markerade malmlinser.*

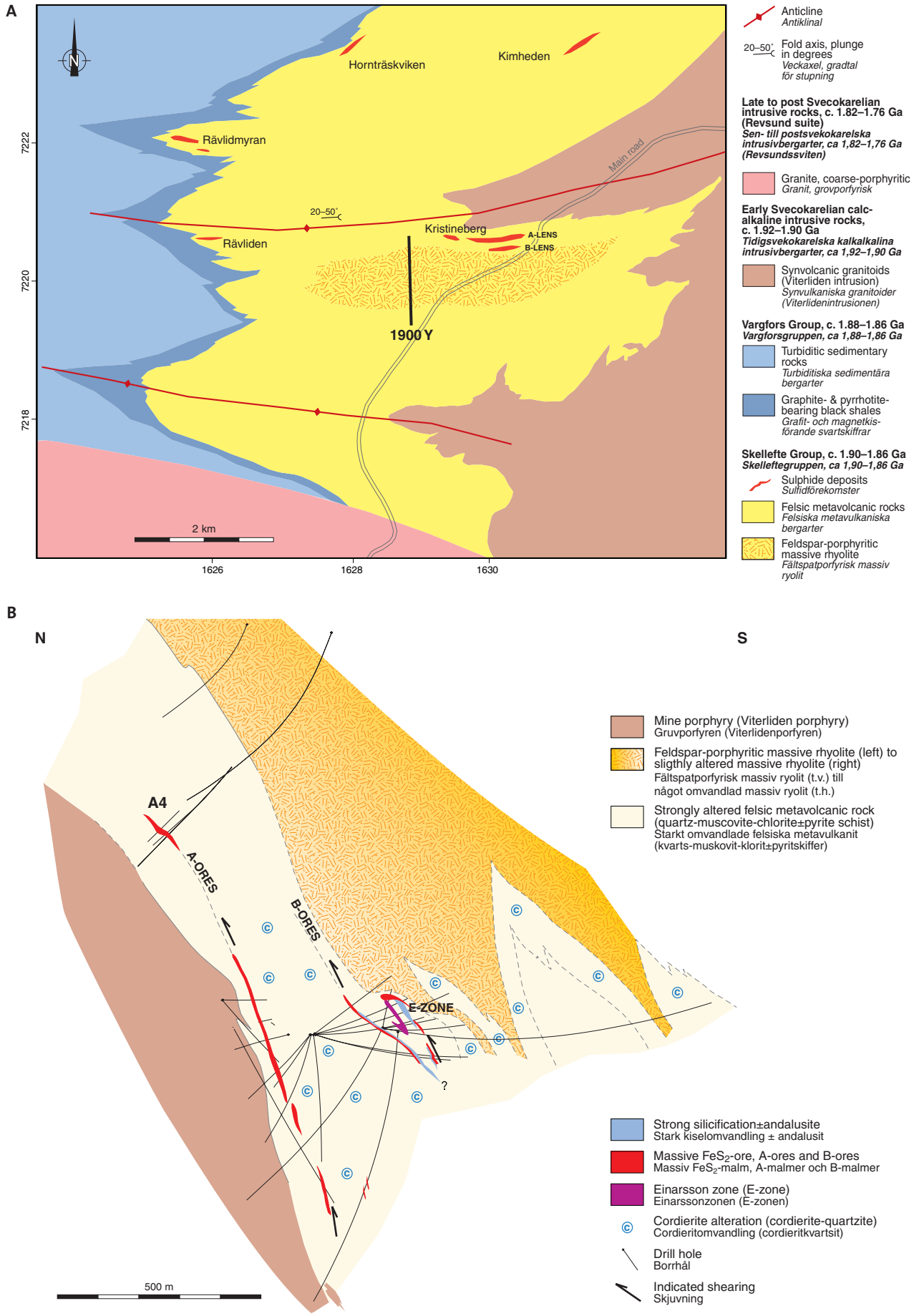

A
N
Hornträskviken
Kimheden
Rävlidmyran
Main road
20–50°
Kristineberg
A-LENS
B-LENS
Rävliden
1900 Y
2 km
7222
7220
7218
1626
1628
1630
Anticline
Antiklinal
20–50°
Fold axis, plunge in degrees
Veckaxel, gradtal för stupning
Late to post Svecokarelian intrusive rocks, c. 1.82–1.76 Ga (Revsund suite)
Sen- till postsvekokarelska intrusivbergarter, ca 1,82–1,76 Ga (Revsundssviten)
Granite, coarse-porphyritic
Granit, grovporfyrisk
Early Svecokarelian calc-alkaline intrusive rocks, c. 1.92–1.90 Ga
Tidigsvekokarelska kalkalkalina intrusivbergarter, ca 1,92–1,90 Ga
Synvolcanic granitoids (Viterliden intrusion)
Synvulkaniska granitoider (Viterlidenintrusionen)
Vargfors Group, c. 1.88–1.86 Ga
Vargforsgruppen, ca 1,88–1,86 Ga
Turbiditic sedimentary rocks
Turbiditiska sedimentära bergarter
Graphite- & pyrrhotite-bearing black shales
Grafit- och magnetkis-förande svartskiffrar
Skellefte Group, c. 1.90–1.86 Ga
Skelleftegruppen, ca 1,90–1,86 Ga
Sulphide deposits
Sulfidförekomster
Felsic metavolcanic rocks
Felsiska metavulkaniska bergarter
Feldspar-porphyritic massive rhyolite
Fältspatporfyrisk massiv ryolit
B
N
S
A4
A-ORES
B-ORES
E-ZONE
?
500 m
Mine porphyry (Viterliden porphyry)
Gruvporfyren (Viterlidenporfyren)
Feldspar-porphyritic massive rhyolite (left) to sligthly altered massive rhyolite (right)
Fältspatporfyrisk massiv ryolit (t.v.) till något omvandlad massiv ryolit (t.h.)
Strongly altered felsic metavolcanic rock (quartz-muscovite-chlorite±pyrite schist)
Starkt omvandlade felsiska metavulkanit (kvarts-muskovit-klorit±pyritskiffer)
Strong silicification±andalusite
Stark kiselomvandling ± andalusit
Massive FeS2-ore, A-ores and B-ores
Massive FeS2-malm, A-malmer och B-malmer
Einarsson zone (E-zone)
Einarssonzonen (E-zonen)
Cordierite alteration (cordierite-quartzite)
Cordieritomvandling (cordieritkvartsit)
Drill hole
Borrhål
Indicated shearing
Skjuvning

Table 7. Production tonnage and grades of the VMS deposits in Kristineberg area.
Producerat tonnage och halter för VMS-malmer I Kristinebergsområdet.

Mine	In operation (year)	Tonnage (Mt)	Gold g/t	Silver g/t	Copper %	Zinc %	Lead %	Sulphur %
Kristineberg*	1941–	21.1	1.05	36	1.04	3.64	0.24	25.9
Kimheden	1968–1970 1974–1975	0.13	0.44	7	0.95	0.27	–	18.4
Rävlidmyran	1950–1991	7.18	0.79	51	0.95	3.96	0.54	17.8
Rävliden	1941–1950 1966–1988	1.56	0.45	90	1.00	4.23	0.79	16.9
Hornträskviken M.	1981–1991	0.64	0.71	72	1.01	4.90	0.67	11.1
Total	1941–2001	30.3						

* To end of year 2001, excluding Einarsson Au-Cu lenses

The rocks surrounding the Kristineberg deposit have been strongly hydrothermally altered and are multiphase folded and strongly sheared. The schistose rocks are now dominated by quartz, muscovite, chlorite, and pyrite in varying proportions, and exhibit marked sodium depletion and co-enrichment of magnesium and potassium. Cordierite, phlogopite, and andalusite occur in considerable amounts. Kyanite has been observed in a few places, mainly associated with quartz veins. In general, the iron-magnesium alteration minerals are magnesium-rich and the modal chlorite content increases towards the Kristineberg ore horizon, which is surrounded by a halo of more muscovite-rich rocks.

The Kristineberg ore body has been divided into (1) the A-ores (main ore lenses) consisting of massive pyrite-dominated polymetallic (pyrite-sphalerite-chalcopyrite) lenses, (2) the B-ores, which are massive pyrite lenses rather poor in base metals (pyrite-chalcopyrite±sphalerite), situated in the structural hanging wall of the A-ores, and (3) the Einarsson zone, recently defined near the 1000 m level, and consisting mainly of gold- and copper-rich semi-massive pyrite-dominated lenses but also zinc-rich lenses, closely associated with the B-ores (Årebäck et al. 2000).

The bedrock of the Kristineberg deposit is shown in cross-section 1900Y (Fig. 74b). The mine porphyry (Viterliden porphyry) occurs in the footwall of the Kristineberg deposit, and a massive, feldspar porphyritic rhyolite forms the hanging wall. Close to the deposit, this rhyolite gradually becomes slightly to moderately muscovite±chlorite-altered. The intervening ore hosting sequence consists of strongly altered and schistose volcanic rocks. The dominating mineral assemblage of this unit is quartz, muscovite, chlorite, phlogopite, and pyrite with or without andalusite and cordierite.

The Adak domain

The north-western part of the Skellefte District is characterized by andesites and basalts of the Vargfors Group, which outcrop around the late to post Svecokarelian Adak pluton. A number of mineralizations are known from this area: Hälträsk (Allen et al. 1996), the Adak ores (including the Lindsköld, Brännmyran and Rudtjebäcken deposits), and the recently discovered Storliden deposit (Chevalier 1999).

The Adak area (Gavelin 1948) is a structural dome with the stratigraphically oldest, hydrothermally altered, felsic metavolcanic rocks of the Skellefte Group in the core, surrounded by mafic metavolcanic rocks of the same group. The Skellefte Group metavolcanic rocks in the Adak dome are almost entirely altered to cordierite-biotite-quartz-andalusite schists or gneisses (Ljung 1974). Strong alteration with antophyllite-cummingtonite-chlorite-magnetite assemblages occurs closer to the ore zones. Calc-silicate assemblages with grossular, wollastonite, and anorthite are frequent (Gavelin 1948).

Ores of the Adak domain are of two principal types: the "normal" VMS-type pyrite-zinc-copper deposit (Rudtjebäcken in the north-eastern contact zone between the Skellefte Group and the Vargfors Group) and a number of disseminated to semimassive chalcopyrite-pyrrhotite deposits. The Lindsköld deposit in the western part of the domain, and the Brännmyran deposit in the southern part, are stratiform, similarly to the Rudtjebäcken deposit, and seem to be at least partly hosted by metavolcanic rocks of the Skellefte Group. The Adak deposit and the smaller Karlsson and Långreven mineralizations are entirely hosted by altered Skellefte Group metavolcanic rocks and occur as a series of smaller ore lenses with a strong structural control. Below the ore lenses in the Adak mine, the altered volcanic rocks gradually pass into migmatites.

The Rakkejaur domain

A number of relatively large, but low-grade deposits, the Rakkejaur, Näsliden, Mensträsk (Sjömalmen Inre and Sjömalmen Yttre), and Maurliden Västra ores, occur in the western part of the central Skellefte District.

In this area, Skellefte Group metavolcanic rocks of mainly rhyolitic composition occur in a number of antiformal structures, with Vargfors Group sedimentary rocks in narrow synforms in between. Graphite- and sulphide-bearing argillites form an important marker horizon between the groups. The rhyolites form coherent porphyritic subvolcanic intrusions or volcaniclastic mass flows. Breccias of varying origins are common (Allen et al. 1996). To the south, Vargfors Group sedimentary rocks dominate and to the north, the Gallejaur–Högnäs intrusive complexes are exposed within the Vargfors Group volcanic and sedimentary rocks.

The western part of the central Skellefte District is intensely mineralized and several regional alteration zones exist with or without ores. Most alteration zones include weak quartz-sericite alteration with sulphide dissemination in porous volcaniclastic rocks. Carbonate alteration is common and may be mistaken for small occurrences of sedimentary carbonates in the ore-bearing stratigraphic horizons (Allen et al. 1996). Most alteration zones and ore deposits are restricted to the stratigraphic levels just below the above-named argillitic horizon.

The VMS ores in the area include some of the largest deposits in the Skellefte District, such as the Rakkejaur deposit (cf. Trepka-Bloch 1985, 1989). The tonnage figure (>20 million tonnes) for the Rakkejaur deposit (Fig. 75) in Table 3 is a conservative estimate on the upper part of the ore body. The total tonnage, including the poorly known deeper parts, probably exceeds 30 million tonnes. Generally, the deposits of the Rakke-

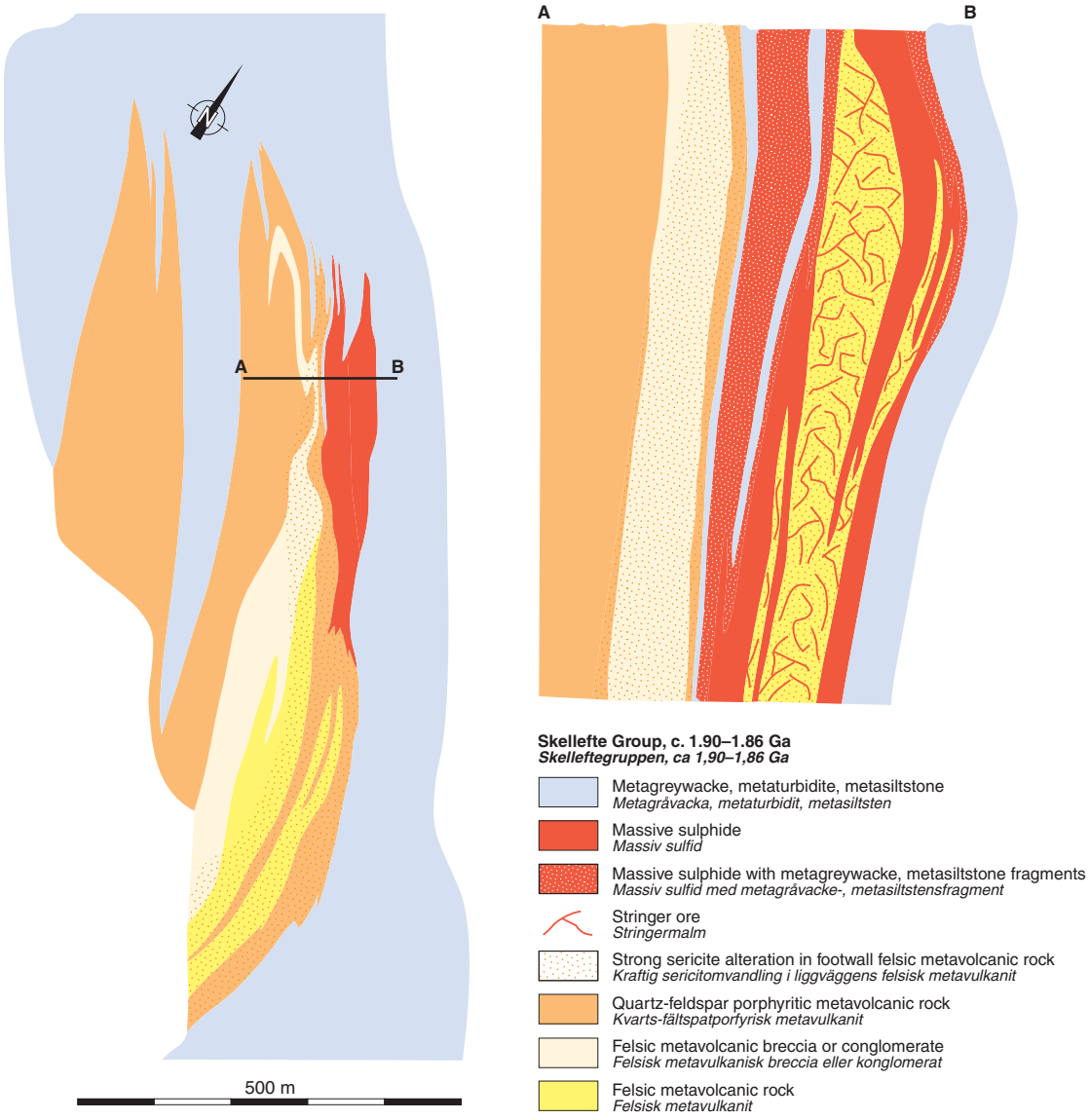


Fig. 75. Surface plan and cross-section through the Rakkejaur VMS deposit (modified from Trepka-Bloch 1989).
Ytgeologi och profil genom Rakkejaurs VMS-malm (modifierad från Trepka-Bloch 1989).

jaur domain are large, pyritic (S >30%) ores with low base metal content (Cu+Zn+Pb ~3–5%, with Zn/Cu ~3–5), and the economic potential of the deposits is dependent on the precious metal content (and size). The Näsliden deposit (cf. Svenson 1983) shows somewhat higher grades and is therefore the only ore body that has been mined (Fig. 76). Arsenic and arsenopyrite are common components within the pyrite ore (1.6% in the Rakkejaur deposit). The ores show zoning patterns with alternating zinc- and copper-rich zones. Silver occurs mainly in the zinc-rich parts, and gold and arsenic within the copper-rich parts. Alteration zones with sulphide dissemination and copper-rich stringers often exist.

A recently opened mine in the Skellefte District is the Maurliden Västra deposit, which started production in 2000. The geology of the four Maurliden deposits (Västra, Östra, Norra, and Centrala) has been described by Montelius (2001). The author describes massive, semi-massive, and vein type mineralization

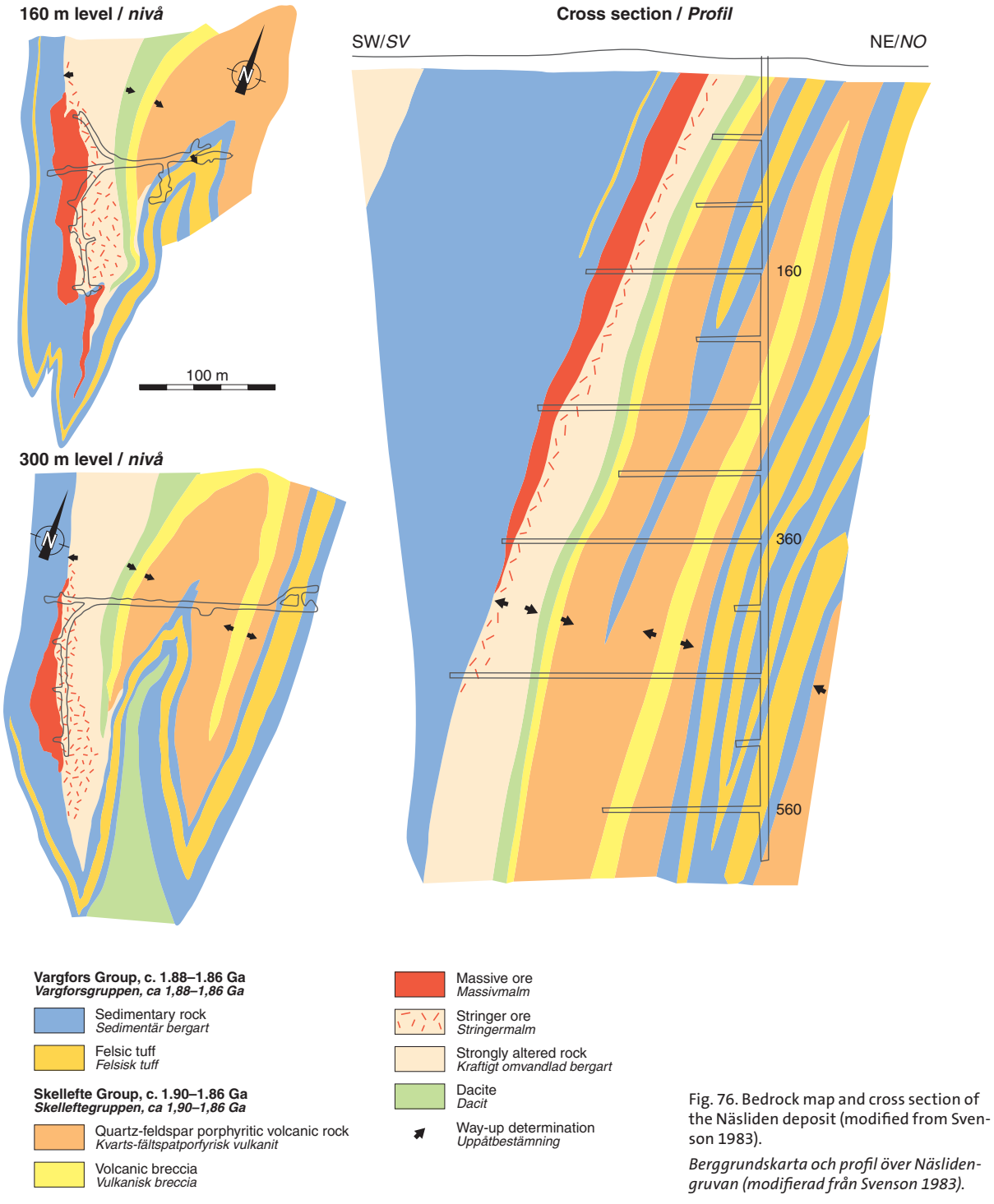


Fig. 76. Bedrock map and cross section of the Näsliden deposit (modified from Svenson 1983).

Berggrundskarta och profil över Näsliden-gruvan (modifierad från Svenson 1983).

hosted in a quartz-feldspar porphyritic coherent rhyolite and suggest that the replacement style of mineralization is transitional between typical VMS, porphyry, and high sulphidation type ores.

The Malånäset domain

The Central Skellefte District (CSD, Fig. 51) is characterized by numerous relatively small VMS deposits with varying metal contents. The Malånäset domain in the central part of the CSD includes Skellefte Group metavolcanic rocks and Vargfors Group sedimentary rocks, which occur along the river Skellefteälven, e.g. the traditional Malånäset area (7217010/1686010) south of the river and the Petikträsk area (7223580/1684160) north of the river. The Skellefte Group in the Malånäset domain consists mainly of rhyolitic, commonly quartz porphyritic subvolcanic intrusions and lava domes and their clastic equivalents and basaltic–andesitic lavas and sills (Gavelin 1939). No clear stratigraphic relationship between the felsic and mafic components is established, but most of the mafic volcanic rocks are probably older than the quartz porphyritic rocks. Intercalations of small mudstone lenses, volcanic breccias, and conglomerates are common in the upper part of the stratigraphy, and the favourable ore horizon is often found there.

The Vargfors Group sedimentary rocks are mainly mudstones–siltstones and greywackes in the lower part of the stratigraphy, but grade upwards into coarse conglomerates and sandstones (Allen et al. 1995).

The VMS ores of the Malånäset area are associated with both larger and volumetrically restricted alteration zones. Some copper-rich deposits, for example the Bjurfors Östra deposit, have extensive chlorite dominated alteration, whereas the zinc-rich Högkulla Östra deposit has scarcely any alteration zone. Increasing metamorphic overprint towards the south, for example in the Bjurliden and Bjurträsk Östra (Fig. 77) deposits, resulted in garnet-cordierite-gedrite-andalusite-bearing assemblages (cf. Gavelin 1939).

The ores are generally small (<1 million tonnes) and the metal content varies from pure copper deposits to zinc-dominated pyrite ores. The Holmtjärn deposit was rich in gold (Nicholson 1993), and the Högkulla Östra deposit is rich in zinc and silver.

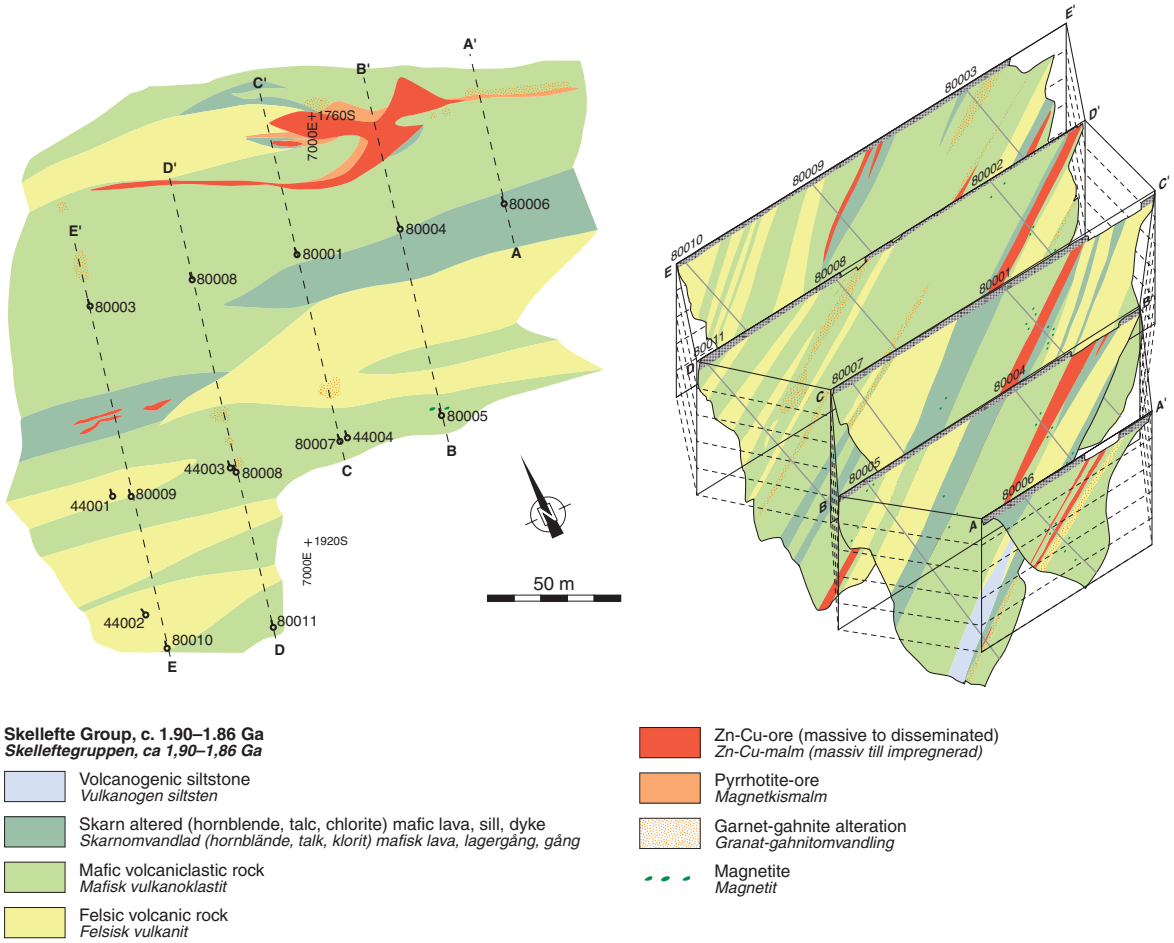


Fig. 77. Bedrock map and cross-sections of the Bjurträsk VMS deposit (modified from Claesson et al. 1981).
Berggrundskarta av och profiler genom Bjurträsks VMS-malm (modifierad efter Claesson m.fl. 1981).

The Udden domain

The Udden domain contains the Udden, Kedträsk, Svansele, and Åsen ÖM ores in the eastern part of the Central Skellefte District (Fig. 78). This part of the district is very poorly exposed and the geological information depends very much on results from drilling.

The bedrock in the Udden domain consists mainly of fine-grained, partly laminated, mafic and felsic volcaniclastic rocks. These rocks occur below the ore-bearing stratigraphic position, which is characterized by siltstones and quartz porphyritic volcanic rocks (Svenson & Jonsson 1992). Mudstones, siltstones and stratigraphically younger greywackes of the Vargfors Group occur at some distance above the ore-bearing levels.

The ores of the Udden domain generally lack widespread alteration zones including copper-rich stringers. Most alteration, as for example silicification, is restricted to the ore-bearing horizons, and chert horizons have been observed. The ore bodies are stratiform and form relatively thin but laterally extensive sheets (Fig. 79). The Åsen ores form a 4 km long, more or less continuous sheet. The ore bodies, mentioned in Table 3, may be regarded as local accumulations. Many of the ores in the Udden domain have Zn/Cu ratios around 10, except for the Åsen ores, which are more copper-rich, and the Svansele ore, which is a pyrrhotite-pyrite ore with very low base metal content. A more zinc-rich ore zone is found at depth in Svansele, but no figures are available. A specific feature of the Åsen ores is the high baryte content (Rickard et al. 1979).

The Renström domain

The high-grade Renström (cf. Duckworth 1991, Nordin et al. 1997, Allen & Svenson 2004) and Petiknäs ores are described as a separate domain between the Udden domain and a north-east to south-west trending late to post Svecokarelian granite intrusion of the Revsund suite. The geology of the Renström domain is described as one key area, "Renström–Petiknäs", on page 92 (Fig. 54). The Renström domain is confined

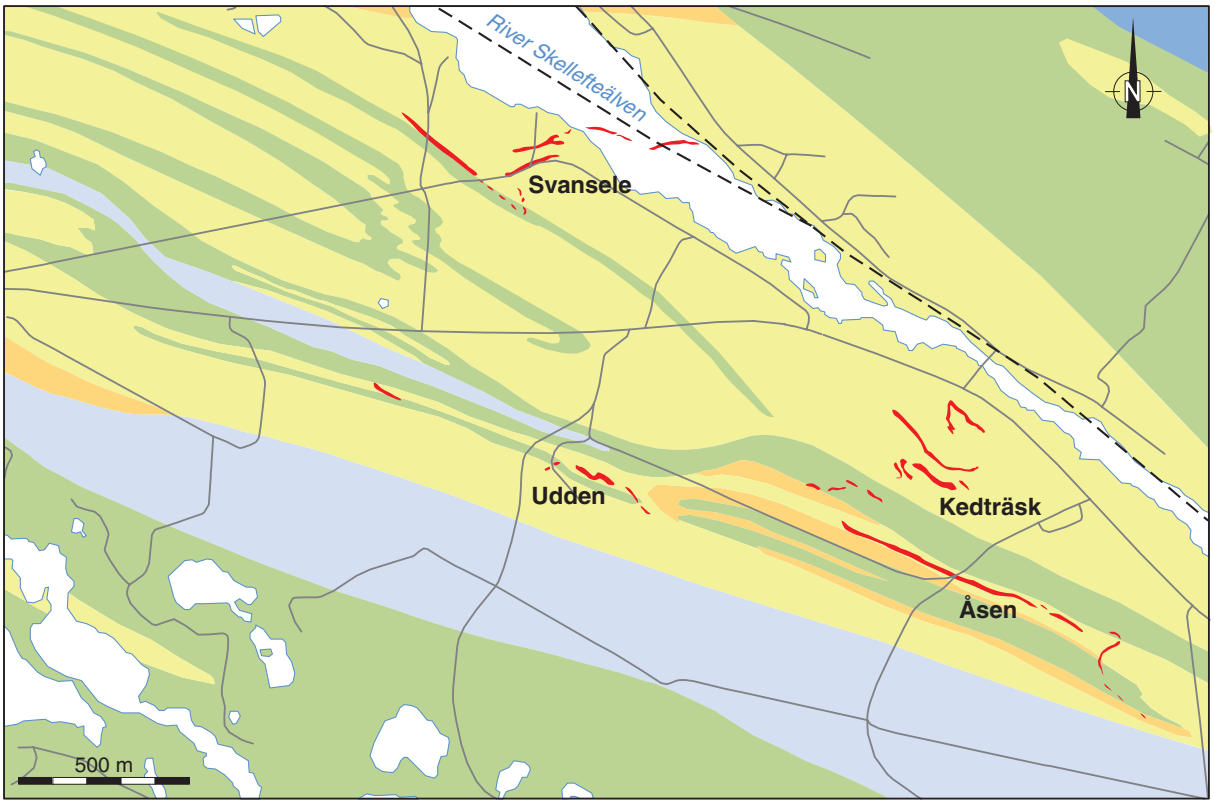


Fig. 78. Bedrock map of the Udden–Åsen area (Boliden Mineral AB, unpublished).

Berggrundskarta över Udden–Åsen-området (Boliden Mineral AB, opublicerad).

by the Rengård pluton (7209090/1699940) in the south and the Vänträsket pluton (7214400/1707550) in the north-east, both belonging to the Jörn GI suite. The metagranodiorite of the latter pluton is extensively overprinted by albite-chlorite alteration.

The ores in the Renström area are the Renström Västra, Renström Östra, and Renström Kyrkväg ore bodies (Fig. 80). Only the Renström Västra ore body is mined at present. It was discovered in 1921 and deep mine prospecting currently develops new ore bodies at

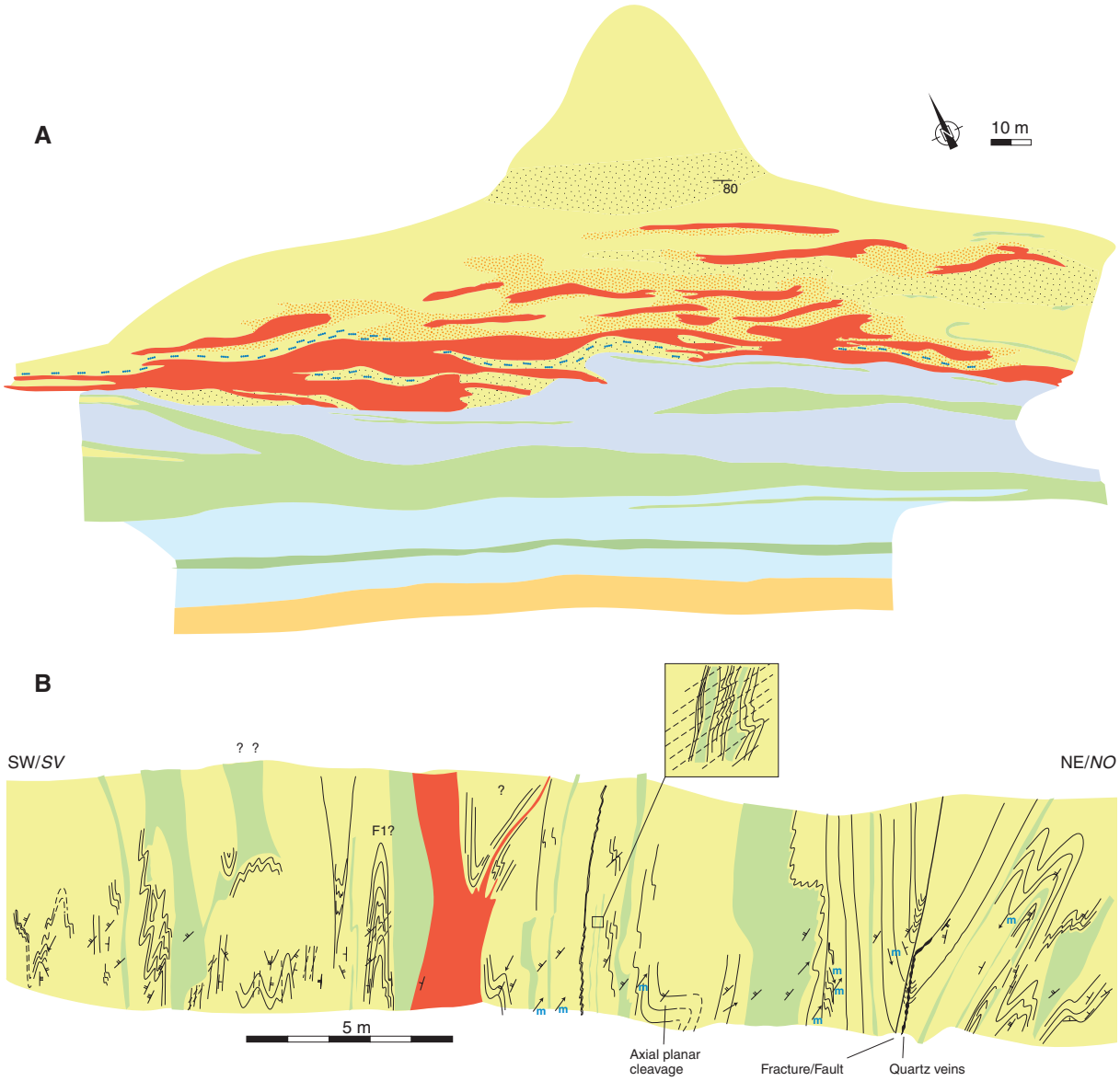


Fig. 79. Bedrock map of the Udden deposit. **A**. Surface geology of the Udden open pit. **B**. Structural interpretation of the eastern wall of the open pit. (Boliden Mineral AB, unpublished).

*Berggrundskarta över Uddengruvan. **A**. Ytgeologin i Uddens dagbrott. **B**. Strukturell tolkning av östra väggen i dagbrottet. (Boliden Mineral AB, opublicerad).*

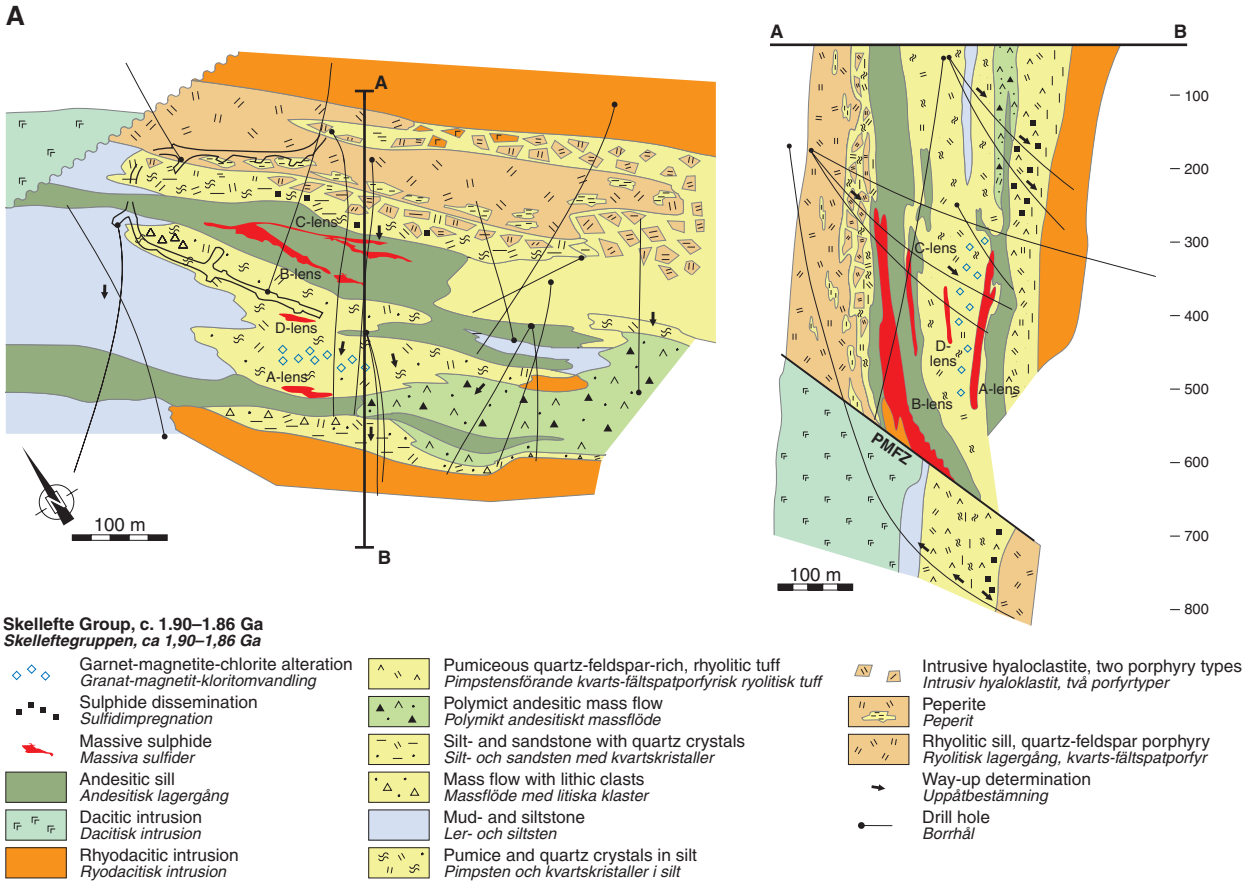


Fig. 80. **A**. Bedrock map of the 300 m level and cross-section through the Petiknäs deposits (modified from Nordin et al. 1997), PMFZ: Petiknäs Main Fracture Zone. **B**. Bedrock map of the Renström deposit (modified from Nordin et al. 1997).

***A**. Berggrundskarta över nivån 300 m och profil genom Petiknäsmalmen (modifierad från Nordin m.fl. 1997). PMFZ: Petiknäs huvudförkastningszon. **B**. Berggrundskarta över Renströmmalmen (modifierad från Nordin m.fl. 1997).*

depth. The host rocks are partly altered beyond recognition by chloritization, silicification, dolomitization, and sericitization, but a general lithologic sequence was presented by Nordin et al. (1997). The footwall sequence in all three ore bodies consists of more or less clastic basalts to andesites, partly emplaced in shallow water. The ore-bearing unit is a pumice-bearing silt- or sandstone. As the ore-bearing unit contains ash-flow tuffs, it must have been emplaced too rapidly for syngenetic ore formation. The ores are consequently regarded as replacement ores (Allen et al. 1996) and are underlain by distinct feeder zones with copper stringer mineralization. The hanging wall unit consists of laminated silt- and sandstones with black phyllite interbeds with traces of pyrrhotite and graphite. This unit is in turn covered by thick, rhyolitic mass flow deposits. Quartz-feldspar porphyritic rhyolite domes intrude both the ore-bearing unit and the hanging wall sequence and are associated with hyaloclastic and peperitic rocks.

In the Petiknäs area, the first of the Petiknäs Norra ore bodies was discovered in 1986, followed by one of the Petiknäs Södra ore bodies, in 1988. The footwall sequence of the Petiknäs Södra ore body consists of several rhyolite–rhyodacite domes, which have intruded at a shallow level into unconsolidated silty sediments. These domes have shed pumiceous silt- and sandstones into their surroundings. Together, the domes and silt- and sandstones form the ore-bearing unit in Petiknäs Södra. The hanging wall unit is dominated by a polymict, mafic mass-flow breccia of exotic provenance. Clearly, there was no room for syngenetic ore formation within the intrusive rocks of the ore-bearing unit and therefore also these ores are regarded as replacement ores. The volcanic rocks of the Petiknäs Södra mine are garnet-chlorite-altered and the mine sequence is strongly sheared. The main alteration minerals are sericite, chlorite, quartz, carbonate, and talc (Schlatter et al. 2004).

The ore stratigraphy in the Petiknäs Södra mine is cut by the Petiknäs Main Fracture Zone (PMFZ, see above) at the 775 m level. This deformation zone also separates the Petiknäs Södra ore bodies from the Petiknäs Norra ores, which are situated in another block, dominated by a sequence of more uniformly coherent, rhyolitic metavolcanic rocks. However, the ore-bearing unit in Petiknäs Norra is a rhyolitic, syn-eruptive mass-flow deposit, similar to the one in the Renström Västra mine.

The Boliden domain

The eastern part of the Skellefte Group contains numerous important VMS deposits. The Skellefte Group here is stratigraphically overlain by metasedimentary rocks of the Bothnian Supergroup towards east. The structural trend changes from the normal Skellefte District west-northwest trends to north and north-east trending folds and fault structures within the metasedimentary rocks. VMS deposits are confined to the southern part of the Boliden domain, and the Skellefte Group rocks are almost devoid of mineralization farther to the north.

The lower part of the Skellefte Group in the Boliden domain consists of rhyolitic lavas, subvolcanic intrusions, and volcaniclastic rocks, whereas the upper part is composed of dacitic subvolcanic intrusions and volcaniclastic rocks. Some minor sedimentary intercalations occur locally between the two units. Small quartz porphyritic stocks intruded the dacites, for example in the footwall of the Boliden and Långsele deposits. Mafic volcanic rocks are found in the uppermost part of the Skellefte Group, immediately below the argillites, indicating the transition into the metagreywackes of the Bothnian Supergroup. In the area north of the Kankberg deposit and east of the Boliden–Långsele–Långdal deposits, this transition zone is characterized by volcanic mass flows of rhyolitic and dacitic composition interbedded with mudstones and siltstones.

The rocks of the Boliden domain show several types of alteration assemblages. Regional, weak quartz-sericite alterations are common in porous volcaniclastic rocks, whereas the lavas and subvolcanic intrusions are generally less altered. Close to the VMS deposits, there are more intense sericite–chlorite alteration zones. Rather intense quartz–sericite–pyrite alteration zones without any known associated ore deposit are occasionally encountered. Characteristic of the Boliden area is a syn-metamorphic growth of actinolite, which occurs frequently and with varying intensity in all types of rocks.

The VMS deposits of the Boliden domain include the large pyrite ore body of Långsele, the sphalerite-galena-rich Långdal ore (Martinsson 1987b, Talbot 1988, Assefa 1990, Weihed et al. 2002b) and the copper-rich deposits of Åkulla Västra, Åkulla Östra, and Kankberg. A precious metal-rich ore zone occurs in the stratigraphic footwall to the massive ore of the Långdal deposit. High gold grades are common within the chalcopyrite-rich zones in Åkulla Östra and Kankberg.

The most complicated ore in this domain is the Boliden deposit (Fig. 81), which consists of a large pyrite-chalcopyrite ore body with sphalerite and large pods of massive arsenopyrite (Ödman 1941, Grip & Wirstam 1970). These pods are brecciated with chalcopyrite-pyrite-quartz stringers and contain high grades of gold. Below the massive ore a characteristic zoned alteration zone occurs, which shows increasing depletion of cat-

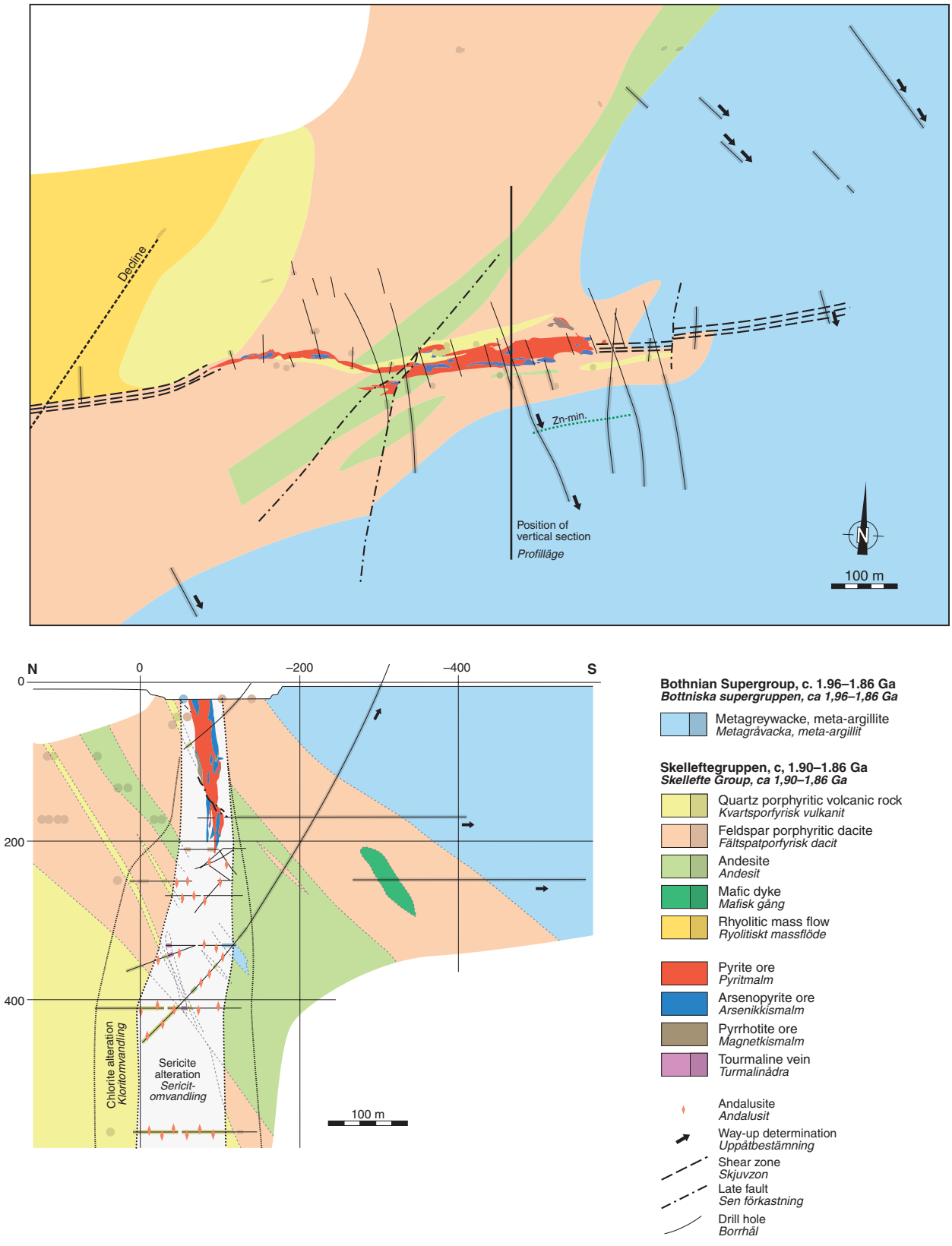


Fig. 81. Bedrock map of and cross-section through the Boliden deposit (modified from Bergman Weihed et al. 1996). Shaded parts of the legend boxes represent hand specimens and drill cores.

Berggrundskarta över och profil genom Bolidenmalmen (modifierad från Berman Weihed m.fl. 1996). Rastrerade delar av teckenförklaringslådorna representerar stuffer och borrkärnor.

ions inwards and quartz-tourmaline-gold lodes in the central andalusite-bearing core (Nilsson 1968, Bergman Weihed et al. 1996).

2. Replacement copper-zinc (Cu±Zn) deposits

In the Skellefte District, there are numerous copper mineralizations that have an unclear genetic relationship with the metavolcanic rocks of the Skellefte Group. Although they share many characteristics with the VMS deposits described above, they have been distinguished here as a separate type. The most important examples are found in the Adak area in the north-western part of the Skellefte District (the deposits are described above in the VMS section). In the Adak area, there is probably a genetic relationship between the Adak, Brännmyran, and Lindsköld replacement-type copper deposits and the Rudtjebäcken VMS deposit. Other replacement copper-zinc (Cu±Zn) deposits such as Storliden and Svartliden do not have this clear association with typical VMS ores.

The recently discovered Storliden deposit north of Malå (Imaña et al. 2004) is hosted by a sequence of andesitic volcaniclastic rocks and greywackes on the south-eastern side of the late to post Svecokarelian Adak pluton (cf. Chevalier 1999). The metamorphism is low grade, and the alteration zones are restricted mainly to the rock volume adjacent to the ore. The host rocks are mainly greyish and greenish laminated and massive rocks with an andesitic to dacitic composition and evidence of substantial reworking. Local intercalations of syneruptive, andesitic volcaniclastic rocks can be observed. Older quartz-feldspar porphyritic rhyolite intrusions occur to the south. To the north, the greywackes are separated from the andesites by north-west–south-east trending faults. The Storliden deposit forms an almost horizontal thick blanket, 100–150 m below surface. It consists of a high-grade massive stockwork, breccia, and dissemination of sphalerite-chalcopyrite-pyrrhotite ore with low precious metal content and minor arsenopyrite and galena. It bears some resemblance to the stratiform chalcopyrite-pyrrhotite Lindsköld and Brännmyran deposits in the Adak area. The major difference is the sphalerite content, which is very low in the Adak ores.

The metal content of the replacement copper-zinc (Cu±Zn) deposits is generally dominated by copper with low precious metal grades. In the Storliden deposit, however, copper is associated with 10% zinc (cf. Chevalier 1999), which only occurs in trace amounts in the Adak deposits. Arsenic is common in the Adak ores and massive arsenopyrite pods occur in the Lindsköld deposit (Ljung 1974).

The replacement copper-zinc (Cu±Zn) deposits locally form semi-massive chalcopyrite-pyrrhotite±sphalerite disseminations, commonly (but not exclusively) in stratiform ore lenses, enveloped in low-grade sulphide disseminations. As discussed above, the Adak and Storliden deposits are hosted by mafic volcaniclastic rocks of the Skellefte and Vargfors Groups respectively, whereas the Svartliden deposit is hosted by rhyolitic metavolcanic rocks of the Skellefte Group.

The ores are accompanied by extensive alteration with cordierite-antophyllite-chlorite-biotite assemblages in the medium-grade metamorphic Adak area and chlorite-dominated assemblages in areas of low metamorphic grade. Similar chlorite-dominated alterations exist in the copper-dominated VMS ores such as Bjurfors Östra and Åkulla Östra, and these VMS deposits probably constitute a transitional type of deposit between classical VMS type and replacement copper-zinc (Cu±Zn) type.

3. Porphyry copper-gold (Cu-Au) deposits

Large tonnage, low-grade copper mineralizations, commonly hosted by porphyritic granitoids, are an important deposit type in Mesozoic continental and island arc systems. Precambrian analogues are relatively sparse, but have been described from virtually all shield areas, for example from Finland (Gaal & Isohanni 1979) in a geological environment similar to that of the Skellefte District, the Australian Shield, Indian Shield, Canadian Shield, and the South African Shield (see Sikka & Nehru 1997 and references therein).

Porphyry copper mineralizations in the Skellefte and Arvidsjaur volcanic arc systems are confined mainly to the Jörn granitoid complex in the north central part of the Skellefte District (cf. Weihed 1992a). Local disseminations of sulphides are found in the intrusive rocks of the Perthite monzonite suite, but these are not economically important. Copper disseminations related to chloritic alteration occur at Viterliden (7220870/1632350) in the Kristineberg massif. The albite-chlorite alteration in the Vänträsket pluton (7214400/1707550) of the Jörn GI suite shows weak mineralization, but only the Jörn GI metagranitoids of the Jörn granitoid complex contain substantial mineralizations.

In the Tallberg and Granberg deposits (Table 3), chalcopyrite-pyrite±gold disseminations are associated with small quartz-feldspar porphyritic stocks and dykes, which are intrusive into the Jörn GI metagranitoids of the Jörn granitoid complex (Weihed 1992a, b). These porphyritic rocks are broadly coeval with the hosting Jörn GI metagranitoids (Weihed & Schöberg 1991), but their chemical composition is different, which sug-

gests a somewhat different origin. Porphyry intrusions without substantial mineralization, but commonly with trace sulphides, are found in several places in the Jörn granitoid complex. Abundant mafic dykes intrude the Jörn GI metagranitoids as well as the porphyritic rocks, but whether or not the dyke frequency is higher in the Tallberg and Granberg areas, compared with the rest of the Jörn granitoid complex, is unclear.

In the Tallberg area the copper-gold (Cu-Au) mineralization is related to a large alteration zone (Fig. 82). The hosting metatonalite and subordinately the porphyry dykes are altered into a chlorite-epidote-sericite-calcite-magnetite assemblage with low-grade pyrite dissemination (Weihed 1992a, b). A quartz brecciation is coeval with the alteration. In the central part of the mineralized area, the breccia includes sulphide stringers with pyrite, chalcopyrite, molybdenite, and sphalerite. The molybdenum content is restricted to the central high-copper core, whereas the zinc and lead contents are higher in the outer parts of the mineralized area (Weihed 1992b).

4. Epithermal gold (Au) deposits

Gold deposits form an important metallogenetic component in many volcanic arc systems. In modern arcs, gold mineralizations are mainly epithermal and related to volcanic or plutonic activity within active hydrothermal fields. From a number of areas in the world, it has



Fig. 82. Bedrock map of the Tallberg deposit (from Weihed 1992a).

Berggrundskarta över Tallbergfyndigheten (från Weihed 1992a).

recently been suggested that old metamorphic analogues to epithermal deposits can be identified by mineralogical and geochemical means. The most characteristic features are strongly cation-leached rocks formed by advanced argillitic alteration. The greenschist–amphibolite facies metamorphic analogues to these deposits are altered rocks dominated by quartz and andalusite (cf. Bergman Weihed et al. 1996).

In the Skellefte District, some deposits are possibly of an epithermal origin. The Boliden deposit was interpreted by Bergman Weihed et al. (1996) to be an epithermal system. Other possible analogues are the bismuth-tellurium-bearing andalusite-rich rocks at Mångfallberget (see pages 96 and 146), and the silicified sulphide-bearing quartz porphyritic volcanic rocks in the Stentjärn deposit.

The Boliden deposit has been described above as a very complex deposit with a variety of ore types. The main ore body consists of a massive pyrite-chalcopyrite-sphalerite ore with large massive arsenopyrite ore pods and quartz-chalcopyrite-pyrrhotite breccia stringers. An east–west-striking fault cuts the ore zone, and the massive ores are strongly deformed, with tectonic banding in the pyrite ore, strong brecciation of the arsenopyrite ore, and apophyses and remobilization of sulphides (Bergman Weihed et al. 1996). Mafic dykes that intruded the ore have been brecciated. A prominent alteration zone occurs below the massive ore with strong zoning from an outer chlorite zone, an intermediate sericite zone, and an andalusite-rich central core (Bergman Weihed et al. 1996, Hallberg 2001). Within the central part of this alteration zone, quartz-tourmaline lodes, young fault zones, and rutile-rich rocks are associated with high gold grades. The alteration zone follows the major fault zone, and gold-bearing zones have been found down to 800 m depth which is 500 m below the lowest section of the massive ore. The strong leaching of cations in the centre of the alteration zone and the association with quartz-tourmaline-gold lodes suggest that an epithermal hydrothermal system was active, possibly focused on the fault zone.

MAGMATIC DEPOSITS RELATED TO ULTRAMAFIC AND MAFIC ROCKS

Magmatic sulphide deposits are sulphide segregations formed from mafic and ultramafic magmas. They are typically nickel-copper and platinum group element (PGE) deposits related to mafic–ultramafic rocks. Nickel exploration in the 1940s led to the discovery of the small Lainijaur deposit (Fig. 83), a lopolithic gabbro hosted by sedimentary rocks in the western part of the Skellefte District (Grip 1961, Martinsson 1987a). Apart from Lainijaur, no important nickel mineralization was found within the Skellefte District at that time, partly because of the lack of knowledge about the host rocks of nickel deposits. In the Burträsk area, the Swedish state started exploration for nickel in the early 1970s, based on two important factors: the discovery of a number of important nickel deposits in a similar environment in Finland (cf. Papunen & Gorbunov 1985) and the availability of aeromagnetic maps. Soon, a number of nickel mineralizations related to small ultramafic intercalations in paragneisses were found along an important west-southwest–east-northeast striking tectonic zone, subsequently called the Nickel zone (Nilsson 1985). The Nickel zone (cf. Ba 57:3 map "Ni deposits in the so-called Nickel zone") form a border zone between rocks of the Skellefte Group and metagranitoids of the Jörn GI suite in the north, and high-grade paragneisses and migmatites of the Bothnian Supergroup in the south. The Nickel zone is a c. 20 km wide zone of parallel west-southwest–east-southeast trending, anastomosing shear zones, which were probably active over a long time span. The metamorphic grade in the area is middle to upper amphibolite facies, with the common occurrence of garnet-bearing, muscovite-free veined paragneisses and amphibolites. The metamorphic assemblages in the Nickel zone (few garnets, no sillimanite) suggest lower pressure than the high-pressure (abundant garnet-sillimanite) grade metamorphic rocks to the south.

Within the Nickel zone, trial mining was performed in e.g. the Lappvattnet deposit (Fig. 84). However, for various reasons the ore was not exploited, but is now the target of renewed interest. After the activities in the Burträsk area, the Njuggträskliden A–D deposits were found in the Risliden area (7192090/1671680), and indications of nickel mineralizations were also found in the Älvsbyn area. Since the mining of the Lainijaur deposit during World War II, no nickel ore has been produced from the Skellefte District.

The host rocks of the mafic–ultramafic hosted magmatic ore deposits are here divided into two types: deposits related to ultramafic intrusions in metasedimentary rocks, and deposits related to younger gabbroic rocks. The deposits of the former type have Ni/Cu ratios around 5, whereas the gabbro-related deposits have a much higher copper content. Deposits of the gabbro-related type also contain some PGE mineralizations. The Njuggträskliden ultramafic deposits also have a significant PGE content, which makes them the only examples of their kind, different from the ultramafic deposits of the Nickel zone. Most nickel deposits also contain traces of cobalt. The nickel content of the ultramafic deposits, calculated to 100% sulphides is generally 7–10%, but follows the MgO content and may be higher in rocks

with a high MgO content (Nilsson 1985). The gabbro related deposits have a nickel content of approximately 3%, when calculated to 100% sulphides.

5. Ultramafic associated nickel (Ni) deposits

The ultramafic rocks within the Nickel zone occur as sills, pipes, or remnants of larger, layered intrusions hosted by the paragneisses. Larger ultramafic bodies, which probably constitute parts of primary layered intrusive complexes, are found at Rörmyrberget and Mora (7162870/1734960). Most ultramafic rocks are serpentinized peridotites or picrites and in several places they contain weak sulphide disseminations (Nilsson 1985). Preserved igneous textures are very rare. Gabbroic rocks are sparse in the area. The paragneisses that host ultramafic rocks are commonly rich in graphite and sulphides.

The nickel-copper ores are confined mainly to the ultramafic bodies. Extensive remobilization has occurred in many deposits, and the sulphides have probably been mobilized into the surrounding paragneisses as fragmental or breccia ores (Nilsson 1985). The fragmental ore is a sulphide-rich type with numerous inclusions of surrounding rocks. In the ultramafic bodies, the ore occurs both as an even distribution of sulphides and as veins. A massive ore type has only been encountered in a minor part of the Mjövattnet deposit. In the Rörmyrberget deposit, several minor ore lenses are hosted by ultramafic rocks. The ore occurs as separate lenses with varying metal content, mostly of low grade. The Rörmyrberget data in Table 3 concern the main ore zone, but the combined tonnage of all the Rörmyrberget ore lenses is much higher.

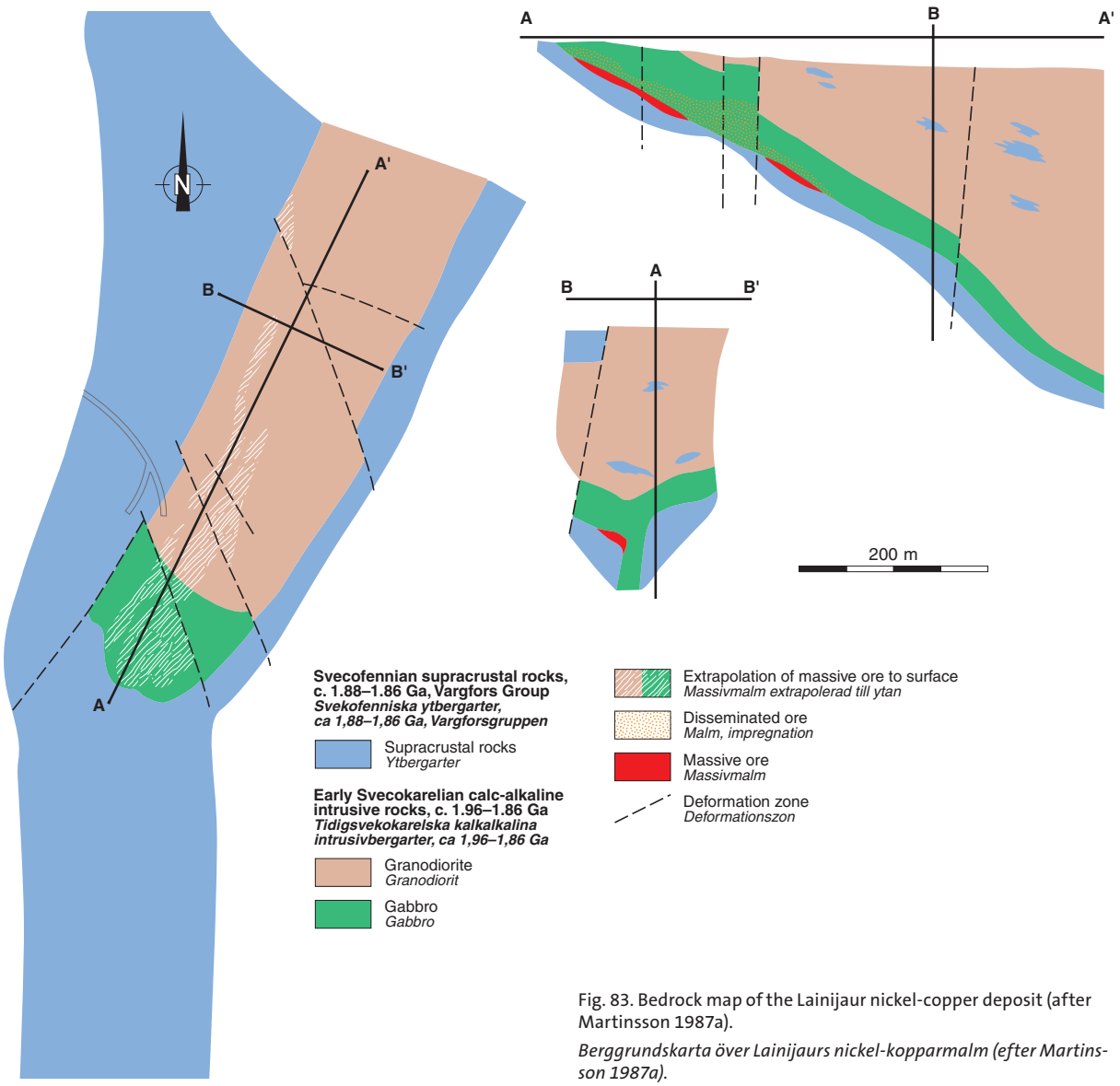


Fig. 83. Bedrock map of the Lainijaur nickel-copper deposit (after Martinsson 1987a).

Berggrundskarta över Lainijaurs nickel-kopparmalm (efter Martinsson 1987a).

6. Mafic associated nickel (Ni) deposits

The group "Mafic associated nickel (Ni) deposits" is a heterogeneous group including mineralizations in post Svecokarelian gabbros, small gabbroic intrusions with an unclear stratigraphic position, and platinum group element (PGE) mineralizations in larger layered gabbro complexes. The deposits also show wide variations in tonnage and grade (Table 3).

The Lainijaur deposit constitutes two small massive ore lenses at the bottom of a lopolithic gabbroic–dioritic intrusion (Fig. 83; Grip 1961, Martinsson 1987a, 1996),

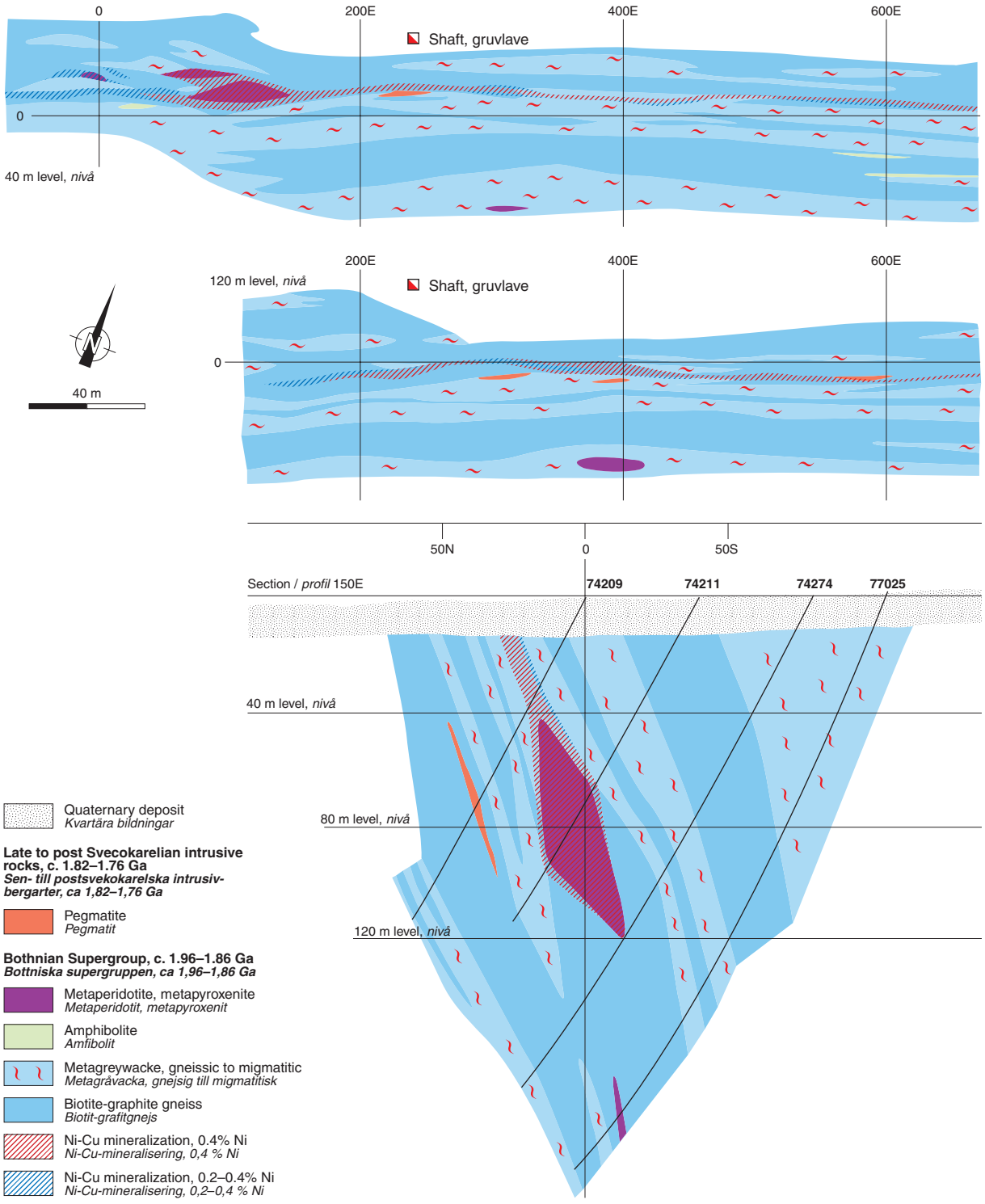


Fig. 84. Bedrock maps of and cross-section through the Lappvattnet nickel-copper deposit (after Nilsson 1985).
Berggrundskartor över och profil genom Lappvattnets nickel-kopparmalm (efter Nilsson 1985).

grading upwards from gabbro via diorite to granodiorite at the top. A fine-grained dyke in the lower central part has been interpreted as a feeder (Fig. 83). The gabbroic components are divided into a fine-grained olivine gabbro, forming a cumulate rock probably older than the ore lenses, and a younger, coarse-grained, sulphide-bearing, ophitic gabbro (Martinsson 1987a, 1996). The massive ore lenses are located at the interface between the coarse-grained gabbro and the supracrustal rocks below and on both sides of the feeder dyke. The gabbro, diorite, and granodiorite show a continuous tholeiitic fractionation trend. They crystallized from a single magma source in three separate pulses. The granodiorites contain numerous xenoliths of different types of country rocks. The supracrustal host rocks to the Lainijaur intrusion are greywackes of the Vargfors Group. The stratigraphic position of the intrusion is unclear, but the layering within the gabbro seems to run parallel with the bedding in the greywackes, which suggests pretectonic emplacement.

Three principal ore types occur at Lainijaur. Apart from the massive ore, there is a sulphide dissemination grading into the gabbro from the massive ore lenses, with approximately 0.2% nickel and 0.2% copper. The third ore type is represented by nickel-, arsenic-, and copper-bearing veins, which radiate from the massive ore (Grip 1961).

A similar but much smaller deposit has been found in the Storbodsund area, farther north. There, a massive ore lens occurs at the bottom of a gabbro sill which is intrusive into rocks of the Perthite monzonite suite.

The Älgliden deposit (Fig. 82) is hosted by a 20–100 m thick and more than 3 km long gabbro dyke in metagranitoids of the Jörn GI suite (Grip 1973, Nilsson 1985). The gabbro dyke contains sulphide dissemination almost throughout, but in the central, wider part of the dyke, a copper-rich ore zone exists. The dyke intruded the Jörn GI metagranitoids in a north-northeast to south-southwest direction, which is a common direction of dykes and shear zones north of the Skellefte District proper. Other gabbro dykes have been observed to have this strike outside the Jörn granitoid complex and they crosscut the regional north-west–south-east trending foliation in the Skellefte District.

GOLD DEPOSITS

7. Orogenic gold (Au) deposits

In the Skellefte District, gold mineralizations are mainly structurally controlled lodes within deformed and metamorphosed rocks. Most gold mineralizations are hosted by or spatially related to Svecokarelian intrusions. Regional-scale tectonic "breaks", similar to what can be found in Archaean greenstone belts as a first-order tectonic control of gold deposits, appear to be absent from the Skellefte District. Nurmi et al. (1991) describe gold mineralizations in the Fennoscandian Shield as discrete quartz-vein hosted deposits adjacent to intrusions with weakly developed wall-rock alteration and enriched with arsenic, bismuth, tellurium, and tungsten. The gold deposits in the Skellefte District share many properties with similar deposits in Finland.

Two deposits, Björkdal and Åkerberg, have been brought into production during the 1980s and 1990s. Both are located in the eastern part of the Skellefte District which is dominated by metagreywackes of the Bothnian Supergroup with north–south structural trends. Other gold deposits in the eastern part of the Skellefte District area are the old Grundfors workings (Grundfors Södra) and the Storklinten deposit. Gold deposits hosted by the Vargfors Group occur in the Vindelgransele (Middagsberget, Fäbodliden A–C, Vargbäcken) and Vinliden areas (Bergström & Weihed 1991, Öhlander & Markkula 1994, Sundblad et al. 1993). Besides the gold-rich VMS and epithermal deposits described above, only a few minor gold mineralizations have been found within the metavolcanic rocks of the Skellefte Group (e.g. Skäggträskberget Södra and Önusberget). Generally, the deposits found in rocks of the Bothnian and Vargfors Groups are dominated by arsenopyrite dissemination, whereas deposits hosted by Skellefte Group rocks consist mainly of pyrite and chalcopyrite.

In the Jörn granitoid complex, gold mineralizations are related to ductile shear zones with quartz veinlets and pyrite dissemination. The type deposit is the Tallberg Södra mineralization (cf. Fig. 82) , but the less known Älgträsk deposit is of similar style. As described above, the porphyry copper deposit in Tallberg is characterized by propylitic (chlorite, calcite) and phyllic (sericite, quartz, pyrite) alteration and quartz-sulphide brecciation. Farther south-east, more intense phyllic quartz-sericite alteration is related to the Tallberg Södra gold-copper deposit (Weihed 1992a, Sundblad et al. 1993). The most intense alteration is related to north-east–south-west striking shear zones with a higher content of pyrite, sphalerite, and gold. The shear zones occur in the continuation of the Älgliden gabbro dyke (described above), and numerous partly mineralized, andesitic dykes characterize the area.

A new interesting area is currently being explored in metagreywackes of the Bothnian Supergroup between Lycksele and Storuman. In this area, several promising prospects and mineralizations (Svartliden [in production 2005], Fäbodliden, Stortjärnhobben [type 12 in Table 3], and Barsele 1–2) seem to be structurally controlled and associated with quartz veins or silicification

in greywacke- and amphibolite-dominated units. The host rocks to all these prospects and mineralizations have an indicated age of >1.9 Ga and hence may be older than the Skellefte Group volcanic rocks. Close to the Caledonian front, the two Ersmarksberget (Blaiken) zinc-lead (type 11 in Table 3) and gold deposits (type 12 in Table 3) are hosted in brittle to semi-brittle faults within supracrustal units. These mineralizations are probably much younger than all other gold deposits and are possibly related to hydrothermal events during the Caledonian orogeny.

In the Rengård area, a minor gold-copper mineralization is associated with a shear zone with chloritic alteration and chalcopyrite-pyrite-sphalerite dissemination and local high gold grades. This mineralization type is not well known, and has never been described in the literature.

The Björkdal gold deposit (Fig. 85), situated in the eastern part of the Skellefte District, is the largest gold deposit in Sweden (20 Mt at 2.5 g/t gold). The gold at Björkdal is associated with centimetre to metre wide subvertical quartz veins (Figs. 86 a,b) at the north-western contact between a quartz monzodioritic to tonalitic intrusion and surrounding supracrustal rocks (Åberg & Weihed 1999a, b, Albino & Weihed 1997, Lundström & Albino 1997, Weihed et al. 2003). The main quartz veins strike north-northeast, whereas a minor set of veins strike east-northeast (Fig. 85). The quartz veins terminate against a major thrust duplex at the contact between the intrusion and the structurally overlying supracrustal rocks (cf. Weihed et al. 2003). The mylonitic thrust zone has a 20–40° dip northwards and strikes approximately east–west. A few kinematic observations indicate reverse to obliquely reverse slip on the thrust.

Quartz veins exist in lithons and are truncated by the thrusts within the duplex. The quartz veins in the footwall to the thrust (in the mine) are spatially and temporally associated with moderately to steeply west-dipping reverse shear zones with a north-easterly strike. Weihed et al. (2003) suggest that the quartz veins and the steep reverse shear zones are related to the thrust duplex and were formed more or less simultaneously.

Fluid inclusion and isotope results (Broman et al. 1994, Billström et al. 1997a) indicate that juvenile magmatic fluids were responsible for the precipitation of quartz and sulphides at moderate temperatures and pressures. Titanites from the quartz veins give ages of c. 1.78–1.79 Ga (Billström et al. 1997a) whereas the host pluton is dated at c. 1.90 Ga (Billström & Weihed 1996), indicating a time gap of over 100 Ma between the emplacement of the host rock and titanite growth in quartz veins. The regional deformation and metamorphism is weakly constrained in the area to somewhere between 1.87 and 1.80 Ga. The quartz veins are virtually undeformed, crosscut all grain-shape fabrics and do not exhibit metamorphic fluid inclusions or other evidence of pre-metamorphic origin. Therefore Weihed et al. (2003) interpret the titanite ages in the quartz veins as the age of emplacement of the veins and suggested that the thrust duplex and steep reverse shear zones in the mine are third-order structures related to east–west shortening at c. 1.80 Ga.

In the Åkerberg deposit, gold mineralization is related to an approximately 50 m wide zone of numerous parallel, east–west striking, cm-wide, vertical quartz veinlets in the central part of the Åkerberg gabbro (Fig. 86b). The length of individual quartz veins can be hundreds of metres. The ore zone is unusually poor in sulphides, containing only very small amounts (commonly <1%) of arsenopyrite and pyrrhotite. Alteration is also subordinate. A tonalite–trondhjemite intrusion occurs at the contact with the ore zone. Larger quartz veins with arsenopyrite dissemination exist in other parts of the gabbro body as well as in surrounding high-grade metasedimentary rocks of the Bothnian Supergroup.

Gold mineralizations hosted by small intrusions are known from several areas in the Skellefte District. In the Vindelgransele area (7225010/1617430), there are a number of zones with arsenopyrite dissemination, hosted by quartz monzodioritic sill-like bodies that have intruded sedimentary rocks of the Vargfors Group. The Fäbodliden A–C gold deposit hosts a quartz stockwork with a weak arsenopyrite dissemination. The Vargbäcken deposit (cf. Blomquist & Leijd 1999) is a low sulphide gold mineralization associated with thin quartz veinlets in two dominant directions at the contact between a diorite and greywackes. The largest gold mineralization in the Vindelgransele area, the Middagsberget deposit, contains arsenopyrite dissemination, which is related to the formation of abundant quartz veins and late gold-bearing carbonate veins (Öhlander & Markkula 1994). Arsenopyrite is also found in intermediate intrusive rocks and greywackes. Alteration minerals include early albite and late sericite-chlorite with no well-defined zoning. Similar mineralization types occur in the Vinliden and Storklinten deposits (cf. Bergström 1996, Bergström & Weihed 1991), where the related intrusions are tonalite–trondhjemites, similar to the intrusion spatially associated with the Åkerberg deposit. Sulphides here are related to quartz veins, veinlets or fractures in the intrusions or the surrounding metasedimentary rocks. In the Vinliden deposit, the sodium-rich intrusions are associated with sodic alteration followed by formation of microcline-biotite-sulphide filled fractures. In the Storklinten deposit, the tonalite is intruded by a large, syn to post mineralization, mafic–ultramafic dyke.

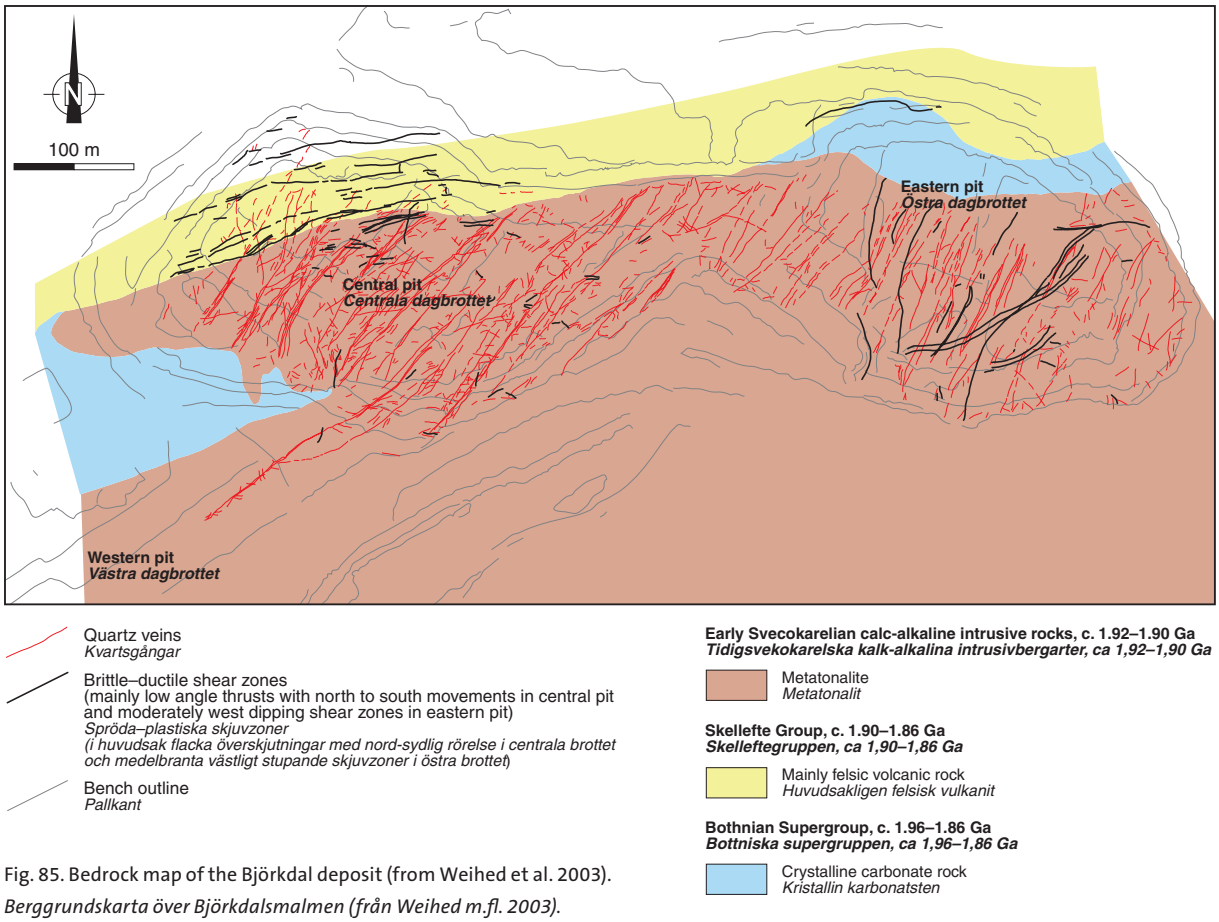


Fig. 85. Bedrock map of the Björkdal deposit (from Weihed et al. 2003).
Berggrundskarta över Björkdalsmalmen (från Weihed m.fl. 2003).



Fig. 86. **A**. Intersection of two auriferous quartz veins in the Björkdal open pit. The veins are part of the conjugate quartz vein system that constitutes the bulk ore at Björkdal. **B**. Premining photo of narrow cm-wide, parallel quartz veins in Åkerberg. Photo Pär Weihed.
***A**. Två korsande guldförande kvartsgångar från dagbrottet i Björkdal. Gångarna är en del av det konjugata set av kvartsgångar som utgör huvuddelen av malmen i Björkdal. **B**. Foto av cm-tunna, parallella kvartsgångar i Åkerberg före brytning.*

Gold mineralizations related to quartz veins and fractures in metavolcanic and metasedimentary rocks of the Bothnian Supergroup are known from the Grundfors Södra and Krångfors Västra and Östra deposits (Bergman 1992) in the Grundfors area to the west of Skellefteå. No intrusive rocks have been identified; otherwise a number of properties are identical with those of the deposits described from the Vindelgransele area. Bergman (1992) described the structural framework for the Grundfors area and showed that the quartz veins form north-east–south-west and north-west–south-east conjugate systems controlled by large north–south striking faults and shear zones. Most of the quartz veins, especially the larger ones, are restricted to intercalated amphibolites, whereas the metasedimentary rocks host only a minor part. Sulphides are relatively sparse and gold grades are very erratic and normally low. The highest grades are found in almost massive arsenopyrite veinlets, hosted by graphite-bearing argillites.

DEPOSITS RELATED TO LATE TO POST SVECOKARELIAN INTRUSIVE ROCKS

Mineralizations formed and hosted by intrusive rocks are well documented from many areas in the world. Apart from the porphyry copper, porphyry gold, and porphyry molybdenum deposits associated with convergent plate margins and magmatic arcs, intrusive rocks with stronger crustal affinity within collision or back-arc settings produce a wide variety of deposits including precious metal deposits (Thompson et al. 1999). The rocks may have a complex composition including I-, S-, and A-characteristics, depending on mantle or crustal influence, fractionation trends, and magma evolution (Breiter et al. 1999).

A major part of the investigated area is occupied by late to post Svecokarelian intrusive rocks of the Transscandinavian Igneous Belt (TIB; Revsund, Sorsele, Adak, Edefors, and Ale suites). The area occupied by these rocks was considered by earlier prospectors to be of no interest for mineral exploration, but a number of exploration attempts in the 1970s and 1980s changed this view when different mineralization types were discovered.

The Revsund suite is dominated by coarse porphyritic granites to quartz monzonites, which form batholithic intrusions mainly in the Bothnian Supergroup south and west of the Skellefte District. The Revsund type porphyritic intrusive rocks gradually change into more even-grained, red varieties within or north of the Skellefte District. The magmatic mineralogy and geochemical composition is similar, but mafic components and magma mingling or mixing processes seem to be more common farther north. The structural style changes from pluton-shape with substantial roots in high-grade country rocks of the Bothnian Supergroup into shallow sheets that intruded low-grade rocks of the Skellefte, Arvidsjaur, and Vargfors Groups. The change in structural and textural style, and probably magma source, is also reflected in the mineralization type associated with the Revsund suite. The mineralizations to the south are tin±tungsten, gold, and low temperature zinc deposits, whereas the mineralizations in the north are dominated by uranium (and molybdenum). The few mineralizations found in the Revsund suite in the Skellefte District are copper-rich.

8. Tin-tungsten (Sn±W) deposits

A number of tungsten mineralizations with varying amounts of tin, zinc, arsenic, molybdenum, and precious metals occur in the Storuman area. These deposits were discovered during an exploration campaign by the SGU during the 1970s. Most of the mineralizations are poorly known and in many cases the exploration ended before grades and tonnages could be estimated. Two principal types may be outlined: (a) the Svärtträsk type, which includes a number of scheelite mineralizations, hosted by mafic rocks within metasedimentary rocks of high metamorphic grade, and (b) the Stortträsket type, which is characterized by wolframite-bearing quartz veins within or adjacent to felsic intrusive rocks. Arsenopyrite is a common accessory or even a major mineral. Cassiterite is common in some veins of the latter type, for example in the Tvåtjärnmyran N deposit. Molybdenite occurs in deposits like Stortträsket. Sphalerite and precious metals occur locally. The most notable alteration is of greisen type with transformation of feldspars to micas, mainly muscovite.

Several mineralizations are situated in the Svärtträsk area, about 5 km north-northeast of Storuman. Svärtträsk (Holmqvist 1979), the largest of these mineralizations, is epigenitic and hosted by a tabular body of coarse hornblendite, conformable with layering in high-grade metasedimentary rocks. The ore-bearing fluids are interpreted to be derived from the nearby late to post Svecokarelian granite intrusion of the Blaiken massif. This major intrusion of late to post Svecokarelian granite is situated approximately 600 m to the west. The hornblendite is brecciated by barren quartz veins and pegmatites. Scheelite disseminations occur in highly fractured zones, especially in mica-rich veins. The smaller mineralization Metartjärn, similar to Svärtträsk, is situated in the same area. It contains scheelite dissemination in an ultramafic rock and in a vesuvianite-bearing skarn lens.

The Storträsket deposit (Sandahl et al. 1982, Petersson 1995), located about 25 km east-southeast of Storuman, is hosted by the Grundfors pluton (7208280/1585280) of the Revsund suite (Fig. 87). A similar mineralization, Tolvmannamyran, occurs 1 km farther to the southeast. Both deposits are composed of wolframite-bearing quartz veins with a preferred orientation in north-northeast–south-southwest. The quartz veins form 100 m wide zones, which can be followed for at least 100 m along strike but with an unknown depth. They are hosted by a leucocratic, contact metamorphic variety of the porphyritic granite of the pluton and are associated with alteration halos, characterized by greenish muscovite and albite. Molybdenite occurs in some quartz veins, and scheelite locally occurs as an alteration product of wolframite. Sulphides, mainly pyrrhotite, occur predominantly in the central parts of the mineralized areas, both within the quartz veins and in the altered leucogranite.

Rostberget is a tin-tungsten (Sn±W) mineralization (Gerdin & Triumf 1984, Petersson 1995) hosted by the large Joran dome of the Revsund suite in the southern part of the Storuman area. The Joran dome (7205360/1576950) is an approximately 300 km^2 large granite complex dominated by a grey microcline porphyritic type. In the southern part of the complex, younger fine- to medium-grained, peraluminous phases occur, containing lithium mica and topaz (Simeonov 1984). Large areas of the entire granite complex have experienced late- to postmagmatic alteration, and anomalously high radioactivity characterizes the whole complex. In the Rostberget mineralization, several parallel, north-northeast–south-southwest trending, thin greisen veins are composed of quartz, iron-rich muscovite, and biotite. These veins host wolframite, some molybdenite, and purple fluorite. They are associated with alteration halos, where muscovite has replaced microcline megacrysts of the porphyritic granite (Petersson

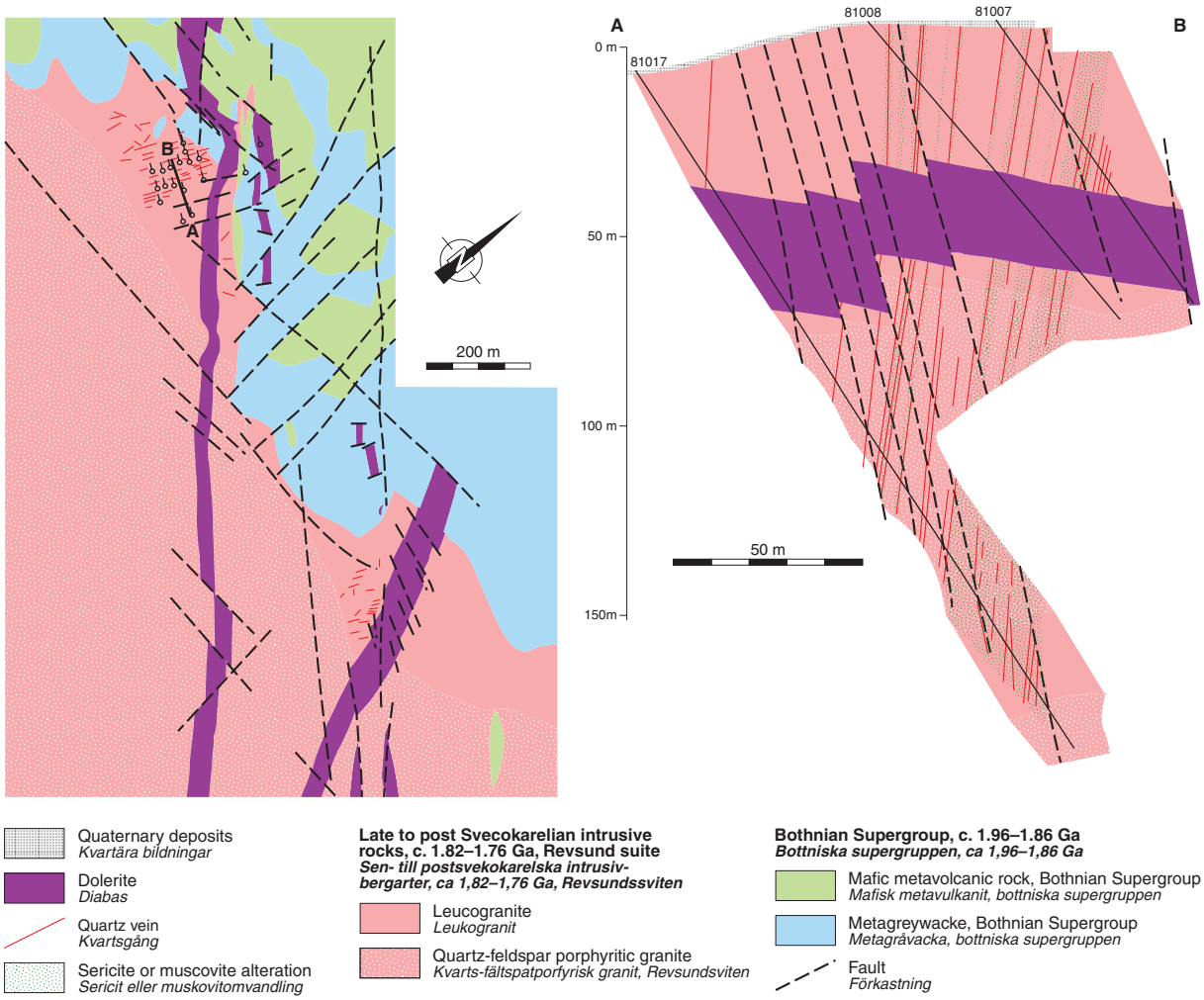


Fig. 87. Bedrock map of and cross-section through the Storträsket tungsten mineralization, after Sandahl et al. (1982).
Berggrundskarta över och profil genom Storträskets wolfram-mineralisering, efter Sandahl m.fl. (1982).

1995), and albite is strongly sericitized. Fluorite and sulphides, mainly arsenopyrite, are common accessory minerals in the alteration zone.

9. Uranium (U) deposits

Uranium deposits occur scattered within and around the main Revsund plutons in the western part of the investigated area. Most of the mineralizations were found in the 1970s and the 1980s during a major state exploration campaign, using airborne radiometric maps, and hand-held scintillometric equipment for detailed mapping of outcrops and boulder trains. Among many small and low-grade mineralizations, a number of more prominent deposits were found, mainly in the Arvidsjaur area and farther north-west in the Arjeplog area (outside the present map area).

Deposits in the lake Storavan–Arvidsjaur area

The volcanic rocks of the Arvidsjaur Group and the intrusive rocks of the Perthite monzonite suite west of Arvidsjaur are transversed by large-scale north–south or north-northeast–west-southwest striking deformation zones, probably with a long and repeated history of activity. The youngest, readily observed expressions of deformation along these zones are epidote-filled fractures, faults, and cataclastic rocks. Many of the faults have a sinistral sense of movement with an unknown vertical component (Bergman Weihed 1997).

A number of uranium deposits, related to these deformation zones, are mainly restricted to areas adjacent to the faults. Dating of uraninite (Hålenius et al. 1986) suggests that the mineralizations were formed contemporaneously with faulting and shearing at c. 1.75 Ga, i.e. after the intrusion of the rocks of the Revsund suite. Most of the uraninite is related to small, late-stage fractures within alteration zones, which are characterized by depletion of quartz and growth of albite (episyenitization). The formation of uraninite mineralizations is also associated with growth of calcium-bearing minerals and oxidation (Hålenius & Smellie 1983).

The Björklund deposit consists of uraninite in fracture fillings in altered and red-coloured alkali-feldspar granite. Mineralization occurs in three, approximately north–south trending zones, sub-parallel to the uranium-bearing fractures (Laurikko 1980). The associated alteration formed albite after quartz and microcline, two generations of calcic garnet, amphibole, titanite, and epidote. Magnetite, fluorite, and calcite are related to the late uraninite-forming stages.

The Rävaberget deposit is hosted by a plagioclase porphyritic granodiorite to granite. Uraninite occurs as dissemination and fracture fillings in zones of episyenitization. Strong albitization and formation of biotite after amphiboles was followed by oxidation of titanite and titanomagnetite to rutile, anatase and haematite (Hålenius & Smellie 1983). Uraninite occurs along grain boundaries and microfractures.

The Björkråmyran type

The Björkråmyran uranium-zirconium mineralization (Fig. 88) is situated about 50 km south-west of Lycksele in the south-western part of the project area. The mineralization was examined during 1982 and 1985, when 87 drillholes with a total length of 7765 m were drilled (Kullman 1989). It contains 1300 tons of uranium with a grade of 0.16% grade and an additional zirconium content of 0.48%. The mineralization is structurally controlled and hosted in albitized fracture zones with common cataclastic breccias within intrusive rocks of the Revsund suite. The mineralized zones are strongly enriched with sodium but depleted in potassium, compared with unmineralized country rocks. Evidence of multistage fracturing is common. Uranium is hosted mainly in a metamict zirconium-uranium-silicon phase, whereas zirconium is also hosted in zircon.

Stratabound uranium (U) deposits of the Dobblon area

A specific type of uranium mineralization is found in the Dobblon area about 20 km west-northwest of Sorsele. Here, stratabound uranium concentrations (Duobblon deposit) occur in ignimbritic ash flow deposits in the Björnknösen Formation in the 1.8 Ga old Dobblon Group. The figures in Table 3 concern the lithophysal parts in the central part of the exposed Björnknösen Formation (Lindroos & Smellie 1979). The ore-bearing beds vary between 1 and 10 m in thickness and contain a thin, almost barren conglomerate layer. The uranium occurs in uranotitanite, uranium-bearing micas, and uraninite in small fractures around the lithophysae. The uraniferous rocks show a wide variety of colours due to sericite and chlorite alteration. Heavy coating of haematite is common in places.

UNSPECIFIED DEPOSITS

10. Unspecified copper (Cu) deposits

The Gråberget deposit is situated in the Ledfat area about 20 km west of the north-westernmost exposure of the Skellefte Group in the Adak area. It is hosted by a fine-grained, porphyritic granite of the Adak suite. The

porphyritic granitic host rock forms a wide east–west striking dyke, which is intrusive into conglomerates of the Ledfat sedimentary succession. Similar granite dykes occur in a number of places in the area between the Gråberget and the Malådalen (see below) deposits, but no other mineralizations are known. Both deposits are copper-bearing, with accessory molybdenum and low precious metal content. The Malådalen deposit occurs within andesites of the Vargfors Group south-southeast of Adak. It is situated adjacent to a granite similar to the host rock of the Gråberget deposit and it is locally controlled by an east–west striking deformation zone.

The Gråberget deposit (Claesson 1979, Weihed 2001) consists of large rock volumes with sulphide disseminations and veinlets along the contact between the granitic dyke and the Ledfat conglomerate. Higher

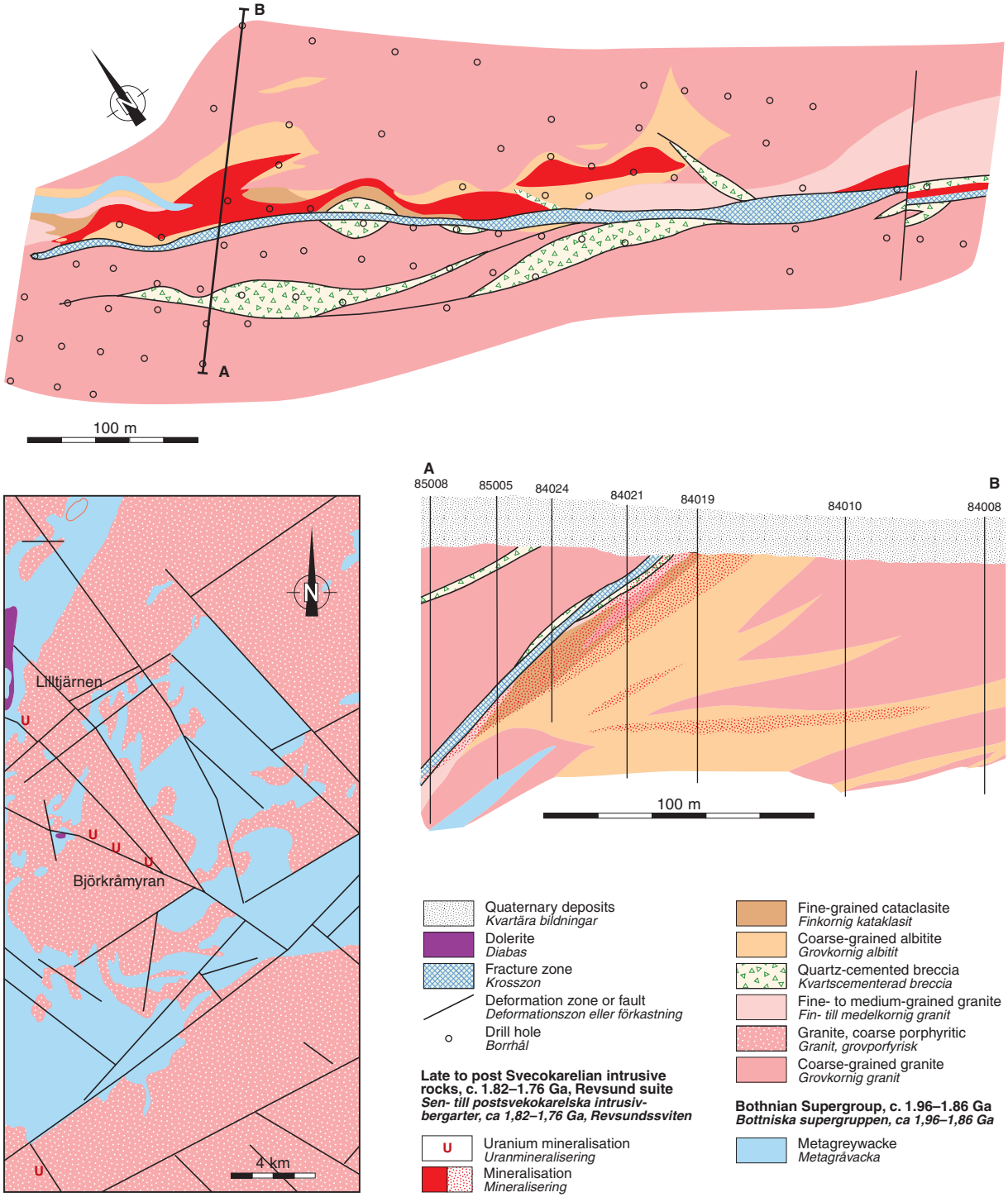


Fig. 88. Bedrock map of and cross-section through the Björkråmyran uranium deposit (modified from Kullman 1989).
Berggrundskarta över och profil genom Björkråmyrans uran-mineralisering (modifierad från Kullman 1989).

grades of copper can be discerned in two separate ore lenses (Fig. 89). The western A lens consists of veins of fine-grained pyrite and chalcopyrite with accessory magnetite, molybdenite, and sphalerite. The host rock is sericite- and epidote-altered. The eastern B lens is hosted by both the granite and the conglomerate. Pyrite and chalcopyrite dissemination is accompanied by copper oxides and bornite within haematite-stained rocks. The granite is epidote-altered. Uranium has been detected locally with gamma logs. The mineralization shows many similarities to classical porphyry copper-type deposits (cf. Weihed 2001), but is described in this section as it is clearly associated with the late to post Svecokarelian Adak suite.

The Malådalen deposit is a small mineralization hosted by a sericite-altered andesite within a deformation zone. Pyrite dissemination, with small amounts of chalcopyrite, molybdenite, and bornite, constitutes the mineralization. A small pegmatite dyke also hosts some cassiterite and arsenopyrite.

11. Unspecified zinc-lead (Zn-Pb) deposits

A recently defined mineralization type is represented by the quartz-calcite-breccia-hosted zinc-lead (Zn-Pb-Ag) Hemberget deposit north-east of Storuman and the Ersmarksberget Norra deposit, south of lake Storjuktan (cf. Ersmarkberget gold deposit below). Both deposits are hosted by high-grade, graphite- and pyrrhotite-bearing meta-argillites and metagreywackes of the Bothnian Supergroup. Stratigraphical correlations between the two deposits are uncertain, as they are strongly deformed. The mineralizations occur a short distance from a major intrusion of late to post Svecokarelian granite, and tungsten deposits in both areas are situated closer to the granite intrusion.

The Hemberget ore lenses are generally stratabound, with a general thickness of 5–60 m, several hundred metres long and of unknown depth. Reddish sphalerite and minor galena occur in small irregular quartz-calcite veinlets or as fracture fillings within the strongly schistose metasedimentary rocks. An additional ore type occurs in the Hemberget deposit and also in the small, nearby situated Rackosjön (7222240/1566910) mineralization. In this type, the sphalerite dissemination follows the laminations of the metasedimentary rocks and is overprinted by the quartz veinlet ore type. No alteration is associated with this ore type.

The Ersmarksberget deposits consist of a long, approximately north–south trending stratabound zinc ore (Ersmarksberget Norra) and a separate gold mineralization (Ersmarksberget, described below) in the southern part. The ore is hosted by strongly deformed, partly graphite-bearing meta-argillites and metagreywackes, which are

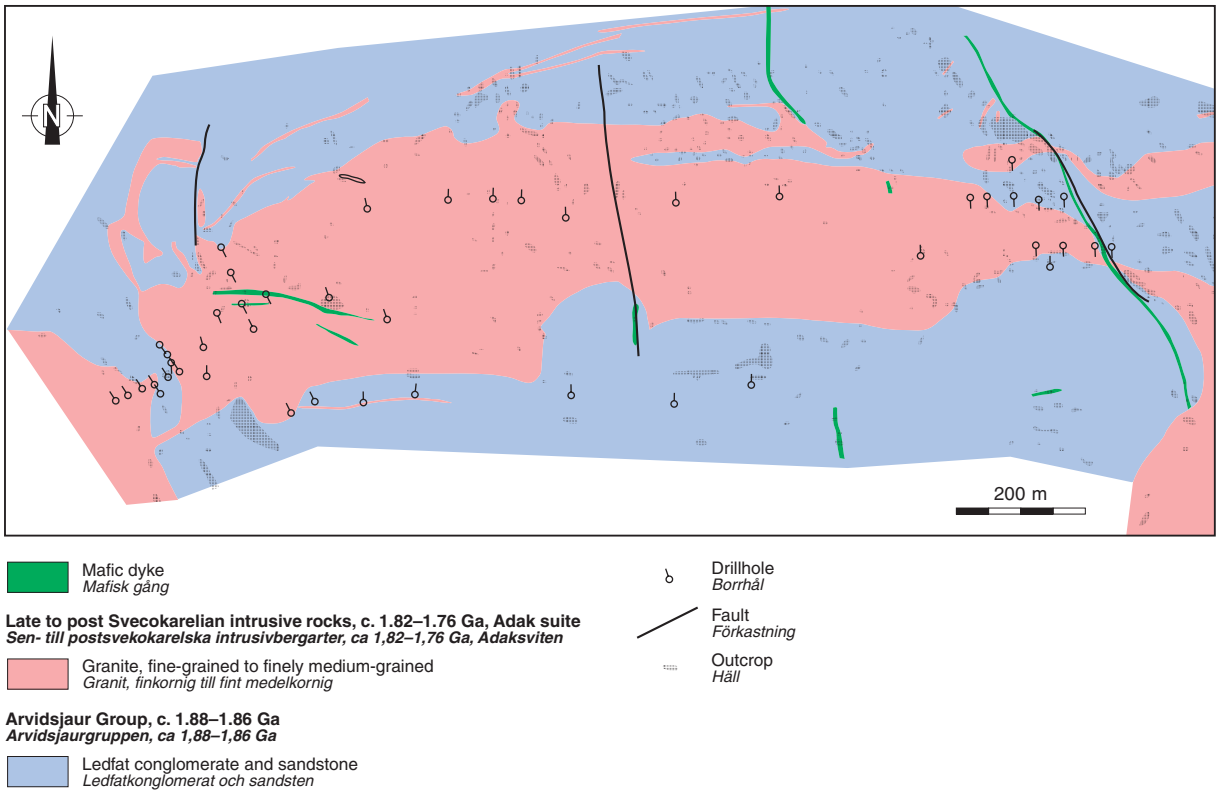


Fig. 89. Bedrock map of the Gråberget copper deposit (modified from Claesson 1979).
Berggrundskarta över Gråbergets kopparmineralisering (modifierad från Claesson 1979).

intruded by small tonalite dykes. The dykes are identical with and probably originate from a large tonalite pluton west of the ore-bearing metasedimentary units. The tonalite dykes contain numerous barren quartz veins. The zinc ore has no sharp contacts with the barren host rock and contains higher grade zones in the centre. The grade and tonnage in Table 3 correspond to a large tonnage, low grade reserve calculation, suitable for open pit mining. The owner ScanMining AB plans to start mining the two deposits in the summer of 2005.

12. Unspecified gold (Au) deposits

During the exploration for the tin-tungsten (Sn-W) deposits mentioned above, mineralizations with appreciable amounts of precious metals were also discovered. These gold-only deposits are very similar to the gold lode deposits presented on page 138, and no clear distinction can be made between them besides the spatial relationship with the Revsund suite intrusions for the deposits described here.

In the southern part of the zinc ore of Ersmarksberget Norra, described above in section 11, high gold grades are related to a system of quartz veins along the tonalite pluton, west of the zinc ore. The quartz veins are of several generations and associated with small amounts of sulphides, mainly arsenopyrite. The trend of the gold ore is partly different from that of the zinc ore, but the close spatial relationship suggests a possible genetic connection.

The Duobblonbäcken deposit (Einarsson 1985b) consists of a pyrite dissemination with gold in altered and fractured even-grained granite of the Revsund suite.

The Svartliden deposit (cf. Hart et al. 1999) is hosted by altered metasedimentary rocks and metabasalts of the Bothnian Supergroup close to small granite stocks and dykes of the Revsund suite. Mining of this deposit commenced in 2005 and further data regarding this deposit will probably soon be available.

The Fäbodliden deposit west of Lycksele is hosted by arenitic and argillitic metagreywackes with intercalated banded iron formations (BIF). According to recent estimations the tonnage is approximately 18 million tons, with 1.5 g/t gold. This deposit has recently been described as a hypozonal orogenic gold deposit by Bark & Weihed (2004).

IRON DEPOSITS

13. Iron (Fe) deposits

The Skellefte District is an extreme sulphide province, and ferric oxide ores are not present, except for small mineralizations found in the high-grade metasedimentary rocks of the Bothnian Supergroup, exemplified by the Bygdsiljum mineralization and one somewhat larger deposit on Hindersön Island east of Luleå. One gabbro-hosted ferric oxide deposit (Näsberget 2) was worked at Näsberget hill south-west of Långträsk (7261080/1710820) in the 19th century. Minor occurrences of banded iron formations have been noted in the metagreywackes of the Bothnian Supergroup (cf. Fäbodliden above), all without any economic significance.

The Hindersön deposit is a magnetite-bearing lens hosted by a dolomitic intercalation in a sequence of mafic volcanic rocks. These probably form part of a larger unit continuing northwards into the Kalix area. Silt- and sandstones form other sedimentary intercalations, apart from dolomite, within the volcanic rocks. A tremolite skarn and some sulphides occur in the iron ore zone (Frietsch 1973).

The Näsberget deposit is hosted by the Näsberget layered intrusion associated with the Jörn granitoid complex (cf. Filén 2001). Iron ore was found here as early as 1832. In 1833 the Mine Inspector visited the discovery and noticed that the ore occurred as veins and was often contaminated with pyrite. The last ore was mined in 1908. The magnetite ore was associated with tourmaline and pyrrhotite. The Näsberget intrusion was reinvestigated for platinum group elements (PGE) in the 1980s and boulders and outcrop samples contained anomalous contents of PGE and gold (cf. Filén 2001).

INDUSTRIAL MINERALS

14. Andalusite

Andalusite-bearing rocks exist in a number of places, mainly related to alteration zones associated with epithermal gold deposits in rocks of the Skellefte Group. In the Boliden epithermal gold deposit, almost monomineralic andalusite rocks occur in large rounded, elongated pods, forming the core of the alteration zone. Andalusite also occurred as a dissemination in the sericite-altered rocks surrounding the central andalusite core. Andalusite production took place in the Boliden mine, during World War II. There is a possibly similar type of mineralization and alteration system in the Mångfallberget deposit, 2 km north of Boliden. Here, an andalusite-corundum rich core is enveloped by sericite- and chlorite-altered metarhyolites of the Skellefte Group. Some sulphides and quartz veins with bismuth tellurides are present.

The Säter deposit is an andalusite-enriched alteration zone south of the Kristineberg deposit. Large volumes of

sericite- and chlorite-altered metavolcanic rocks around Kristineberg have been altered further into medium-grade cordierite-andalusite assemblages. The Säter deposit is situated in a small area where the andalusite grades are higher than in the surrounding andalusite-bearing volcanic rocks.

15. Graphite

Graphite is a common constituent of the argillitic parts of the turbiditic metagreywackes of the Bothnian Supergroup. Graphitic schists are therefore a potential source of graphite in this area. No economically worthwhile deposits have been found in the map area, but during World War II trial mining of a small deposit at Flarken was undertaken. However, the low concentration of graphite made mining uneconomic and it was soon abandoned.

16. Dolomite, calcite

Carbonate deposits in the Skellefte District occur in lenses of crystalline carbonate rocks in the Skellefte Group and the Bothnian Supergroup. The explosive nature of the Skellefte Group deep-water volcanism did not generally promote carbonate deposition, but within the Bothnian Supergroup east of Boliden and in the Burträsk area, the environment has been rather more favourable. The carbonate deposits consist of limestones with minor dolomite (Shaikh et al. 1989, SIND 1979), except for the two deposits Gruvskogen and Hannosviken on Hindersön east of Luleå, which were formed in a different environment. Many of the deposits, especially the smaller ones, are associated with calc-silicates, mica, quartz, and sulphide impurities.

The Häbbersfors, Björkdal, Rönnberget, and Norrberget deposits are situated within a unit of crystalline carbonate rocks on the northern side of the tonalitic Björkdal pluton which forms the host rock for the Björkdal gold deposit (see above). The carbonate beds are intercalated with various felsic and mafic volcanic rocks close to the stratigraphic contact with the metasedimentary rocks of the Bothnian Supergroup. Sandberget is a small isolated occurrence within the same geological environment, west of the deposits in the Björkdal area.

The crystalline carbonate deposits Grannäs, Innansjön, Gravlund–Göksjöliden, Brännbergsliden, Kvarnby, and Lappsjöbäcken are all situated around lake Burträsket in the south-eastern part of the map area. The carbonate lenses are normally associated with metabasalts in strongly deformed metavolcanic sequences within the Nickel zone. The carbonate beds are partly intercalated with metasedimentary and metavolcanic layers. The volcanic units are metamorphosed to high grade, and late to post Svecokarelian migmatite granite including pegmatite veins locally intrude the carbonate horizons. Various types of skarn are common in these deposits.

17. Quartz, feldspar

The quartz-feldspar deposits can be divided into two principal types: (a) quartz-feldspar deposits and (b) the lithium-, rubidium-, and caesium-bearing pegmatite at Varuträsk. Pegmatites are generally associated with late to post Svecokarelian migmatite granites in high-grade metamorphic areas.

Quartz has been mined on a small scale at several places, among others Häbbersfors (see also carbonates above) during the 1960ies and 1970ies. Feldspar has also been mined on a small scale for example at Hedensbyn, about 5 km east of Skellefteå, in the 1930s and in Ytterklinten, 10 km west of Robertsfors, during 1946–1947 (cf. SIND 1979).

The Varuträsk deposit is hosted by an almost horizontal pegmatite body, present in amphibolites approximately 20 km east of Boliden. Lithium-rubidium-caesium "replacement units" with abundant lepidolite, petalite, pollucite, and spodumene occur in the central part of the pegmatite (Quensel 1956, Quensel 1960).

18. Fluorite

Fluorite is associated mainly with the Neoproterozoic to Early Palaeozoic autochthonous cover sequence below the allochthonous units of the Caledonian orogen. The main occurrence is the Granlidknösen deposit. The fluorite is hosted by sandstones and arkoses. The mineralization is estimated to contain 22 Mt of approximately 14% fluorite (cf. SIND 1979).

19. Diatomite

Diatomite has been extracted from a few places, primarily in the south-eastern part of the project area. During c. 1940–1975, deposits at lakes Kvarntjärnen (7160360/1692480), Gåstjärnen (7154440/1693780), Hemträsket (Degernäs, 7147590/1700340), and Inreträsket (7148260/1700160) together produced around 1000 tonnes per year (Beckman 1986). Since 1975 some exploration has been conducted in the same general area but without success (cf. Lundh 1984, Holmqvist et al. 1984).

Geological evolution of the Skellefte district

The concept of the evolution of the Skellefte District is intimately related to ideas of ore genesis and for the past three decades, the advances in geochronological techniques. Ore genetic concepts have changed with time (see above) and the now fairly substantial database on ages and provenance of rocks (Tables 1a and 1b) means that it is possible in a broad sense to define the exact age and origin of the different rock types. This has of course also been facilitated by the immense database on lithogeochemistry that now includes nearly all rock types in the area. In this chapter we discuss current concepts and prevailing ideas on the geological evolution of the Skellefte District in the light of geochemistry and isotope geology.

GEOCHEMISTRY AND TECTONIC SETTING OF DIFFERENT ROCK SUITES

Archaean rocks

The Archaean rocks have a main tonalite–granodiorite–adamellite trend, and a less pronounced quartz monzonite–adamellite trend, using the P–Q classification diagram (Fig. 90a) of Debon & Le Fort (1983). They are calc-alkaline to alkali-calcic according to Peacock (1931) and calc-alkaline using the Sylvester (1989) discrimination diagram (Fig. 90f). In the Maniar & Piccoli (1989) diagram (Fig. 90c) as well as in the Debon & Le Fort (1983) A–B diagram (Fig. 90b) they show a metaluminous to peraluminous trend.

Palaeoproterozoic rocks

Early Svecokarelian calc-alkaline intrusive rocks

Early Svecokarelian 1.95–1.90 Ga intrusive rocks

$\varepsilon_{Nd\ (t=1.89)}$ values are greater than +3 for the Kattisavan-Blåviksjön pluton (Westerlund 1996) north-west of Lycksele, dated to 1902±3 Ma (Björk 1995), the Kristineberg massif (Bergström et al. 1999), dated at 1907±13 Ma and the Björkdal pluton, dated at c. 1905 Ma (cf. Billström & Weihed 1996). These values indicate no influence of Archaean material during magma genesis (Westerlund 1996, Bergström et al. 1999, Eliasson, pers. com. 1999, Billström & Weihed 1996). The $\delta_{18}O$ values for the Kattisavan-Blåviksjön pluton cluster around +8‰ (Westerlund 1996).

The 1.95–1.90 Ga metagranitoids can be divided into subgroups, where the Knaften metagranitoids, c. 1.95 Ga, are peraluminous and the 1.92–1.90 Ga rocks are metaluminous. Whereas most of the rocks in this group have an alkali-calcic affinity, according to Peacock (1931), almost all are calc-alkaline in the classification of Sylvester (1989; Fig. 90f).

Early Svecokarelian 1.90–1.88 Ga intrusive rocks

The outer GI phase of the Jörn granitoid complex has $\varepsilon_{Nd\ (t=1.9)}$ values ranging from +1.8 to +3.0 (Wilson et al. 1987a) and $\delta^{18}O$ values from +5.8 to +7.6 ‰ (Wilson et al. 1987a). It is calcic in character according to Weihed (1992a, b), who also emphasized the volcanic arc signature (low Rb, Y, and Nb).

An age determination by Weihed & Schöberg (1991) yielded 1886^{+15}_{-9} Ma for several intrusive quartz-feldspar porphyritic dykes and stocks within the Jörn GI suite metagranitoids at Tallberg, with an $\varepsilon_{Nd\ (t=1.9)}$ value of +4.0 (Weihed & Bergström, unpublished). Weihed (1992a, b) showed the strongly depleted HREE signature for the porphyritic dykes and stocks from the Tallberg area. These porphyritic dykes and stocks were interpreted by Weihed (1992a, b) as high-level, possibly subvolcanic intrusions, which may constitute a link between the Jörn GI suite metagranitoids and the Skellefte Group volcanic rocks.

The Haparanda suite metagranitoids show a distinct gradient in $\varepsilon_{Nd\ (t=1.9)}$ values from slightly positive in the south-west to negative in the north-east (Mellqvist 1997). This gradient coincides with the presence of Archaean megaxenoliths and the occurrence of Bälinge type magmatic breccias, which are considered to be a subvolcanic feature of the intrusive rocks of the Haparanda suite (Wikström et al. 1996a).

The geochemical composition of the Haparanda suite is typical of "volcanic arc granitoids" with little rubidium, yttrium, and niobium (Mellqvist 1997). The rocks of the Haparanda and Jörn GI suites (1.90–1.88 Ga metagranitoids) are classified as tonalites to granodiorites in the Debon & Le Fort (1983) P–Q diagram (Fig. 90a). They show a calc-alkaline trend in terms of Peacock (1931; Fig. 90e) and Sylvester (1989; Fig. 90f) and are metaluminous to slightly peraluminous in a Maniar & Piccoli (1989) A/NK–A/CNK diagram (Fig. 90c).

Early Svecokarelian 1.87–1.83 Ga intrusive rocks

The group "Early Svecokarelian 1.87–1.83 Ga intrusive rocks" includes the Jörn GII phase of the Jörn granitoid

complex, the Stavaträsk intrusion and younger members of the Haparanda suite. Wilson et al. (1987a) reported $\delta_{18}O$ values of +7.0‰ from the Jörn GII phase. A small tonalite stock at Pultarliden (7223500/1715820) about 5 km west of Stavaträsk, which has similar characteristics to the Stavaträsk tonalite–trondhjemite, has an ε_{Nd} value of +4.4 (Bergström, unpublished results). Lundström et al. (1997) showed that the Stavaträsk intrusion has a fractionated REE pattern.

The 1.87–1.83 Ga intrusive rocks are classified as gabbro, monzogabbro, tonalite, and granodiorite–adamellite (monzogranite) in the Debon & Le Fort (1983) P–Q diagram (Fig. 90a). They show a calc-alkaline trend in terms of Peacock (1931) and are mostly metaluminous in a Maniar & Piccoli (1989) A/NK–A/CNK diagram (Fig. 90c).

Early Svecokarelian intrusive rocks (Perthite monzonite suite)

The Jörn GIII–GIV phases of the Jörn granitoid complex are dated at 1873^{+18}_{-14} Ma (Wilson et al. 1987b) and show ε_{Nd} values between +1.1 and +3.4 (Wilson et al. 1985). The $\delta^{18}O$ values cluster around +6 to +7‰ (Wilson et al. 1985). Wilson et al. (1987a) showed the chemical difference between the arc-type Perthite monzonite suite and the Jörn GI suite, where samples from the former displayed much higher high field strength (HFS) element concentrations.

The Perthite monzonite suite can be classified as a suite of quartz monzonite–adamellite–(monzogranite)–granite rocks, according to the Debon & Le Fort (1983) P–Q diagram (Fig. 90a). In the Maniar & Piccoli (1989) AN/K–A/CNK diagram the suite is peraluminous to metaluminous (Fig. 90c). An alkaline trend is apparent in the Peacock (1931) and Sylvester (1989) diagrams (Figs. 90e,f). In the diagram of Batchelor & Bowden (1985), the rocks of the Perthite monzonite suite plot in the area for late and post orogenic rocks (Fig. 90g).

Late to post Svecokarelian granites (Skellefte-Härnö suite)

Within the granites of the Skellefte-Härnö suite, $\varepsilon_{Nd\ (t=1.8)}$ values vary from –0.5 to +0.5, and the $\delta^{18}O$ values are around +10‰ (or even more positive for fractionated ore-related phases), which may indicate a significant sedimentary component in the source (Wilson et al. 1985). The granites are generally rich in potassium, rubidium, uranium, and thorium (Wilson et al. 1985).

The Skellefte-Härnö suite is characterized by its restricted SiO_2 range between 72 and 74 wt.%. In the Batchelor & Bowden (1985) diagram (Fig. 90g) this suite plots in the field of monzo- and syenogranites, and in the P-Q diagram of Debon & Le Fort (1983) in the fields for adamellite (monzogranite) and granite (Fig. 90a). The granites are peraluminous according to Shand's index (Shand 1927) and in the A–B diagram of Debon & Le Fort (1983; Fig. 90b). Their high content of rubidium and depletion of europium is characteristic.

Transscandinavian Igneous Belt (TIB): Intrusive rocks (Revsund–Sorsele–Adak–Edefors–Ale suites)

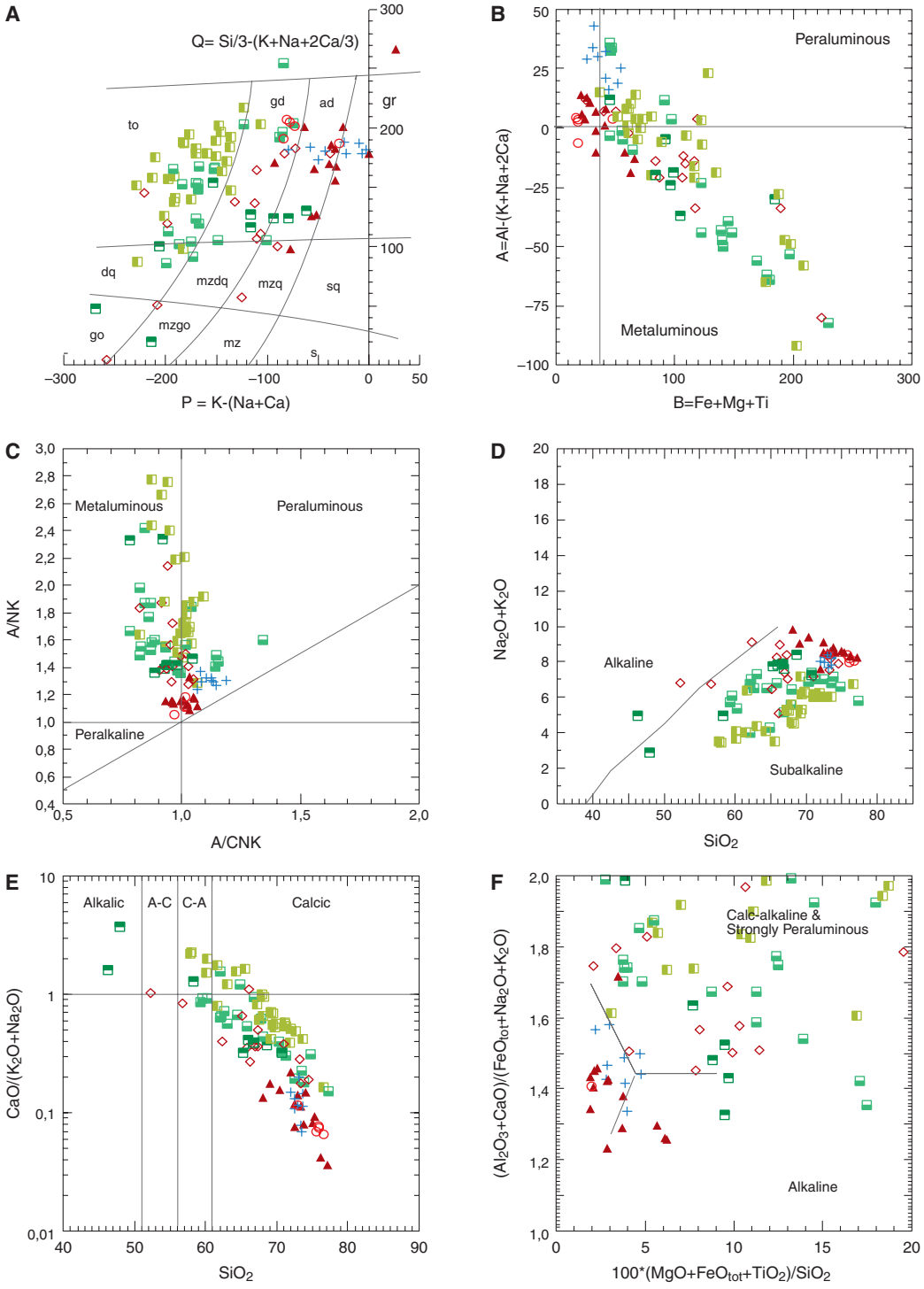
$\varepsilon_{Nd\ (t=1.8)}$ values for intrusive rocks of the Transscandinavian igneous Belt include +1.8 for the Adak suite and +0.7 for the Joran pluton of the Revsund suite (Billström pers. com. 1999). The Ale massif is strongly negative in this respect, $\varepsilon_{Nd\ (t=1.8)}$ values are –5.2 and –3.7 for the core and the rim of the intrusion, respectively. Reported $\delta^{18}O$ values (Wilson et al. 1985) are +9 to +10‰ for the fractionated, ore-related Joran and Grundfors plutons.

The intrusive rocks of the TIB can be classified as quartz monzodiorites–quartz monzonites–adamellites (monzogranites)–granites in the P–Q diagram of Debon & Le Fort (1983; Fig. 90a). They show metaluminous to peraluminous trends in the Maniar & Piccoli (1989) diagram (Fig. 90c) and display alkaline affinities in the Peacock (1931) and Sylvester (1989) diagrams (Figs. 90e,f). Lithophile elements are enriched, and the rocks display pronounced negative europium anomalies in the chondrite-normalized REE diagram.

Regional similarities and variations of intrusive rocks

The early Svecokarelian calc-alkaline intrusive rocks in Sweden are very heterogeneous. Within the map area, they are normally calc-alkaline with some calcic exceptions and display a tonalitic to granitic trend, whereas most of the early Svecokarelian rocks encountered north of the map area show an alkali-calcic affinity and a monzonitic trend. Rocks from both areas are metaluminous. This is in contrast to the early Svecokarelian intrusive rocks in central Sweden, which are calc-alkaline, peraluminous, and display a narrow range of silica content and an adamellitic (monzogranitic) to granitic trend (Ahl et al. 2001).

The Perthite monzonite suite has a quite uniform monzonitic to granitic geochemical composition. The rocks are more peraluminous in character in the present map area, compared with similar rocks to the north.



- Late to post Svecokarelian intrusive rocks, 1.82–1.76 Ga (Transscandinavian Igneous Belt)
  Sen- till postsvekokarelska intrusivbergarter, 1,82–1,76 Ga (Transskandinaviska magmatiska bältet)
- Late to post Svecokarelian granites, 1.82–1.78 Ga (Skellefte-Härnö suite)
  Sen- till postsvekokarelska graniter, 1,82–1,78 Ga (Skellefte-Härnö suite)
- Early Svecokarelian granites-syenites-monzonites and associated mafic rocks, 1.88–1.86 Ga (Perthite monzonite suite)
  Tidigsvekokarelska graniter-syeniter-monzoniter och associerade mafiska bergarter, 1,88–1,86 Ga (Pertitmonzonitsviten)
- Early Svecokarelian calk-alkaline granitoids and associated mafic rocks 1.87–1.83 Ga
  Tidigsvekokarelska, kalk-alkalina granitoider och associerade mafiska bergarter, 1,87–1,83 Ga
- Early Svecokarelian calk-alkaline granitoids and associated mafic rocks, 1.90–1.88 Ga
  Tidigsvekokarelska, kalk-alkalina granitoider och associerade mafiska bergarter, 1,90–1,88 Ga
- Early Svecokarelian calk-alkaline granitoids and associated mafic rocks, 1.95–1.90 Ga
  Tidigsvekokarelska, kalk-alkalina granitoider och associerade mafiska bergarter, 1,95–1,90 Ga
- Archaean rocks
  Arkeiska bergarter

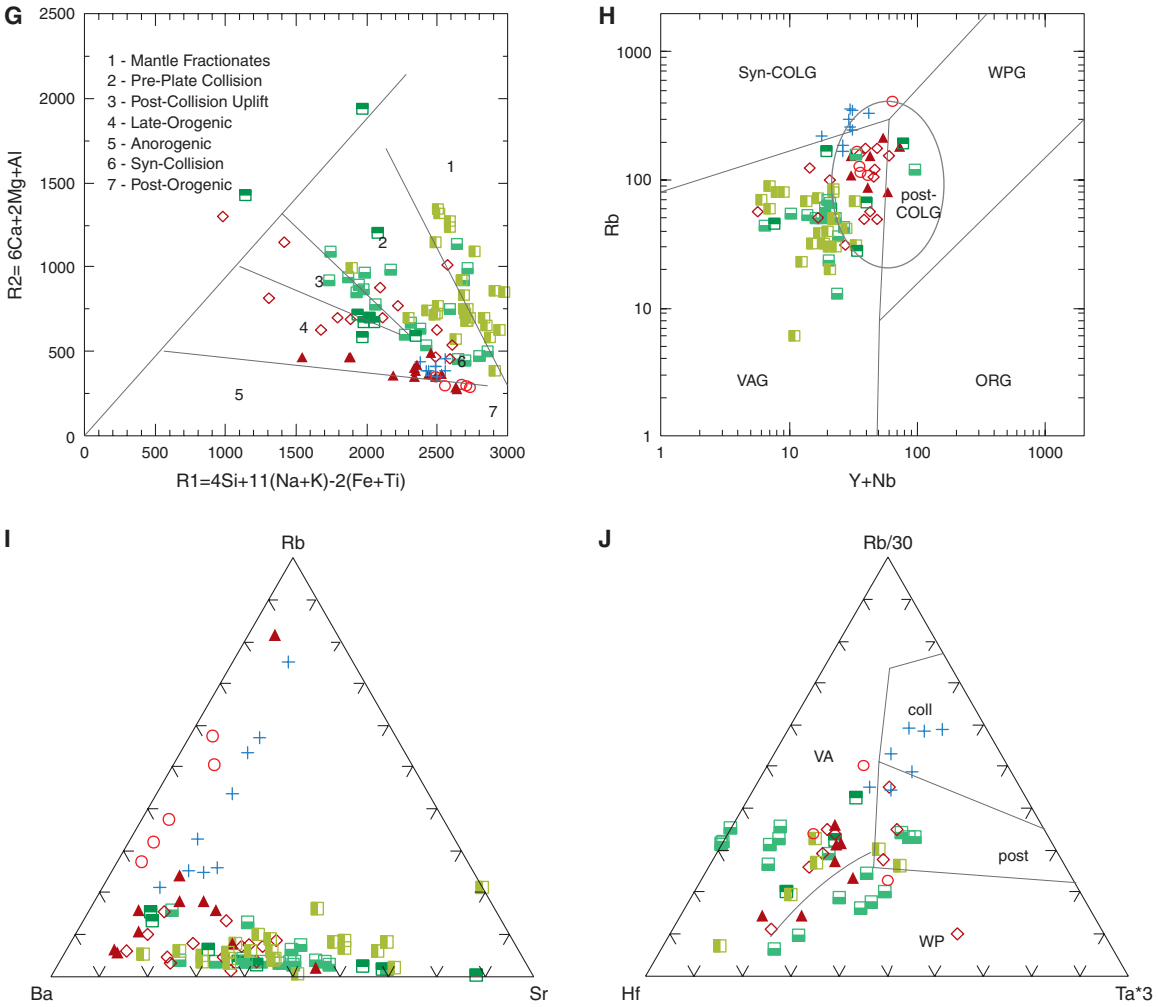


Fig. 90. Geochemical diagrams of intrusive rocks in the Skellefte district and surrounding areas (after Ahl et al. 2001). **A**. P-Q diagram of Debon & Le Fort (1983). gr = granite, ad = adamellite, gd = granodiorite, to = tonalite, sq = quartz syenite, mzq = quartz monzonite, mzdq = quartz monzodiorite, dq = quartz diorite, s = syenite, mz = monzonite, mzgo = monzogabbro, go = gabbro. **B**. A-B diagram of Debon & Le Fort (1983). **C**. Classification according to Maniar & Piccoli (1989). **D**. Classification according to Irvine & Baragar (1971). **E**. Peacock (1931) classification. **F**. Sylvester (1989) classification. **G**. Tectonic discrimination according to Batchelor & Bowden (1985). **H**. Tectonic discrimination of granitoids after Pearce (1996). Abbreviations: Syn-COLG= syn-collision granites, WPG = within-plate granites, VAG = volcanic arc granites, post-COLG = post-collision granites, ORG = ocean ridge granites. **I**. Rb-Ba-Sr diagram. **J**. Harris et al. (1986) tectonic discrimination.

*Geokemiska diagram över intrusivbergarterna i Skellefteområdet med omnejd. **A**. P-Q diagram efter Debon & Le Fort (1983). gr = granit, ad = adamellit, gd =granodiorit, to = tonalit, sq = kvartssyenit, mzq = kvartsmonzonit, mzdq = kvartsmonzodiorit, dq = kvartsdiorit, s = syenit, mz = monzonit, mzgo = monzogabbro, go = gabbro. **B**. A-B diagram efter Debon & Le Fort (1983). **C**. Klassificering enligt Maniar & Piccoli (1989). **D**. Klassificering enligt Irvine & Baragar (1971). **E**. Peacock-klassificering (1931). **F**. Sylvester-klassificering (1989). **G**. Tektonisk diskriminering enligt Batchelor & Bowden (1985). **H**. Tektonisk diskriminering av graniter enligt Pearce (1996). Förkortningar: Syn-COLG= syn-kollisionsgraniter, WPG = kontinentalplattegraniter, VAG = öbågegraniter, post-COLG = post-kollisionsgraniter, ORG = graniter, relaterade till oceaniska ryggar. **I**. Rb-Ba-Sr diagram. **J**. Tektonisk diskriminering enligt Harris m.fl. (1986).*

The late to post Svecokarelian granites of the Skellefte-Härnö suite are generally granites *sensu stricto*, with a SiO_2 content between 70 to 80 wt.%. All have highly fractionated features. The granites of the map area are somewhat variable in LREE and HFS element contents; they plot in the field of collision granites, maybe due to sedimentary precursors.

The Transscandinavian Igneous Belt constitutes a large, heterogeneous group of rock suites which was emplaced over a time span of nearly 200 Ma. There is a large overlap in chemical composition between the different suites. In general they show an alkaline affinity. In the area north of the present map area, they exhibit a pronounced syenitic trend, whereas the Revsund suite of the map area represents a poorly defined quartz monzodioritic trend, which is also the case for similar rocks to the south.

Svecofennian supracrustal rocks: Bothnian Supergroup

Analyses of mafic metavolcanic rocks of the Bothnian Supergroup include samples from two principal metamorphic assemblages: the homogeneous basaltic lavas and volcaniclastic rocks (HBLV) and the fractionated basalts–andesites–dacites–rhyolites (FBADR). The samples are mainly from the Knaften area, from various parts of the Storuman area, and subordinately from the Varuträsk area. Generally, the Bothnian Supergroup samples have low Na_2O+K_2O, but some samples show high K_2O, probably due to alteration. The HBLV cluster in the basaltic and picritic fields, whereas the FBADR form a continuous trend from basaltic andesite to rhyolite. The latter group is generally peraluminous.

The HBLV generally have flat REE patterns ($La_N/Yb_N = 1$), and most are LREE depleted, although some are HREE depleted. The latter samples are mainly from the Skarvsjö area (7208080/1561700) south of Storuman and have high magnesium and nickel contents indicating accumulation of olivine. For the FBADR samples, the REE patterns are fractionated ($La_N/Yb_N = 4–7$). The basaltic andesites do not show any negative europium anomaly, whereas dacitic and rhyolitic samples show an increasingly more negative europium anomaly.

In the Al_2O_3–FeO*+TiO_2–MgO-diagram (Jensen 1976, not shown in Fig. 91) the HBLV plot in the high-Fe field, typical of tholeiitic rocks. Some samples trend towards the MgO apex, which reflects a more primitive composition or, more likely, indicates cumulate processes. The FBADR typically plot towards the Al_2O_3 apex and show calc-alkaline trends, starting in the high magnesium tholeiite field. A Mullen (1983) diagram (Fig. 91k) gives a clear discrimination for the basaltic rocks of the two assemblages.

The HBLV plot within or close to the fields for mid-ocean ridge basalts (MORB) in the diagram of Meschede (1986; Fig. 91j). In the diagram of Mullen (1983), they plot in the MORB field and the IAT field for island arc tholeiites (Fig. 91k). Some samples, mainly from the Skarvsjö area south of Storuman, plot within or close to the within-plate field in a Zr–Ti/100–Y·3 diagram (Pearce & Cann 1973) as seen in Figure 91h. These are possibly cumulate rocks.

The FBADR basalts have calc-alkaline basalt signatures. The dacites and rhyolites plot in the volcanic arc field of the Rb–Y+Nb diagram (Pearce et al. 1984, not shown in Fig. 91), where the rhyolites are more fractionated (higher Y+Nb) than the dacites and plot closer to the WPG field.

Svecofennian supracrustal rocks: Skellefte Group

Analyses of rocks of the Skellefte Group include samples from basalts to rhyolites from most parts of the Skellefte District. As the volcanic rocks of the Skellefte Group have been subject to widespread alteration processes, only the least altered samples have been used in this study. The samples show a low-potassium trend in the total alkali versus silica (TAS) diagram (Le Maitre 1989, not shown in Fig. 91) and a limited number of samples have SiO_2 contents between 57 and 63 wt.%. Vivallo & Claesson (1987) suggested this to be evidence of a weak bimodality in the Skellefte Group. Many rhyolite samples are extremely rich in SiO_2, indicated by the quartz porphyritic texture. The dacites are metaluminous to peraluminous, whereas the rhyolites are mainly peraluminous.

The REE patterns of the basalts and the basaltic andesites of the Skellefte Group are generally weakly fractionated ($La_N/Yb_N = 3$). The REE diagram of the dacites normally shows a concave upwards shape with no europium anomaly, whereas the rhyolites are enriched in LREE and have a negative europium anomaly. Both dacites and rhyolites have $La_N/Yb_N = 5–7$. A limited number of highly fractionated quartz-feldspar porphyritic subvolcanic intrusions show a flat REE pattern with a more distinct negative europium anomaly.

The basalts and andesites of the Skellefte Group plot in the island arc or calc-alkaline basalt fields in the different discrimination diagrams. The Zr/Y ratio discriminates between oceanic and continental arcs (Pearce & Norry 1979) and the low ratio of 2–4 for the Skellefte Group suggest an oceanic arc setting. In the Zr–Ti/100–Y·3 diagram (Pearce & Cann 1973), the

Skellefte Group mafic volcanic rocks plot all over the A, B and C fields for low-potassium tholeiites, ocean floor and calc-alkaline basalts (Fig. 91h). The low-potassium tholeiite samples from the Långdal area (Vivallo 1987) represent a stratigraphically high unit in the easternmost part of the Skellefte District, possibly reflecting a late extensional event and influx of new primitive magma. In the Zr–Ti/100–Sr/2-diagram of Pearce & Cann (1973), most samples plot in the fields for island arc (IAB) and calc-alkaline (CAB) basalts, but a number of samples plot in the OFB field for ocean floor basalts (Fig. 91g). These samples are mainly from the Granbergsliden area and exhibit strontium depletion due to alteration processes (Nicholson 1993). The felsic volcanic rocks plot in the volcanic arc field of the Rb–Y+Nb diagram (not shown in Fig. 91) of Pearce et al. (1984).

Two principal compositional groups are found within the volcanic rocks of the Malå area (Tjamstan Formation of Bergström & Sträng 1999a,b), one with basalts–andesites and one with volumetrically subordinate dacites. All samples show a low Na_2O+K_2O trend on the total alkali versus silica (TAS) diagram (Le Maitre 1989, not shown in Fig. 91), which is similar to other metavolcanic rocks of the Skellefte Group. The total REE content of the basalts–andesites is generally very low (REE<100 ppm) and the REE patterns are flat (La_N/Yb_N = 1–2). The dacite samples have more fractionated patterns, with negative europium anomalies, which is different from metavolcanic rocks of similar composition in the Skellefte Group. The Tjamstan Formation samples generally plot as volcanic arc basalts–andesites. The low Zr/Y value suggests an oceanic island arc setting.

Svecofennian supracrustal rocks: Arvidsjaur Group

The Arvidsjaur Group samples have been collected from the entire Arvidsjaur District, but with sample locations concentrated to the type areas around Arvidsjaur. They include volcanic rocks of all compositions. The Arvidsjaur Group shows a high-potassium trend on the total alkali versus silica (TAS) diagram (not shown in Fig. 91) after Le Maitre (1989). Volcanic rocks mapped as rhyolites clearly plot clustered in the rhyolite field, whereas the mapped dacites include many samples which plot as trachydacite and trachyandesite in the TAS diagram (T and S3 fields). A potassium-enriched signature is evident also for the mafic volcanic rocks, mainly plotting in the trachyandesitic S2 and S3 fields. Most of the rhyolites are peraluminous and mildly peralkaline.

Most basalts and andesites have weakly fractionated REE patterns (La_N/Yb_N = 3) with small or non-existent negative europium anomalies. The plagioclase porphyritic andesites–dacites are more fractionated. The dacites show small negative europium anomalies, whereas most of the rhyolites have more pronounced negative europium anomalies. The total REE content of the felsic rocks is relatively high compared with similar rocks of the Skellefte and Bothnian Groups. Samples with a quartz-latitic composition do not show a europium anomaly, but do have a wavy pattern similar to the andesites and dacites.

The subdivision of the mafic volcanic rocks from the Arvidsjaur Group in more primitive basalts–andesites and evolved plagioclase porphyritic andesites–dacites is seen in most discrimination diagrams. The basalts–andesites plot in the high magnesium tholeiite field in the Jensen diagram (Jensen 1976, not shown in Fig. 91), whereas the plagioclase porphyritic andesites–dacites cluster in the CA-TD fields. The low magnesium and calcium (MgO+CaO = 8–12%) and high SiO_2 content of the andesites–dacites make them unsuitable for many of the plots, and the results are to be considered as indications on magma composition during fractionation. The Zr/Y ratio above 4 for most samples indicates a continental margin setting (Pearce & Norry 1979). The basalts–andesites–dacites generally plot in or partly outside the calc-alkaline basalt fields in the diagrams of Pearce & Cann (1973, Fig. 91) and in the field for continental rocks in the diagram of Pearce et al. (1975, Fig. 91i). The felsic volcanic rocks of the Arvidsjaur Group show a volcanic arc signature in the Rb–Y+Nb diagram (Pearce et al. 1984, not shown in Fig. 91). A strong crustal influence is indicated for the rhyolite samples, which trend into the within-plate field.

Svecofennian supracrustal rocks: Vargfors Group

The heterogeneous character of the volcanic rocks of the Vargfors Group is evident in a total alkali versus silica (TAS) diagram (Le Maitre 1989, not shown in Fig. 91). The mafic rocks of the Malå–Kristineberg area are magnesium-, chromium-, and nickel-enriched komatiitic basalts to basalts. They plot within the basalt field of the TAS diagram (Le Maitre 1989, not shown in Fig. 91), but show a trend with fractionation into more alkali-rich compositions. The Gallejaur volcanic rocks delivered both basalt samples and a number of samples forming a trend from andesite to dacite.

The mafic rocks of the Malå–Kristineberg area generally display flat to mildly LREE-enriched patterns with La_N/Yb_N = 1–3. This is common for virtually all strongly magnesium-, chromium- and nickel-rich ultramafic rocks to basalts. Basalts from the Gallejaur area have a fractionated pattern without a negative europium

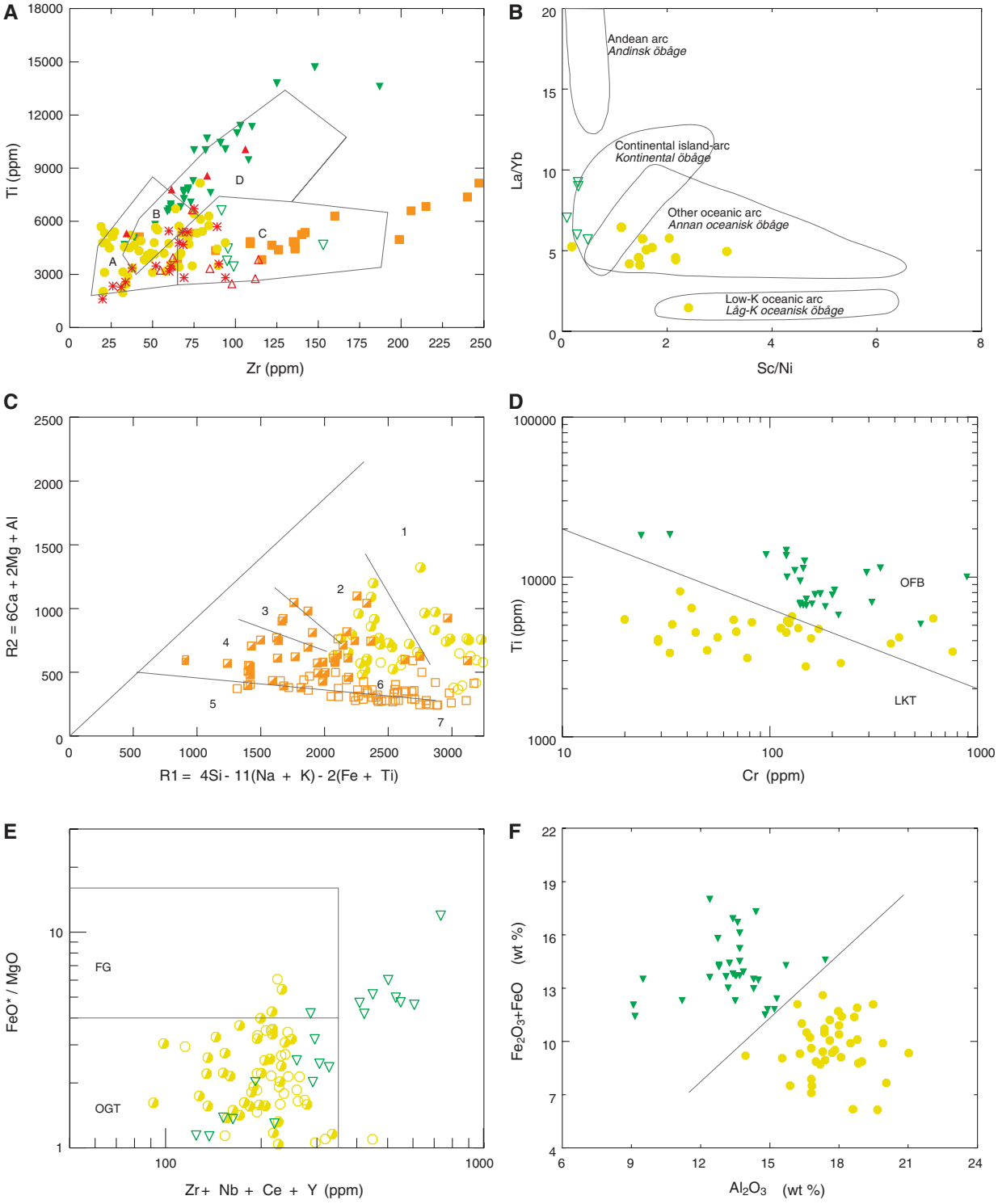
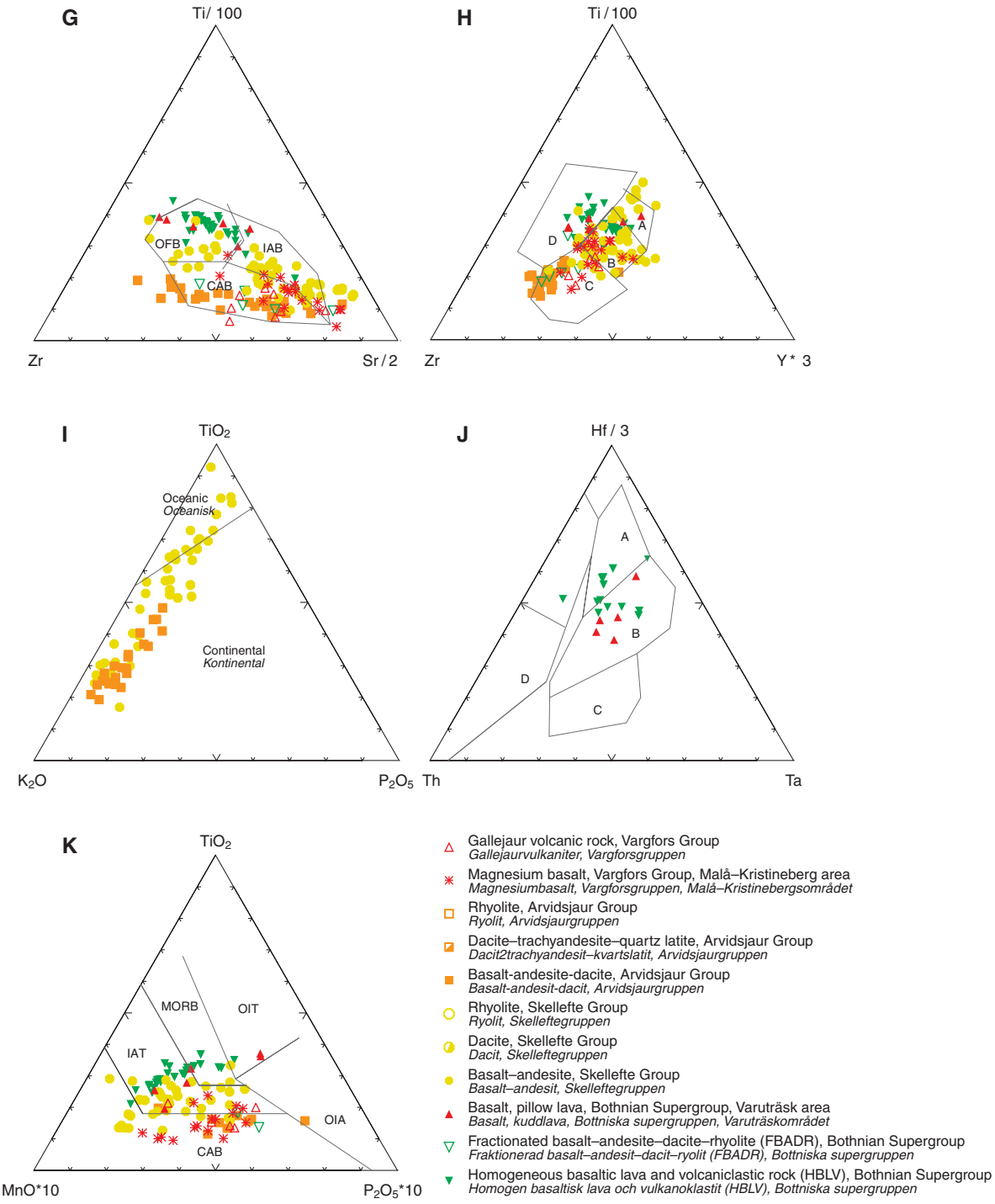


Fig. 91. Geochemical diagrams of volcanic rocks in the Skellefte District and surrounding areas (from Bergström 2001). **A**. Tectonic discrimination Zr-Ti diagram for basaltic rocks according to Pearce & Cann (1973). Ocean floor basalts plot in fields D and B, low-potassium tholeiite basalts plot in fields A and B, and calc-alkali basalts plot in fields A and C. **B**. La/Yb-Sc/Ni diagram (Bailey 1981). **C**. R1-R2 diagram (De la Roche 1980, Batchelor & Bowden 1985) for felsic volcanic rocks of the Skellefte and Arvidsjaur Groups. 1 = mantle fractionates, 2 = pre-plate collision, 3 = post-collision uplift, 4 = late orogenic, 5 = anorogenic, 6 = syn-collision, 7 = post-orogenic. **D**. Ti-Cr diagram according to Pearce (1975). LKT = low-potassium tholeiite basalt, OFB = ocean floor basalt. **E**. tectonic discrimination for granitic rocks according to Whalen et al. (1987). FG = fractionated felsic granites, OGT = orogenic granite types. **F**. Fe_2O_3+FeO-Al_2O_3 diagram. **G**. Zr-Ti/100-Sr/2 diagram (Pearce & Cann 1973). OFB = ocean floor basalts, IAB = island arc basalts, CAB = calc-alkaline basalts. **H**. Tectonic discrimination Zr-Ti/100-Y·3 diagram for basaltic rocks according to Pearce & Cann (1973). Within-plate basalts = D, ocean floor basalts = B, low-potassium tholeiite basalts = A and B, and calc-alkali basalts = B and C. **I**. K_2O-TiO_2-P_2O_5 diagram of Pearce et al. (1975). **J**. Th-Hf/3-Ta diagram according to Meschede (1986). A = N-type MORB (mid-ocean ridge basalt), B = E-type MORB and within-plate tholeiites, C = alkaline within-plate basalts, D = volcanic arc basalts. **K**. Mn·10-TiO_2-P_2O_5·10 tectonic discrimination diagram for basaltic rocks (SiO_2 = 45–54 wt.%) according to Mullen (1983). OIT = ocean island thooleiite basalt, OIA = ocean island al-



kali basalt, MORB = mid-ocean ridge basalt, IAT = island arc tholeiite basalt, CAB = calc–alkaline basalt.

Geokemiska diagram över de vulkaniska bergarterna i Skelleftefältet med omnejd (från Bergström 2001). ***A****. Tektonisk diskriminering, Zr-Ti-diagram för basaltiska bergarter enligt Pearce & Cann (1973). Oceanbottenbasalter plottar i fält D och B, låg-K-tholeiitiska basalter plottar i fält A och B och kalk-alkalina basalter plottar i fält A och C.* ***B****. La/Yb-Sc/Ni-diagram (Bailey 1981).* ***C****. R1-R2-diagram (De la Roche 1980, Batchelor & Bowden 1985) för felsiska vulkaniska bergarter i Skellefte- och Arvidsjaurgruppen. 1 = mantelfraktionat, 2= prekollision, 3 = postkollision upphöjning, 4 = senorogena, 5 = anorogena, 6 = synkollision, 7 = postorogena.* ***D****. Ti-Cr-diagram enligt Pearce (1975). LKT = kaliumfattig tholeiitisk basalt, OFB = oceanbottenbasalt.* ***E****. Tektonisk diskriminering av graniter enligt Whalen m.fl. (1987). FG = fraktionerade felsiska graniter, OGT = orogena granittyper.* ***F****. Fe_2O_3+FeO-Al_2O_3-diagram.* ***G****. Zr-Ti/100-Sr/2-diagram (Pearce & Cann 1973). OFB = oceanbottenbasalter, IAB = öbågebasalter, CAB = kalk-alkalina basalter.* ***H****. Tektonisk diskriminering, Zr-Ti/100-Y·3-diagram för basaltiska bergarter enligt Pearce & Cann (1973). Kontinentala basalter = D, oceanbottenbasalter = B, kaliumfattiga tholeiitiska basalter = A och B, och kalk-alkalina basalter = B och C.* ***I****. K_2O-TiO_2-P_2O_5-diagram enligt Pearce m. fl.(1975).* ***J****. Diagram enligt Meschede (1986). A = N-typ MORB (mittoceaniskryggbasalt), B = E-typ MORB och kontinental basalt, C = alkalin kontinental basalt, D = öbågebasalt.* ***K****. Mn·10-TiO_2-P_2O_5·10, tektoniskt diskriminerings-diagram för basaltiska bergarter (SiO_2 = 45–52 wt.%) enligt Mullen (1983). OIT = tholeiitisk oceanisk basalt, OIA = alkalin oceanisk basalt, MORB = mittoceaniskryggbasalt, IAT = tholeiitisk öbågebasalt, CAB = kalk-alkalin basalt.*

anomaly, whereas the dacites show a small but distinct europium anomaly.

The magnesium basalts of the Malå–Kristineberg area are strongly magnesium- and chromium-enriched, which is clearly seen in the Al_2O_3–FeO+TiO_2–MgO diagram of Jensen (1976, not shown in Fig. 91) and a Ti-Cr diagram (Pearce 1975, Fig. 91d). The tectonic setting of these rocks, suggested from most discrimination diagrams (Figs. 91a,g,h,k), is a calc-alkaline volcanic arc setting, where the magnesium basalts represent juvenile, primitive melts.

The basalts from the Gallejaur area are calc-alkaline volcanic arc basalts according to most diagrams (Figs. 91 a,g,h,k), which is similar to the high-magnesium basalts of the Malå–Kristineberg area. Andesites and dacites from the Gallejaur area have calc-alkaline trends in the volcanic arc field in the Rb–Y+Nb diagram (Pearce et al. 1984, not shown in Fig. 91), similar to the Skellefte Group.

Discussion

The homogeneous basaltic lavas and volcaniclastic rocks (HBLV) of the Bothnian Supergroup are interpreted as mid-oceanic ridge basalts (MORB) formed on the ocean floor, based on their flat REE to mildly LREE-depleted patterns and their behaviour in discrimination diagrams. The fractionated basalts–andesites–dacites–rhyolites (FBADR) are interpreted as volcanic arc type rocks. The interpreted tectonic setting of the Bothnian Supergroup is speculative, but the overall setting with mixed MORB-type and arc-type volcanic rocks and sedimentary rocks is interpreted as an arc setting, where the HBLV rocks formed on the ocean floor in marginal basins, surrounded by arc crust. The FBADR blocks constitute younger arc segments. The rocks of the Varuträsk area consist of MORB-type basalts, maybe with a somewhat stronger arc or crustal character than the other metavolcanic rocks of the Bothnian Supergroup. This is interpreted from the higher LREE content, the increasing levels of titanomagnetite crystallization, and the tendency to plot in within-plate fields in many discrimination diagrams. The interpreted tectonic setting for these rocks is a rift basin, possibly a back-arc marginal basin.

The Skellefte Group basalts to rhyolites are interpreted as calc-alkaline rocks formed in a marine volcanic arc. The mafic volcanic rocks have both island arc tholeiite and calc-alkaline components. The felsic volcanic rocks include dacites and rhyolites, which are quartz-enriched and potassium-depleted. The most fractionated end members are coarsely quartz porphyritic subvolcanic stocks with flat REE patterns and negative europium anomalies. They are mildly bimodal, possibly reflecting an arc under extension. As felsic compositions predominate within the Skellefte Group, one would suspect that a significant proportion of continental crust was present in the source area, and that AFC (assimilation–fractionation–crystallization, DePaolo 1981) was the main process that generated the more felsic rocks. Allen et al. (1996) suggested an extensional continental margin arc setting rather than an oceanic arc for the Skellefte Group, based on the physical volcanology of the Skellefte Group volcanic rocks. This is consistent with the geochemical data, with the mixed, but predominantly felsic compositions, the subordinate but present primitive island arc magmas, and the mild bimodality. The Tjamstan Formation mafic metavolcanic rocks are similar to other mafic volcanic rocks of the Skellefte Group. The inferred high stratigraphic level of the Tjamstan Formation indicates a new generation of rather primitive island arc magmas in the arc environment.

The Arvidsjaur Group is a heterogeneous, strongly compositionally fractionated volcanic unit with a substantial crustal component, emplaced in a continental volcanic arc environment. The volcanic rocks show medium- to high-potassium character, which is also evident from abundant microcline phenocrysts. The geochemical signature suggests significant arc maturity. Perdahl (1993, 1995) emphasized that the Arvidsjaur Group rocks from the western part of the Arvidsjaur District around Arjeplog are bimodal, suggesting emplacement in a continental rift, whereas rocks from the central part of the district (which dominate the dataset in this study) are more similar to arc-related rocks.

The Vargfors Group includes two principal units of mafic volcanic rocks, each with a distinct tectonic setting, but on the same principal stratigraphic level. The magnesium basalts of the Malå–Kristineberg area are magnesium-, chromium-, and nickel-rich, highly primitive volcanic arc rocks, indicated from several discrimination diagrams. The volcanic rocks of the Gallejaur area are calc-alkaline and intermediate in composition between the Skellefte and Arvidsjaur Groups.

The Skellefte and Arvidsjaur Groups probably reflect two discrete episodes within the same destructive plate margin setting, separated by 5–10 million years (Billström & Weihed 1996). The rocks of the Skellefte Group were deposited in a marine, extensional environment with influx of primitive island arc melts, whereas rocks of the Arvidsjaur Group formed in a subaerial, compressional, continental margin arc. The geochemical differences between the two groups are mainly related to the much higher degree of crust-derived magmas in the Arvidsjaur Group. This is indicated by higher potassium, rubidium and uranium-thorium contents

and REE patterns with negative europium anomalies, especially in the more felsic rocks. These features are readily seen in spectrometric surveys, where the potassium-uranium-thorium components are much higher in the volcanic rocks of the Arvidsjaur Group, compared with those of the Skellefte Group. The felsic components of the Skellefte Group normally lack microcline phenocrysts and fractionate towards a SiO_2-rich quartz porphyritic end member. Samples from the Skellefte Group, plotted in an R1–R2 diagram (Fig. 91c), suggest a strong mantle component for the Skellefte Group, whereas the Arvidsjaur Group samples have a late-orogenic signature. The mafic rocks in the Skellefte Group include island arc tholeiites, contrary to corresponding Arvidsjaur Group volcanic rocks, which are typically calc-alkaline. In Figure 91i, the Skellefte Group mafic volcanic rocks plot close to the TiO_2 apex and the oceanic arc field and grade towards the Arvidsjaur Group volcanic rocks, which are restricted to the continental arc field and consequently plot close to the K_2O apex.

The time interval between the development of the Skellefte and Arvidsjaur arcs was dominated by the deposition of greywackes, now exposed in the eastern and western margins of the Skellefte District. Mafic volcanic rocks intercalated with the sedimentary rocks exist in both areas, but their chemical compositions differ. The magnesium basalts of the western Skellefte District are highly primitive volcanic arc rocks, whereas the basalts in the eastern Varuträsk area have MORB and within-plate characteristics, probably reflecting a rift environment. The Gallejaur volcanic rocks erupted around the Gallejaur intrusive complex in the central Skellefte District and were deposited on Skellefte Group volcanic rocks. The volcanic rocks of the Gallejaur area are similar to the Skellefte and Arvidsjaur Group rocks, and may be regarded as a variety of Arvidsjaur arc volcanism on top of the Skellefte Arc.

The metamorphic fractionated basalts–andesites–dacites–rhyolites (FBADR) of the Bothnian Supergroup south of the Skellefte District are geochemically similar to the metavolcanic rocks of the Skellefte Group. The FBADR probably represent remnants of older volcanic arcs. The limited exposures of this unit prevent stratigraphical correlations, but age determinations clearly indicate that this unit is at least 50 million years older than the Skellefte Group volcanic rocks. The boundary between similar greywackes of the Bothnian and the Vargfors Groups south of the Skellefte District is somewhat arbitrary, as the subdivision between the Bothnian and Vargfors Groups is a facies transition rather than a stratigraphical boundary. Critical areas for possible contact relations are the Bure area (7274420/1594550) and the area to the west of Norsjö. In the latter area, the contact relations are probably strongly overprinted by deformation. In Figure 91b, basaltic–andesitic volcanic rocks from the FBADR of the Bothnian Supergroup and the basalts and andesites of the Skellefte Group have been plotted in a La/Yb–Sc/Ni diagram of Bailey (1981). The rocks can be distinguished mainly due to the low nickel content of the Skellefte Group rocks, which is a general feature of island-arc basalts (Wilson 1989) and suggests important olivine fractionation in the evolution of the Skellefte Group magmas. The MORB-type basalts of the homogeneous basaltic lavas and volcaniclastic rocks (HBLV) of the Bothnian Supergroup are easy to distinguish from the Skellefte Group (Fig. 91 d,f), mainly due to the strong iron-enriched tholeiitic character of the HBLV rocks.

The following scenario is based on, and in accordance with, the geochemical data discussed above. The Skellefte, Vargfors, and Arvidsjaur Groups represent different tectonic facies within the same destructive plate margin setting. The Skellefte Group was deposited in an early, mainly marine, extensional arc which was followed by the subaerial, compressional, mature Arvidsjaur arc. The Vargfors Group reflects the predominantly sedimentary stages between the two volcanic arc episodes. To the west, an intra-arc basin formed as a deep-water delta, succeeded by primitive, magnesium-rich, mafic volcanism, which may correspond to the initial stage of the Arvidsjaur volcanism. To the east, a rift basin was formed including new oceanic crust. This basin partly separates the Skellefte arc from poorly known felsic and mafic volcanic rocks in the Burträsk area that possibly form an arc remnant.

Conclusions

The Skellefte District and surrounding areas include a number of lithostratigraphic units, which are geochemically distinguishable.

The Bothnian Supergroup, exposed south of the Skellefte District, includes two volcanic units: one older homogeneous basaltic lava and volcaniclastic rock assemblage with MORB signature (HBLV), and one younger fractionated basalt to rhyolite assemblage, formed in a volcanic arc setting (FBADR). Greywacke deposition in the Varuträsk area was succeeded by evolved MORB-type volcanic rocks. This probably reflects the initiation of a rift basin east of the Skellefte District.

The Skellefte Group is a heterogeneous unit of basalt to rhyolite, deposited in an extensional continental margin arc at c. 1.90–1.88 Ga. The stratigraphically uppermost unit consists of primitive metabasalts and meta-andesites of the Tjamstan Formation and mudstones, reflecting the extensional environment.

The Vargfors Group succeeds the Skellefte Group and indicates changing depositional conditions at c. 1.88–1.87 Ga. The western part is dominated by greywackes, overlain by primitive magnesium basalts, which are the first sign of a renewed volcanic activity. Subaerial environment and erosion of the uplifted Skellefte Group rocks characterize the central part of the Vargfors Group.

The Arvidsjaur Group is deposited in the Arvidsjaur District north of the Skellefte District and may (at least partly) be a stratigraphic equivalent to the Vargfors Group rocks. The Arvidsjaur Group is a heterogeneous unit of subaerial basaltic to rhyolitic volcanic rocks, formed in a mature, compressional, continental margin arc.

GEOCHRONOLOGY AND ISOTOPE CONSTRAINTS ON THE EVOLUTION OF THE SKELLEFTE DISTRICT

A geochronological framework

The general evolution of the Svecokarelian bedrock in Sweden shows many similarities between different regions, and this suggests that comparisons with areas adjacent to the Skellefte District are also relevant. Certain references to such areas are given below.

The area covered by this project includes a variety of bedrock associations, spanning from the Archaean to the Phanerozoic in age. The following main geological events, in chronological order, have formed the present-day bedrock of the area:

1. Granitoid magmatism occurred to a minor extent in the Luleå–Piteå area in Archaean time (c. 2.7 Ga ago), along the border zone delineating the hidden Archaean basement to the far north and the more juvenile Palaeoproterozoic terrain towards the south (cf. Lundqvist et al. 1996b, 2000, Mellqvist et al. 1999, Wikström et al. 1996a, see also p. 113).
2. Although uncertain, it is possible that extrusive and sedimentary sequences (basalts with interlayered units of crystalline carbonate rocks) in the archipelago close to Luleå formed during the Karelian at around 2.3–2.1 Ga.
3. A large marine basin, developed at c. 2.0 Ga, was filled with sediments that later became highly metamorphosed. These Bothnian Supergroup metagreywackes can be found in the south and along the coast of the Bothnian Bay (cf. Lundqvist et al. 1998).
4. In this basin, mafic magmatism gave rise to approximately 1.96 Ga old mafic metavolcanic rocks, which occur in the Knaften area south-west of the Skellefte District (Wasström 1993, 1996).
5. The more felsic plutonism that followed the development of the marine basin and the initial deposition of sediments included the emplacement of a sequence of granitoids, which may span a more or less continuous age interval from 1.95 to 1.86 Ga. The intensity of magmatism peaked at c. 1.89–1.87 Ga and includes e.g. the Jörn GI metagranitoids and the Haparanda suite metagranitoids, the latter situated mainly north of the project area (Mellqvist et al. 2003).
6. Within the 1.89–1.87 Ga time span also the subaqueous, volcanic rocks of the Skellefte Group that are host rocks to the VMS ores (Allen et al. 1996) formed. Subaerial volcanic rocks of the Arvidsjaur Group were deposited in the Arvidsjaur District within the time span 1.88–1.86 Ga (cf. Skiöld 1988).
7. Late to post Svecokarelian intrusions and batholiths of the Skellefte-Härnö suite and the Transscandinavian Igneous Belt (TIB) occur in the project area. Both types formed close to 1.8 Ga (cf. Weihed et al. 2002a). The only known extrusive rocks of this age have been observed in the Dobblon area. At about the same time, the Edefors suite and Lina-type granites formed in the north (Öhlander & Skiöld 1996, Skiöld & Öhlander 1994).
8. Dolerite dykes, palaeomagnetically dated at 1.27 and >1.4 Ga (Elming & Matsson 2001, Elming et al. 2004, S.-Å. Elming, pers. com. in Björk & Kero 2000) occur mainly in the southern part of the project area.
9. Mainly epiclastic sediments including the alum shales were deposited on the consolidated Svecokarelian bedrock in the Neoproterozoic and the Early Palaeozoic.
10. To the west, the nappes of the Scandinavian Caledonides were thrust over the Svecokarelian bedrock and the Neoproterozoic to Early Palaeozoic cover rocks in the Middle to Late Silurian.

Detailed subdivision of the chronology of known Palaeoproterozoic magmatic events

Table 1a shows a compilation of all existing magmatic U-Pb ages in the area. These ages have been obtained from conventional U-Pb analytical data of multi-grain fractions, which sometimes introduces uncertainties in the interpretations because of the complexity of the zircon grains (e.g. Weihed et al. 2002a). In some cases, U-Pb ages of rocks from adjoining areas (not shown in Table 1a) have been used in the interpretation of the geological evolution. The references are given in Table 1a and are not repeated here.

Archaean metagranitoids are of two types: a potassium feldspar porphyritic coarse granite and an even-grained TTG (tonalite–trondhjemite–granite) type. Few radiometric age data exist, but the latter is somewhat older (2.71 Ga) than the porphyritic type (2.64 Ga).

The age intervals for the emplacement of Proterozoic magmatic rocks tend to lengthen with the increasing number of new data becoming available. On the other hand, the geological significance of conventional U-Pb ages is not always straight forward; for instance an indicated age of 2.03 Ga for a granite in the Bothnian Basin just south of the study area (Welin et al. 1993) may well be influenced by an inherited zircon population, as was the case for a feldspar porphyritic intrusion at Vinliden.

The 1.96–1.95 Ga interval: Even if no ion probe data yet exist for rocks with an indicated age above 1.93 Ga, the 1.96–1.95 Ga ages for metagranitoids in the Knaften area in the southern part of the project area and a similar age for a metadacite at Barsele (7216860/1577440) in the western part of the project area are interpreted as true crystallization ages.

The 1.95–1.93 Ga interval: Ages in the interval 1.95–1.93 Ga are relatively commonly indicated from ion probe data for rocks that crystallized close to 1.9 Ga. This lends support to the idea that the exposed rocks really are c. 1.95 Ga old, indicating the presence of a crystalline basement that formed c. 50 m.y. prior to the onset of the Skellefte arc magmatism. The extent of the region characterized by 1.96–1.93 Ga ages is not known, and it is possible that such rocks covered significant areas. For comparison, conventional ages at around 1.93 Ga for granitoids are also found in Finland, in e.g. the Vihanti-Pyhäsalmi area which hosts VMS deposits similar to those in the Skellefte District (cf. Weihed & Mäki 1997).

The 1.91–1.90 Ga interval: There is also another group of rocks with apparent ages slightly older than 1.90 Ga (e.g. Björkdal and Kristineberg plutons), and thus older than arc rocks in the Skellefte District proper as defined by the occurrence of Skellefte Group metavolcanic rocks. Ages between 1.91 and 1.90 Ga may be explained by two different mechanisms: (a) these ages are mixtures of two or several zircon populations involving a typical Skellefte District age (1.89–1.87 Ga) and a basement age (1.96–1.93 Ga), i.e. the rocks formed at 1.89–1.87 Ga but assimilated older zircons, (b) the rock actually formed at c. 1.91–1.90 Ga and (i) they are part of the Skellefte arc volcanism (i.e. the age interval for this magmatism must be extended slightly), or (ii) they formed separately from the Skellefte arc magmatism (i.e. they are part of an earlier island arc stage). A preliminary interpretation from ion probe data, although not unambiguous, points to a 1.91–1.90 Ga crystallization age (SGU, unpublished), but additional geochemical work, field work and other studies must be carried out to ascertain if these rocks are part of the Skellefte arc volcanism, or not.

The 1.89–1.87 Ga interval: The 1.89–1.87 Ga interval is, as noted earlier, typical of the Skellefte District, as shown by ages for both volcanic and intrusive rocks. This age interval also includes rocks of the Perthite monzonite suite in northern Sweden, as well as subaerial volcanic rocks of the Arvidsjaur Group. The number of dated volcanic rocks within the Skellefte District is still limited and this makes it difficult to prove significant age differences. Minor age differences could be expected as the district is composed of different domains, with partly differing geological evolutions (Allen et al. 1996), and different lead isotope characteristics (Billström & Vivallo 1994, Vaasjoki & Vivallo 1990). It is noteworthy that mafic rocks become more abundant in the Vargfors Group and the upper part of the Skellefte Group. This could be an expression of an evolving arc that was rifted by the time close to 1.87 Ga (Allen et al. 1996). This age interval also records an uplift event in the Skellefte District. Conglomerates of the Vargfors Group that formed within this interval include pebbles of Jörn GI metagranitoids (1.89–1.88 Ga), suggesting that this uplift stage occurred over a short period of time (e.g. Weihed et al. 1992).

The 1.86–1.85 Ga interval: Possibly the concluding, magmatic event of the Skellefte arc evolution is expressed by the appearance of 1.86–1.85 Ga high-level feldspar porphyritic intrusions (e.g. Boliden, Vinliden). Evidence for this comes from sparse ion probe data, but the field relationships commonly indicate that such porphyritic volcanic rocks intrude other magmatic rocks. These porphyritic volcanic rocks are interpreted as having been emplaced before the last major phase of the regional metamorphism, and their age therefore sets an upper limit for this phase.

The 1.85–1.82 Ga interval: Apparently, no intrusive activity took place during the 1.85–1.82 Ga interval, which was characterized rather by deformation processes and local erosion and sedimentation. Due to crustal thickening, this period probably also involved peak metamorphic conditions. Columbites and tantalites that are assumed to have grown during conditions of post-collisional crustal thickening have given ages close to c. 1.80 Ga in the Bothnian Basin and close to 1.77 Ga in the Luleå area (Romer & Smeds 1997). These ages are probably minimum ages for the peak metamorphism and were interpreted as defining the time of the final accretion of 1.90–1.85 Ga arcs to the Archaean craton.

The 1.82–1.78 Ga interval: This stage is characterized by the intrusion of voluminous granitic magmas, and is considered as a post-arc stage. The resulting granitic plutons appear to have developed at different crustal levels and different parental rocks were involved in their formation. For instance, anatectic S-type granites, like the Lina and Skellefte-Härnö granites, formed close to 1.80 Ga. Intrusive rocks of the Transscandinavian Igneous Belt (TIB) appear to be more deep-seated in origin and also involve a substantial mantle component (Claesson & Lundqvist 1995). The Revsund–Sorsele–Adak–Ale–Edefors suites of the TIB formed, together with volcanic rocks of the Dobblon Group, within a rather limited time interval close to 1.8 Ga.

TEMPORAL AND SPATIAL CONSTRAINTS ON METAMORPHISM AND DEFORMATION

Although the ages of magmatic events are reasonably well known, age constraints on metamorphism and deformational events are less well understood. Briefly, on the basis of field evidence, at least two, possibly three, metamorphic events have affected the study area.

Pre c. 1.88 Ga deformation and metamorphism

The earliest metamorphic and deformational event, which has a minimum age of c. 1.88 Ga, is the least well understood. Its existence is based on field evidence within the study area and its surroundings, and the following observations are relevant to consider:

(1) Seemingly undeformed c. 1875 Ma old rocks of the Perthite monzonite suite occur in northern Norrbotten County (cf. Bergman et al. 2001).
(2) Mafic dykes that are 1.88 Ga old crosscut migmatized sedimentary gneisses close to a c. 10 km wide shear zone that runs from western Finnmark in Norway to the Bothnian Bay and farther to the south (Baltic–Bothnian shear zone). This relationship suggests shearing at 1.88 Ga and the existence of an older migmatization episode (Wikström et al. 1996c).
(3) The 1.88 Ga old Degerberg granite appears to be involved in migmatite-forming processes (Romer & Öhlander 1991).
(4) In the north-eastern part of the Skellefte District, 1.88 Ga old plutons crosscut deformed metasedimentary rocks of the Bothnian Supergroup (Lundström et al. 1997, 1999).
(5) In places, undeformed granites of the Perthite monzonite suite (c. 1.87 Ga) are intrusive in Jörn GI suite intrusions (c. 1.89 Ga), which have a grain shape fabric that could be interpreted as tectonic (Lundström & Antal 2000).
(6) The Abborrtjärn conglomerate of the Vargfors Group contains clasts of Jörn GI metagranitoids displaying a grain-shape fabric not visible in the matrix. With different dip and strike in individual clasts, this fabric has been interpreted as tectonic, and hence predating the formation of the conglomerates which have independently been dated at c. 1.875 Ga.
(7) It has been suggested that there is a pre-1.89 Ga deformation and migmatization south-east of the Skellefte District proper (Rutland et al. 2001a,b), based on interpretation of a deformation fabric in metasedimentary rocks that pre-dates the intrusion of c. 1.9 Ga old tonalites.

It should be noted that much of the evidence highlighted above has been questioned and interpreted differently (cf. Weihed 2002).

1.86–1.78 Ga deformation and metamorphism

Much of the deformation and metamorphism recorded in the project area and its surroundings occurred in the interval 1.86–1.78 Ga. At present, it is strongly debated whether deformation and metamorphism can be related to a multistage event, to tectonically separate events, or to one prolonged event that has been diachronous within the area (Lundqvist et al. 1998, Lundström et al. 1997, 1999, Bergman Weihed 2001, Weihed et al. 2002a). Indications within and outside the project area supporting 1.86–1.78 Ga deformation and metamorphism include:

(1) The 1.875 Ga Vargfors Group contains the same deformation as the older units in the Skellefte District and is tightly folded around gently dipping, north-west trending axes (Bergman Weihed 2001, Weihed et al. 2002a).
(2) Major shear zones, recording the last ductile deformation in the area, deform the c. 1.80 Ga intrusive rocks of the Revsund suite (Bergman Weihed 2001). This age relationship is confirmed by titanite ages close to 1.78 Ga from the Röjnoret shear zone. Similar ages close to 1.78 Ga, representative of a late shearing, are also known from the Hassela shear zone south of the study area (Högdahl & Sjöström 1999, 2001).
(3) Granites of the Skellefte-Härnö suite, temporally associated with syn- to post-peak metamorphism, contain 1822 Ma old monazites (Claesson & Lundqvist 1995).

(4) Titanite from a pyroxene skarn at Kvarnberget (7164050/1732330) were dated at 1.82 Ga by Romer & Nisca (1995). For further discussion, see Weihed et al. (2002a).
(5) Migmatization and related emplacement of Lina granite occurred at 1783±3 Ma in the Kalix area (Wikström & Persson 1997b)
(6) Shearing and migmatization are suggested to have occurred at 1.81 Ga in the Pajala area (Pajala shear zone, cf. Bergman et al. 2001).

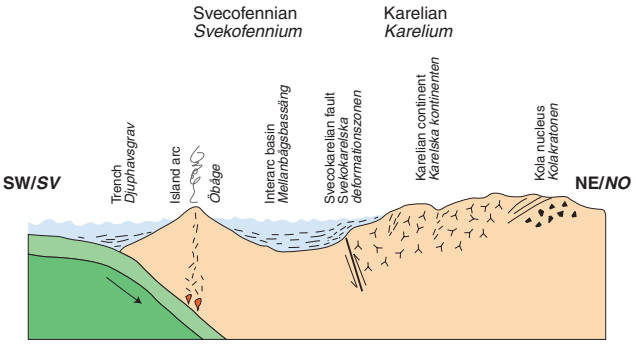


Fig. 92. Early tectonic model for the Svecofennian-Svecokarelian evolution by Hietanen (1975).

Tidig tektonisk model för den svekofenniska-svekokarelska utvecklingen av Hietanen (1975).

PLATE TECTONIC CONCEPTS

Several models have been proposed for the evolution of the Fennoscandian Shield. Most of these involve accretion of volcanic arcs towards the Karelian craton. The Skellefte District has been described as a volcanic arc, but in detail the role of this arc during the plate tectonic evolution is less clear. Already Hietanen (1975) suggested that island arcs, of which the Skellefte District is one, were accreted to the Karelian craton (Fig. 92). In this model the subduction was directed towards the north-east beneath the craton. Gaál (1990) proposed that the ultramafic rocks in the so-called Nickel zone (see page 136) were related to an earlier south-westward subduction which changed polarity. In this model, the metavolcanic rocks of the Skellefte Group were formed in an island arc environment related to the younger north-east-directed subduction.

During the 1980s, geochemical investigations in the Skellefte District (e.g. Claesson 1985, Vivallo 1987, and Vivallo & Claesson 1987) confirmed a volcanic arc affinity for the metavolcanic rocks of the Skellefte Group. In these papers, the authors also suggested that the evolution was different in the eastern, central and western parts of the district. The eastern and western parts are bimodal, whereas the central part has a more cyclic volcanism. Simultaneously with the work on the volcanic rocks, Wilson et al. (1987b) published a paper on the Jörn granitoid complex and suggested that the intrusions of this batholith were emplaced in a convergent margin setting, and that the calc-alkaline intrusions were subduction-related. This was supported by chemistry and Sm-Nd work on the intrusions.

Weihed et al. (1992) argued that the metallogeny of the Skellefte District was itself a key indication of tectonic setting. They argued that the Skellefte District was part of an island arc with back arc basins formed west and east of the district. Further discussions on the plate tectonic setting of the Skellefte District were triggered by the publication of electrical conductivity profiles (Rasmussen et al. 1987) and reflection seismic profiles (BABEL working group 1990, 1993, Juhlin et al. 2002). These authors showed that a north-dipping conductive and reflective slab was situated immediately south of the Skellefte District. This slab was interpreted as a remnant of a subducted ocean plate at the south-western margin of the old craton.

Allen et al. (1996) proposed that the extreme dominance of felsic metavolcanic rocks in the Skellefte Group contradicts a simple primitive island arc setting for these rocks. Instead, they proposed that Skellefte District represents a continental margin arc, which extended at the time of the emplacement of the VMS deposits. Billström & Weihed (1996) concluded that the positive ε_{Nd} values of the volcanic rocks ruled out large amounts of substantially older (Archaean) material as sources for the Skellefte Group metavolcanic rocks. The primitive lead isotopes from galenas (Billström & Vivallo 1994) from VMS ores support this view. Allen et al. (2002) further developed this idea by suggesting that the stratigraphic architecture, range of volcanic compositions, and abundance of rhyolites indicate that the Skellefte District is a remnant of a strongly extensional intra-arc region that developed on continental or mature arc crust.

Rutland et al. (2001a) proposed a different tectonic evolution model for the Skellefte District and surrounding areas. They suggested that regional aeromagnetic and gravity data indicate that the Skellefte District is the site of a major tectonic discontinuity. South of the Skellefte District they defined an older migmatitic unit called the Robertsfors Group (part of the Bothnian Supergroup in this paper) and concluded that the earliest deformation structures pre-date the deposition of the Skellefte Group. They therefore suggested that the Robertsfors Group forms part of a basement of the Skellefte Group. They suggested that the Skellefte Group was deposited in a rift setting, rather than in a juvenile volcanic arc. Furthermore, they attributed the

volcanism in the Skellefte District and the nickel-bearing mafic intrusions in the Nickel zone to an episode of extension related to a contemporaneous active margin lying west of the present exposure of Svecofennian rocks. This tectonic evolutionary model was rejected by Weihed (2002) based on structural and intrusive relationships within the Bothnian Supergroup and the Skellefte District.

Recently, Juhlin et al. (2002) proposed that after rifting of the Archaean craton, south-westward directed subduction began below the rifted continent, resulting in the development of the Arvidsjaur–Kiruna continental arc. Simultaneously the Skellefte island arc developed due to north-east-directed subduction farther to the south-west. At c. 1.87 Ga, the Arvidsjaur–Kiruna arc docked with the Archaean craton, but the Skellefte arc was still active. Shortly thereafter, another arc or micro-continent collided with the Skellefte and Arvidsjaur–Kiruna arcs, resulting in the thrusting of the Arvidsjaur–Kiruna arc over onto the Archaean craton (Fig. 93).

SEISMIC AND MAGNETOTELLURIC WORK

Substantial efforts have been made in various aspects of geophysics focused on the geological evolution of the Skellefte District. Particular emphasis was put on structures and geometries which could reflect subduction processes. The BABEL project (Baltic and Bothnian Echoes from the Lithosphere) investigated the seismic structure of the lithosphere under the Fennoscandian Shield and its south-western margin. The BABEL Working Group (1993) indicated reflectors which are interpreted as being caused by the remnants of a 1.9 Ga subduction zone at Moho depths in the Bothnian Bay south-east of the extrapolation of the Skellefte District offshore. The boundary between the Archaean and Proterozoic rocks was related to the BABEL data by Öhlander et al. (1993) who identified the site of a possible collision, which is characterized by over-thrusting of the volcanic arc terranes of the Skellefte District onto the Archaean craton (Fig. 94). The boundary was later disturbed by north-northeast striking fracture systems, which are visible in regional geophysical data. Recently, a seismic reflection profile was shot onshore (cf. Fig. 65), parallel to the BABEL profiles (Juhlin et al. 2002) across the Archaean–Proterozoic boundary as delineated by the shift in ε_{Nd} values of c. 1.90–1.88 Ga intrusive rocks from negative (Archaean protoliths, Haparanda suite) to positive (juvenile Proterozoic protoliths and sources, Jörn GI suite). The results indicate that the boundary dips to the south-southwest. Reflectivity patterns of the lower crust in this short profile are similar to those observed from the BABEL data, suggesting the same lower crust both onshore and offshore. Interpreted Archaean reflective upper crust in the north-east extends below more transparent Proterozoic crust in the south-west (Fig. 95). This transparent crust contains a number of high amplitude reflectors, which may represent shear zones or mafic rocks within granitoid intrusions. Juhlin et al. (2002) also presented a tectonic model for the plate tectonic evolution of the area (see above and Fig. 93).

A seismic reflection profile (cf. Fig. 95) near Norsjö (Elming & Thunehed 1991) merely indicated reflections with poor continuity, interpreted as deformed primary reflectors with debatable dip and origin.

Information regarding the distribution of electrical conductivity in the area, collected by Rasmussen et al. (1987) in the FENNOLORA project (Fennoscandian Long Range), showed an electrical conductor dipping north-east under the rocks of the Skellefte and Arvidsjaur Groups (Fig. 96). The existence of a conductor in the area was also suggested by Jones (1981). According to Rasmussen et al. (1987), the depth to the conductor is roughly 3 km in the area around Lycksele, where the bedrock is dominated by granitoids of the Revsund suite. Farther north-east, the depth to the conductor increases.

Thunehed (2000) carried out galvanic resistivity measurements in the same area and confirmed the existence of the conductor. Most of the data points show apparent resistivities in the range 10,000 to 30,000 Ωm. All data points with large separations have rather low values, which may indicate a deeply buried conductor (Fig. 97). It was obvious from short soundings, performed to estimate near-surface properties (also shown in Fig. 97), that lateral effects could not cause the low values for large separations. The conclusion was that conductive rocks at great depth remained as the only possible explanation. Assuming a value of 20,000 Ωm for the resistivity of the overlying rocks, the calculation resulted in a depth to the conductor of around 6,000 m. This was about twice the depth suggested by Rasmussen et al. (1987). The model formed from the resistivity measurements was also confirmed by transient electro-magnetic (TEM) soundings from the area (Thunehed 2000). The resistivity of the rocks which overlie the conductor was much higher than in the magneto-telluric (MT) model by Rasmussen et al. (1987). The response of a three-layer model that agrees with the data presented above is shown in Figure 97.

The cause of the low resistivity at great depth is not known. However, the intrusive rocks of the Revsund suite are spatially correlated with the metasedimentary rocks of the Bothnian Supergroup found to the south, east, and north-east of the metavolcanic rocks of the Skellefte Group. These metasedimentary rocks contain

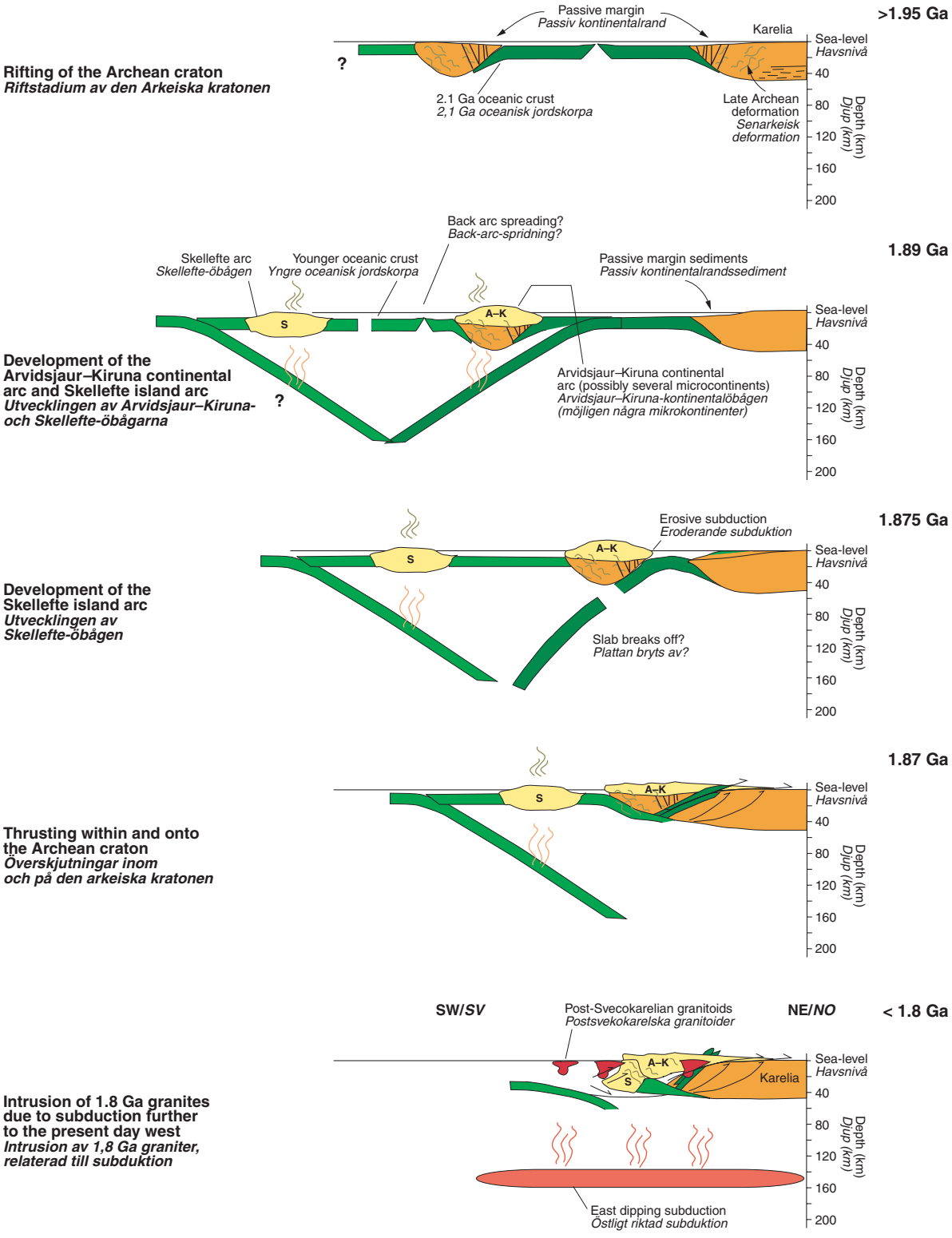


Fig. 93. Recently proposed model by Juhlin et al. (2002) for the tectonic evolution of northern Sweden. For explanation, see main text.
Nyligen föreslagen model av Juhlin m.fl. (2002) för den tektoniska utvecklingen i norra Sverige. För en förklaring se texten.

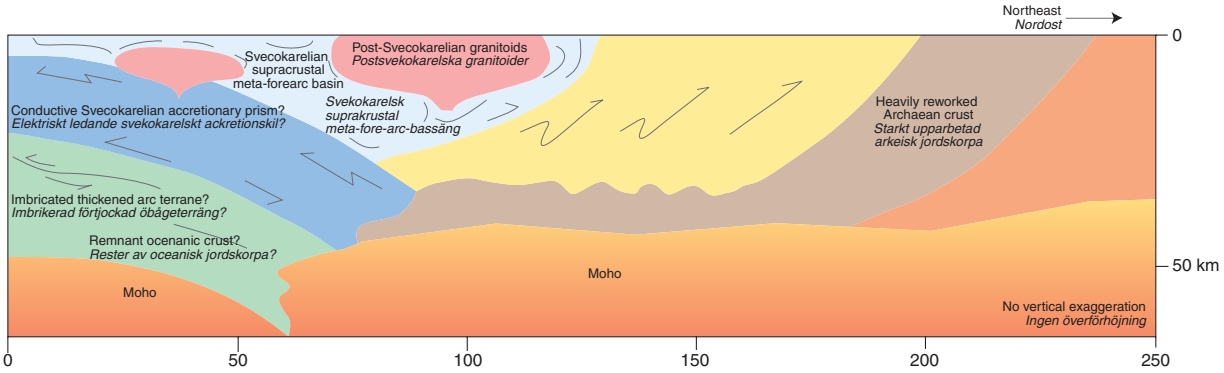


Fig. 94. Model for the composition of the crust beneath the Skellefte District based on seismic reflection data (BABEL working group 1990) according to BABEL Working group (1993) and Öhlander et al. (1993).

Modell för sammansättning av jordskorpan under Skelleftefältet baserad på reflexionsseismiska data (BABEL working group 1990) enligt BABEL Working Group (1993) och Öhlander m.fl. (1993).

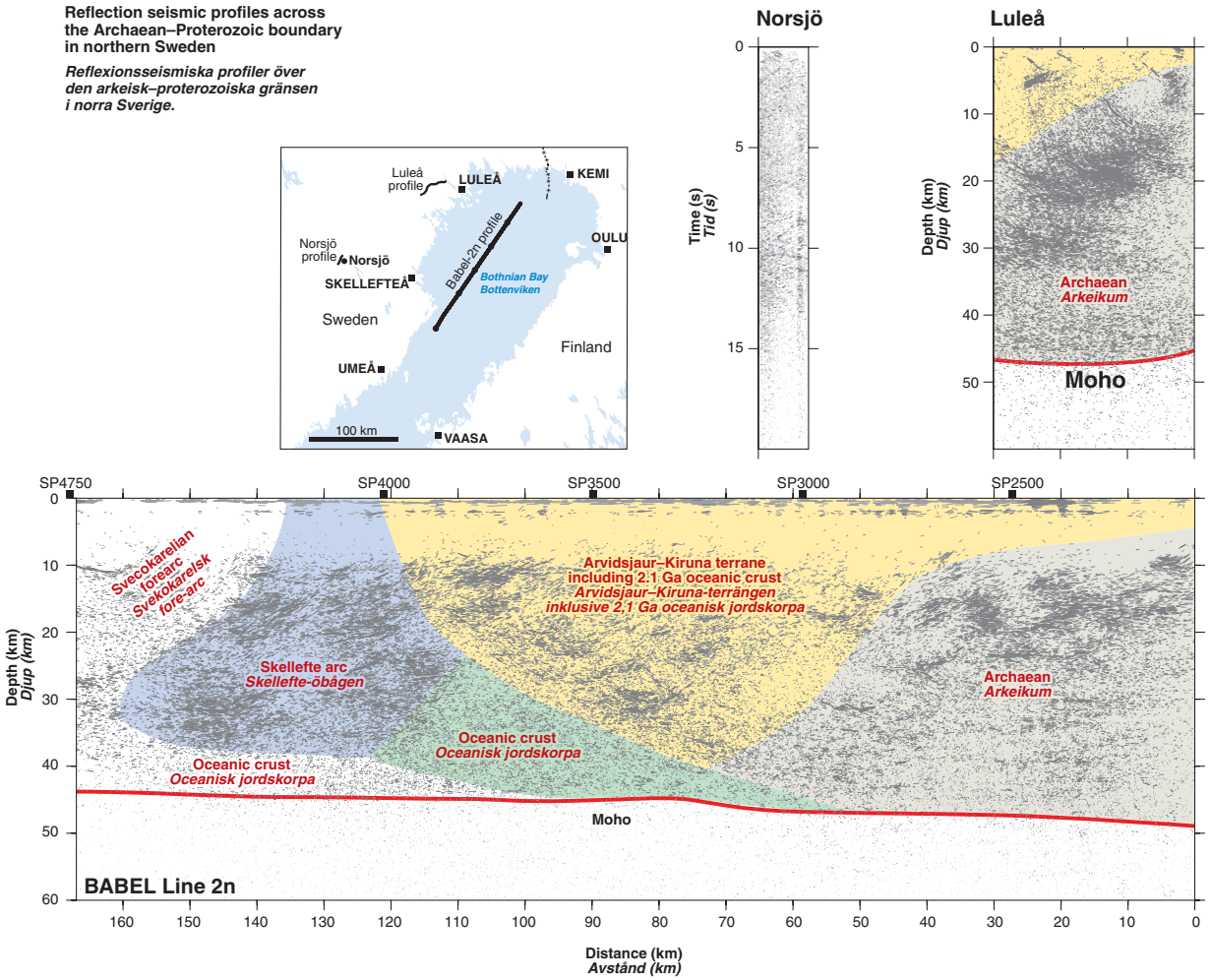


Fig. 95. Seismic data from the three reflection seismic profiles in the project area with interpretations (modified from Juhlin et al. 2002).

Seismikdata från de tre existerande reflexionsseismiska profilerna i projektområdet med tolkning (modifierad från Juhlin m.fl. 2002).

intercalations of pyrrhotite- and graphite-bearing conductive black shales. The most simple explanation for low resistive rocks beneath the rocks of the Revsund suite would be that metasedimentary rocks of this type occur below them. Only moderate amounts of graphite are necessary to explain the data, as the black shales can be very conductive.

The rocks of the Revsund suite intruded into the metasedimentary rocks and formed flat-lying sheets. This probably took place at a depth of more than 12 km, as indicated by an estimate of uplift distances in the nearby Hoting area south-west of Dorotea by Moakhar (1998). The source of the granitic magma must have been deep, as partial melting of the metasedimentary sequences would probably have destroyed the graphite. This granite emplacement mechanism is supported by geochemical data (Claesson & Lundqvist 1995).

If the metasedimentary rocks are the cause of the conductivity anomalies this would also imply that they also underlie the rocks of the Skellefte and Arvidsjaur Groups. What is somewhat confusing, however, is the contradiction between the known geology in the north-eastern part of the MT-profile, the electrical model by Rasmussen et al. (1987), and the geological explanation of the conductor as presented by Thunehed (2000). In this area, fairly large volumes of pyrrhotite- and graphite-bearing metasedimentary rocks are found, though the electrical model displays only very high resistive rock volumes in the uppermost 20 km of the crust.

The models from the FENNOLORA magnetotelluric survey and the BABEL reflection seismics are presented in Figure 96. Apparently, the dip of the interpreted electrical conductor is opposite to the general dip of seismic reflectors near the thrust as deduced from BABEL data. One explanation could be the Baltic–Bothnian megashear described by Berthelsen & Marker (1986) who suggested a displacement in the order of 100 km along the shear zone. Contrary to Berthelsen & Marker (1986), the BABEL Working Group (1990) concluded that the maximum net displacement is less than a few tens of kilometres. Another possible explanation is a mega-fold as indicated by the distribution of rocks in the Bothnian Supergroup, which makes a correlation of identified rock units in the BABEL profile and the FENNOLORA profile quite complex.

The dip of the electrical conductor as proposed by Rasmussen et al. (1987) opens up an opportunity to find large volumes of rocks belonging to the Skellefte

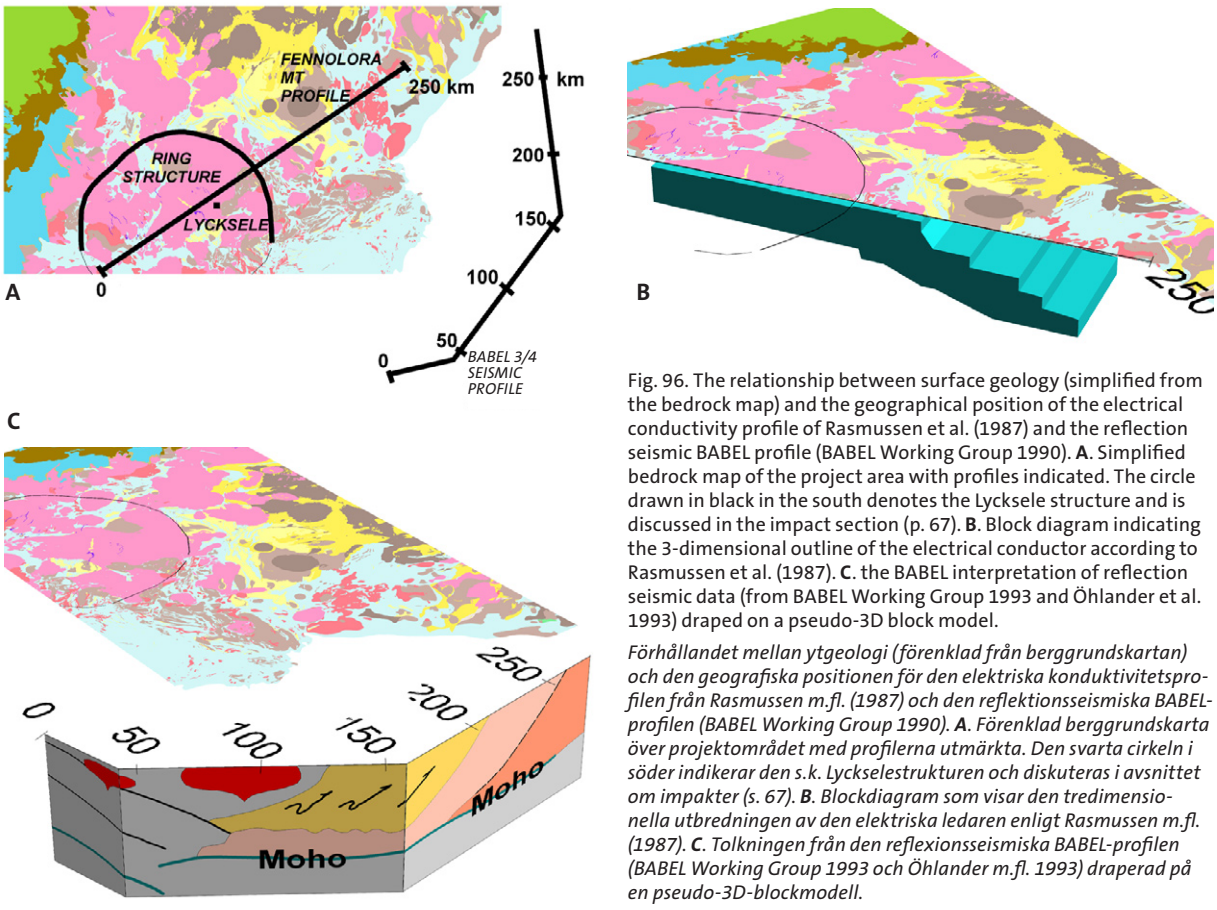


Fig. 96. The relationship between surface geology (simplified from the bedrock map) and the geographical position of the electrical conductivity profile of Rasmussen et al. (1987) and the reflection seismic BABEL profile (BABEL Working Group 1990). **A**. Simplified bedrock map of the project area with profiles indicated. The circle drawn in black in the south denotes the Lycksele structure and is discussed in the impact section (p. 67). **B**. Block diagram indicating the 3-dimensional outline of the electrical conductor according to Rasmussen et al. (1987). **C**. the BABEL interpretation of reflection seismic data (from BABEL Working Group 1993 and Öhlander et al. 1993) draped on a pseudo-3D block model.

*Förhållandet mellan ytgeologi (förenklad från berggrundskartan) och den geografiska positionen för den elektriska konduktivitetsprofilen från Rasmussen m.fl. (1987) och den reflektionsseismiska BABEL-profilen (BABEL Working Group 1990). **A**. Förenklad berggrundskarta över projektområdet med profilerna utmärkta. Den svarta cirkeln i söder indikerar den s.k. Lyckselestrukturen och diskuteras i avsnittet om impakter (s. 67). **B**. Blockdiagram som visar den tredimensionella utbredningen av den elektriska ledaren enligt Rasmussen m.fl. (1987). **C**. Tolkningen från den reflexionsseismiska BABEL-profilen (BABEL Working Group 1993 och Öhlander m.fl. 1993) draperad på en pseudo-3D-blockmodell.*

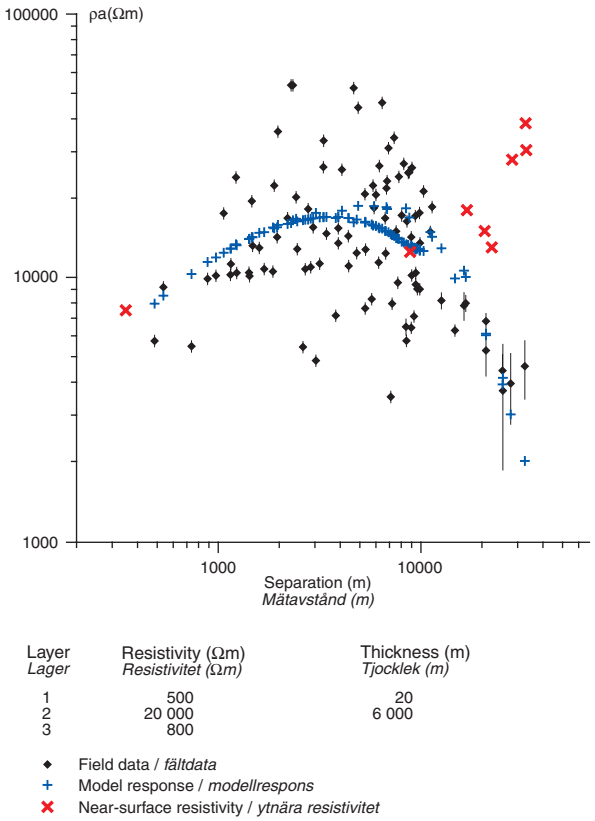


Fig. 97. Galvanic resistivity measurements according to Tunehed (2000). For discussion, see main text.

Galvaniska resistivitetsmätningar enligt Tunehed (2000). För en förklaring se texten.

Group beneath rocks of the Arvidsjaur Group. Observations supporting this have been reported by Perdahl & Frietsch (1993), Kathol & Triumf (2000, 2004), and Thunehed (1999). The latter author identified electrical conductors interpreted as connected to the Skellefte Group under a cover of rocks from the Arvidsjaur Group. This interpretation has a major implication on the estimation of the mineral potential of the region.

CURRENT STRATIGRAPHIC THINKING AND CONCLUSIONS

The knowledge of chronostratigraphy and lithostratigraphy has increased immensely during the last 20 years, since the introduction of geochronology as a tool for regional geological correlation work. Today the use of the U-Pb, Pb-Pb, Sm-Nd, Ar-Ar, Re-Os, and Rb-Sr geochronological methods is a key tool for advancing our understanding of the stratigraphy in the Skellefte District. To date, 77 high quality age determinations exist for the project area (see Table 1a). These determinations, together with results from various 1:50,000 scale bedrock mapping projects and research projects, have paved the way for the stratigraphical scheme used in this project. The introduction of more dynamic evolutionary models such as sequence stratigraphy has also meant that the dynamic environment in which the supracrustal rocks were emplaced is far better understood. The previous work carried out in the Skellefte District on stratigraphy is reviewed above and is not further discussed here. Instead, a brief explanation of current stratigraphic thinking is given below.

In Figure 9, several generalized stratigraphic schemes for different parts of the project area are displayed in the same time frame. This figure illustrates the rapid emplacement of Svecofennian supracrustal sequences in the time span c. 1.96 to 1.86 Ga. As stated previously, the basement to the Skellefte District volcanic rocks (i.e. the Skellefte Group) is not exposed and therefore we can only speculate on the nature of this basement. Less than 100 km north of the Skellefte District (as defined by the outcropping of the Skellefte Group) scattered remnants of Archaean tonalitic to granodioritic gneisses outcrop. These are now interpreted as tectonic slices or megaxenoliths in younger intrusions and constitute the oldest rocks in the project area. After the emplacement of the Archaean rocks, the Fennoscandian Shield was rifted apart and Palaeoproterozoic greenstone belts formed within the rifted craton north and north-east of the present project area. These greenstone belts are poorly dated but are generally believed to be between 2.4 and 2.0 Ga old. A succession of mainly greywackes and carbonates, subsequently deposited on the craton and the craton margin, has been referred to as Kalevian assemblages (Råneå Group). These rocks are not well dated because of a lack of rock units suitable for geochronological work. The relationship between the Kalevian assemblages and the Svecofennian supracrustal rocks is poorly delineated, but they probably overlap in age. We have chosen in this work (see Ba 57:1) not to keep the Kalevian as a stratigraphic unit, because much evidence, such as age constraints, rock types, relationship to deformation, etc., points towards a common origin of Svecofennian and Kalevian rocks.

The oldest Svecofennian assemblages are encountered within the Bothnian Supergroup. In the contact towards the Skellefte and Vargfors Groups, there seems to be a gradual lateral transition. However, the boundary between the Bothnian and the Vargfors–Skellefte Groups also corresponds to a rapid increase in metamorphic grade from greenschist to middle amphibolite facies, which obscures much of the primary relationships between the different groups. It is therefore quite conceivable that units within the Bothnian Supergroup are older, laterally equivalent to, or younger than both the Vargfors and Skellefte Groups. This was also proposed

by Allen et al. (1996) and Billström & Weihed (1996). It should be mentioned that Rutland et al. (2001a, 2001b) recently suggested that a major unconformity is situated within the Bothnian Basin. They regarded the high-grade supracrustal rocks of the Bothnian Supergroup south of the Skellefte Group (their Robertsfors Group) as substantially older than the Skellefte District and implied that a phase of migmatization separated the Skellefte District from the metagreywackes of the Bothnian Basin. They also suggested that the Robertsfors Group forms part of the previously unknown basement to the Skellefte Group and regarded the latter as a supracrustal sequence deposited in a rift setting, rather than a juvenile volcanic arc. However, this view was recently challenged by Weihed et al. (2002a) and Weihed (2002).

Extensive work in the ore-bearing volcanic units in the Skellefte District has led to a fairly good understanding of the stratigraphy of the Skellefte Group. We use the definition of Allen et al. (1996) for the Skellefte Group, meaning that the Skellefte Group is the lowest stratigraphic unit dominated by juvenile volcaniclastic rocks, porphyritic intrusions and lavas. Intercalated sedimentary rocks included in the group comprise grey to black mudstone, volcaniclastic siltstone, sandstone and breccia–conglomerate, volcaniclastic rocks with lime matrix in the centre of the district, and rare limestone. Overlying sedimentary units are excluded from the Skellefte Group and incorporated into the Vargfors Group. We also largely follow Allen et al. (1996) regarding their definition of the Vargfors Group: "The Skellefte Group is overlain by fine-grained and coarse-grained sedimentary successions with locally abundant intercalated volcanic rocks. These overlying successions are interpreted in this study to have mainly gradational and interfingering, conformable contact relationships with each other, and are consequently regarded as one stratigraphic group, the redefined Vargfors Group".

In this project we have used the name Arvidsjaur Group for volcanic rocks of mainly subaerial origin with minor intercalations of sedimentary rocks, which are situated north of the Skellefte District. Based on available geochronological data, the Arvidsjaur Group is considered as a lateral equivalent of the Vargfors Group and hence is younger than the Skellefte Group. The Skellefte Group–Arvidsjaur Group transition is extremely poorly exposed, but younging directions in supracrustal rocks close to the inferred contact also indicate that, at least in the contact area, the Arvidsjaur Group is deposited on top of the Skellefte Group. It should be noted however, that as the basement of the Arvidsjaur Group is not known, the question remains open, whether the oldest part of the Arvidsjaur Group could be coeval with at least parts of the Skellefte Group.

The youngest supracrustal unit is the Dobblon Group which was unconformably deposited on top of the older sequences at c. 1.80 Ga.

The oldest intrusive rocks, apart from the Archaean gneisses, are tonalitic to granodioritic, calc-alkaline intrusions in the Bothnian Basin south of the Skellefte Group metavolcanic rocks with emplacement ages between 1954 and 1900 Ma (Knaften, Lycksele–Blåviksjön, Kristineberg, Björkdal). These have all intruded supracrustal rocks of the Bothnian Supergroup.

The main type of the calc-alkaline intrusive rocks is here referred to as the Jörn GI suite. This suite is between 1.90 and 1.88 Ga old and is temporally and spatially related to the metavolcanic rocks of the Skellefte Group. However, a strict comagmatic relationship remains to be proven. In contrast, a comagmatic relationship between the Arvidsjaur Group metavolcanic rocks and the intrusions of the Perthite monzonite suite has been demonstrated in the Hej area (Kathol & Rapp 1996, Kathol & Persson 1997).

Anatectic, S-type, minimum melt granites, commonly two mica-bearing and pegmatoid in texture, are referred to as the Skellefte-Härnö suite. These rocks syn- to post-date the main deformation in the area and are between 1.82 and 1.78 Ga old. Granitoids of similar type have recently been dated by Rutland et al. (2001b) at c. 1.86 Ga, which indicates that this type of magmatism may have been prevailing during a relatively long time interval.

The youngest Palaeoproterozoic intrusive rocks in the area are intrusions of the Transscandinavian Igneous Belt (TIB; Revsund–Sorsele–Adak–Edefors–Ale suites) which range in composition from gabbro to granite. Most of these intrusions display a monzonitic differentiation trend (see Ahl et al. 2001). The intrusions of the Revsund suite are between 1.81 and 1.78 Ga old and hence overlap with the anatectic granites of the Skellefte-Härnö suite. The intrusions of the Sorsele suite are coeval and possibly comagmatic with the volcanic rocks of the Dobblon area.

Excursion guide

The excursion (days 1–5) is designed to start and end in Skellefteå with overnight stops in Boliden (alternatively Skellefteå), Malå, Storuman, and Arvidsjaur (Fig. 98). Some localities are added in areas not covered by this trip (Luleå, Piteå, Lycksele, and Robertsfors). The information in parentheses after the locality name (e.g. 22K 7d) refers to the topographic map sheet and the square within it. Map coordinates (northing/easting) are given in the Swedish National Grid (RT90). Locality notations (e.g. OIL930091) refer to identity numbers in the outcrop database of the Geological Survey of Sweden (SGU). The prefix meta is dropped for supracrustal rocks in the excursion guide for simplicity.

DAY 1

1:1. Jan-Sakrisaberget (22K 7d): Intrusion breccia. Intrusion of diorite to granodiorite into turbidites of the Bothnian Supergroup.

a. Berget

Outcrop on roadside.
7188550/1716870

Normally graded turbidites contain zones and lenses of calc-silicate rocks. These calc-silicates normally occur within the sandy beds.

b. Jan-Sakrisaberget

Outcrops near the end of the road.
7187200/1715700

The bedrock at Jan-Sakrisaberget consists of a chaotic assemblage of different rock types, which is interpreted as an intrusion breccia. This assemblage occurs between partly migmatized turbidites of the Skellefte District in the east and a dioritic to granodioritic intrusive complex to the west. The chaotic assemblage contains clasts of both sedimentary and igneous origin. The sedimentary clasts are derived from the turbidite sequence and comprise partly carbonate-cemented, sandy greywackes, slates, and conglomerates. Turbiditic structures are preserved in some cases. The igneous clasts comprise granodiorites, quartz diorites, diorites, gabbros, ultramafic rocks, and a felsic, porphyritic volcanic rock. The outcrops lie in a north-east–south-west striking grav-

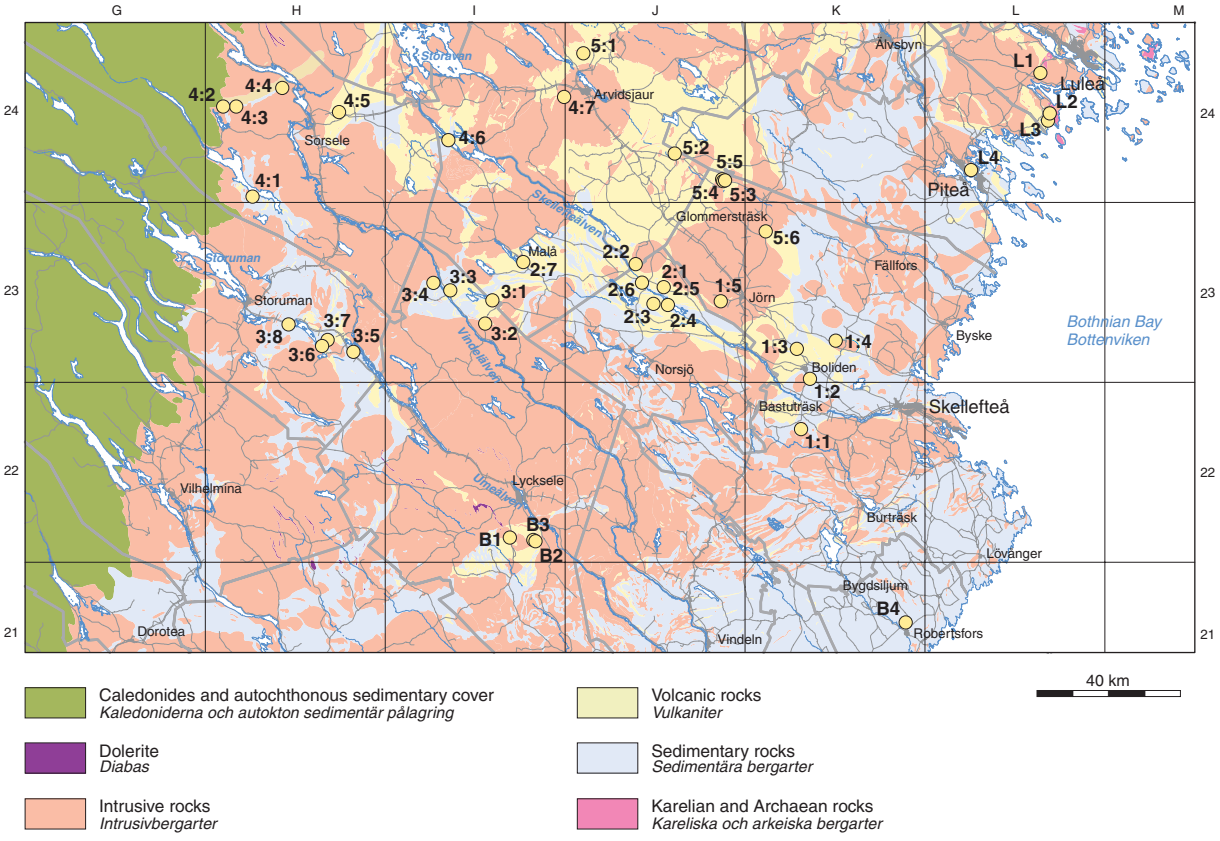


Fig. 98. Map of excursion localities, shown on a simplified bedrock map.
Översikt över exkursionslokalerna på en förenklad berggrundskarta.

ity anomaly, where the gravity maximum is probably caused by mafic rocks.

The generation of the intrusion breccia is considered to be related to the intrusion of granodioritic magma into the turbidite sequence. The clasts are derived from the magma chamber and the sedimentary wall rock. The matrix probably has an igneous and a sedimentary origin. In a later stage, the assemblage at Jan-Sakrisaberget was sheared, which caused rotation and elongation of the clasts.

1:2. Gåstjärnen (23K 0d):
Fold structures in greywackes of the Bothnian Supergroup.

OIL930091. Outcrop at railway trackbed north of Gåstjärn.
7201200/1718250

Layered metasedimentary rocks are folded around easterly plunging fold axes. Bedding and foliation strike east–west in this area, whereas horizontal loop EM (slingram) and aeromagnetic maps show north–south striking anomalies, probably caused by horizons within the metasedimentary sequence.

1:3. Bastuliden (23K 1c):
Volcanic siltstone of the Skellefte Group.

MHA930150. 1 km north of Bastuliden, outcrop on roadside.
7209510/1714640

The outcrop consists of laminated volcanic siltstones with synsedimentary deformation structures and porphyritic, felsic metavolcanic rocks. Apart from these rocks, horizons of rusty weathering, graphite- and sulphide-bearing (chalcopyrite) shales occur within the area. These electrically conductive horizons are indicated by electromagnetic measurements (horizontal loop EM [slingram] and VLF).

1:4. Mörttjärn (23K 2f):
Actinolite alteration in felsic metavolcanic rocks of the Skellefte Group. View over the Björkdal mine.

OIL920014. Short walk into woods west of road.
7211800/1725300

The outcrop consists of an actinolite-altered felsic metavolcanic rock. Reddish, felsic, plagioclase porphyritic, amygdaloidal metavolcanic rocks occur as pods within a greenish, actinolite-rich groundmass. Jigsaw fit and diffuse contacts between groundmass and pods suggest that the latter are alteration relics. Plagioclase porphyritic and amygdaloidal structures, partly occurring in the groundmass, indicate that even the groundmass was formed by alteration of primary felsic material.

The outcrop lies in the northern part of a gravity minimum, which probably is related to felsic bedrock in the area.

1:5. Näverliden (23J 4i):
About 5 km west of Jörn: Tallberget porphyry-copper mineralization in Jörn GI granitoid.

KWI990201. Follow narrow road from Lillgranberget about 1 km to the south. The outcrops are located on the southern slope of Näverliden hill, about 200 m from the road.
7222800/1693400

The outcrops on the southern slope of Näverliden hill reveal parts of the Tallberget porphyry-copper mineralization, which is situated in a metagranodiorite of the outer and oldest GI phase of the composite Jörn granitoid complex. It is associated with high-level quartz-feldspar porphyritic dykes and intrusions. The age of these porphyritic intrusions is 1886^{+15}_{-9} Ma (Weihed & Schöberg 1991) which, taking the errors into account, is the same as the host rock and the age of the host rocks to most massive sulphide deposits in the district. The deposit is of a low grade (0.3% Cu) and high tonnage (>50 Mt) disseminated type.

A typical alteration zoning exists with a proximal zone of phyllic alteration with quartz, sericite, and pyrite grading out into a distal propylitic alteration with abundant chlorite. Ore minerals occur, both disseminated and in a sulphide-quartz vein stockwork which is most intense in the central part of the deposit. Metals are also zoned, with copper concentrated to the central parts, whereas zinc and lead are concentrated within the marginal parts. Magnetite appears to be an early phase of the alteration system. Gold grades are low (<1 g/t), but in strongly sheared sericite alteration zones, cutting the deposit, the gold grades can reach >10 g/t. Stable isotope data and fluid inclusion studies indicate that the sulphides precipitated when magmatic fluids mixed with seawater at elevated temperatures of 450 to 500 °C (Weihed & Fallick 1994, Weihed et al. 1992).

DAY 2

(2:1) Granbergsliden (23J 5f): Mafic volcanic rocks of the Skellefte Group, pillow lavas, "fire-fountain deposit".

JHU000138. Walk up to Granbergsliden hill, about 5 km north-west of Petikträsk.
7226640/1677690

The Granbergsliden mafic volcanic centre constitutes one of the rare opportunities to examine basaltic volcanic rocks of the Skellefte Group. This volcano was at least 400 m thick and 3 km wide. At this stop, basaltic pillow lavas, related pillow breccias, in situ and resedimented hyaloclastites, and quench fragmented spalled bomb rind deposits can be studied. The basaltic pillow lavas are well preserved, with individual pillows up to one metre in size. Well-developed radial gas escapement trails can be seen in the pillow interior. The lavas are overlain by pillow breccias consisting of broken pillows and fluidal bombs, interlayered with deposits of quench fragmented spalled bomb rinds.

The whole sequence is interpreted as a subaqueous, basaltic fire-fountain deposit, which is a subaqueous equivalent to Hawaiian-style fire fountains. The environment was interpreted by Allen et al. (1996) as a high discharge fissure eruption which jetted rapidly quenched bombs above the sea floor, where they were deposited as quench breccias.

2:2. Gallejaur (23J 6d): Mafic volcanic rocks of the Vargfors Group within the Gallejaur structure.

KWI990079. Large road cut between Gallejaur and Järvträsk, about 600 m north-west of Gallejaur village.
7233240/1669915

The road cut show a section through ophitic gabbroid rocks. Grain sizes range from medium-grained in the western part, to coarsely medium-grained in the eastern part of the outcrop. Pegmatitic, 2–10 cm wide gabbroid dykes occur locally.

Mafic metavolcanic rocks of the Vargfors Group surround the Gallejaur and Högnäs (see below) intrusions. The metavolcanic sequence comprises coherent lavas, pyroclastic rocks, and different types of volcanic breccias from in situ hyaloclastites to resedimented monomict and polymict mass flows. The mafic volcanic rocks of the Vargfors Group are characteristically rich in amphibole phenocrysts, probably uralized pyroxene. Amygdales and vesicles are common, and at mount Vithatten they reach 5 cm in diameter.

The mafic metavolcanic rocks of the Vargfors Group show varying but generally high susceptibility values, relating to the outer parts of the round high magnetic structure. On the magnetic anomaly map the Gallejaur intrusion is indicated by a distinct circular magnetic anomaly, about 10 km in diameter. On the Bouguer anomaly map, the intrusion is represented by a distinctive gravity high. Studies using so-called "sandwich technique" indicate a depth between 5 and 10 km for the intrusion.

Recently, the Gallejaur structure has been interpreted by Lilljequist (1999) as being related to a meteorite impact.

2:3. Maurliden–Maurträsket (23J 4e): Felsic metavolcanic rocks of the Skellefte Group, mass flows.

PAW850164. Several outcrops on the ridge between Maurträsket and Bergtjärnberget. A short walk (about 200 m) south-east from road crossing, up to the ridge.
7222000/1674600

In the Maurliden area, the products of submarine, explosive felsic volcanic activity can be studied. The rocks host several massive sulphide deposits, of which the "Maurliden Västra" deposit is now in operation.

Well-exposed and cleaned outcrops show different types of volcanic breccias. Monomict, hyaloclastic in situ breccias, in contact with polymict volcaniclastic deposits, occur on top of the hill. Coherent lavas or domes are fragmented by quenching in contact with the volcaniclastic rocks and show characteristic concave fragment shapes with jigsaw fit. The volcaniclastic breccia, lacking jigsaw fit, contains fragments of various felsic volcanic rocks, partly of flow-banded lava or dome fragments. These rocks are part of the mineralized sequence in the "Maurliden Västra" deposit. The coherent, quartz-feldspar porphyritic cryptodomes of the area acted as a temperature source for hydrothermal systems that deposited the massive sulphide ores in the above-named rocks.

2:4. Maurliden–Gräsandtjärnen (23J 4f): Carbonate-cemented, polymict conglomerate (Mensträsk conglomerate) of the Vargfors Group.

KBK000025–026. Short walk from end of road to a small cliff at Vargfors lake, about 5 km north-west of Vargforsen power station.
7221740/1678820

The clast material in the carbonate-cemented conglomerate is polymict, with clasts mostly from Skellefte Group metavolcanic rocks. The conglomerate shows layering, and the clasts are well rounded to angular. They are flattened in the main cleavage and elongated parallel to the fold axis of the main deformation.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
ILA960031	0–10	2658	–	2.5/2.0/3.1

2:5. Maurliden–Skavberget (23J 4f): Turbiditic metagreywackes of the Vargfors Group.

KBK000011 and ILA960035. Outcrops on both sides of narrow road to Skavberget, south of lake Vargforsdammen, about 7.5 km north-west of the Vargforsen power station.
7223240/1677130

The metagreywackes in these outcrops show evidence of syngenetic deformation, indicating sedimentation in a tectonically active environment. Frequent rip-up clasts, ruptured beds, internal sliding of beds, soft sediment deformation, and small-scale growth faults are common, as well as dewatering structures such as load casts. Complex contact relationships between volcanic rocks and turbidites are indicated by the fact that younging directions in the turbidites commonly indicate younging towards the older volcanic rocks, which is explained by both syn- and post-sedimentation faulting.

The presence of conglomerates with well-rounded clasts in a carbonate-dominated matrix suggests that the environment may have been shallow marine, probably with a pronounced relief.

2:6. Nicknoret (23J 5e): Mass flows of felsic volcanic rocks of the Skellefte Group, passing into conglomerates of the Vargfors Group.

ILA941040 and ILA950507. Several outcrops between gravel pit and river Skellefteälven, about 1.5 km northwest of bridge over river Skellefteälven.
7227670/1671800

The uppermost Skellefte Group and the overlying Vargfors Group can be studied in exposures near river Skellefteälven at Nicknoret. An approximately 200 m long section starts in a probably slightly reworked, monomict, clast-rich felsic volcanogenic mass flow deposit of the Skellefte Group. It continues into successively more reworked and polymict conglomerates of the Vargfors Group which, at their base, are dominated by volcanic clasts. The traverse ends in a polymict conglomerate dominated by metagranitoid clasts (Jörn GI type) intercalated with sand- and siltstones.

Erratic clasts of mafic volcanic rocks of the Vargfors Group as well as intercalated mafic lava flows of the same composition confirm that all rock units at this locality were formed close in time. Approximately 1 km upstream from this stop, a welded ignimbrite yielded an age of 1875±4 Ma (Billström & Weihed 1996) which is considered to represent the mid-section of the Vargfors Group. A felsic volcanic rock about 3 km downstream was dated by Welin (1987) at 1882±8 Ma, which is regarded as the age of the top of the Skellefte Group in this area (cf. Billström & Weihed 1996).

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
ILA941040 (volc.)	13	2720	–	1.6/1.0/0.8
ILA950507 (congl.)	21	2678	–	1.5/3.1/5.7

2:7. Tjamstanberget (23I 6h): Mafic volcaniclastic rocks, sedimentary rocks of volcanic origin with Bouma cycles, andesitic debrites and lavas.

MGN940333–0335. Outcrops around the top of ski slopes at mount Tjamstanberget.
7233700/1638500

The bedrock at Tjamstanberget consists mainly of andesitic lavas and volcaniclastic rocks with several layers of polymict epiclastic breccias. The volcaniclastic rocks comprise two different facies types. The first is characterized by coarse clastic debrites with andesite as the predominant clast lithology. The other type is represented by normally graded, generally arenitic layers of turbiditic character (some complete Bouma units). Lavas occur as intercalations within the volcaniclastic rocks.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	30	-	-	0.8/0.8/1.7

The Tjamstan formation is a distinct volcanic province in the Malå area, whence it extends to Adak in the west and to the area around Sappovare and Småberg in the east. In the south, the Tjamstan formation is separated from the Kristineberg massif by an east–west striking major deformation zone. The occurrence of rocks of the Tjamstan formation below the Adak granite is indicated by gravity anomalies. However, concerning magnetic properties, there are considerable differences between the andesites of the Tjamstan area and the area to the west of Adak.

The andesites of the Tjamstan formation rest on felsic volcanic rocks of the Skellefte Group and are overlain by

sedimentary rocks of the Vargfors Group. In places, the Tjamstan and Skellefte rocks are separated by a thin horizon of black shales. Volcaniclastic rocks are the dominating rock types within the Tjamstan formation; lavas are subordinate. There are sporadic epiclastic breccias of considerable thickness. The geological environment is interpreted as an andesitic volcanic complex with repeated ejection of porphyritic ash-flows over large areas and sporadic intercalations of more proximal lava-flows. Collapse of the volcano led to local slides and the deposition of epiclastic breccias.

DAY 3

3:1. Hornberget/Kristineberg (23I 4g): Chlorite- and sericite-altered volcanic rocks of the Skellefte Group.

a. Hornberget

UJB930042. Outcrops on a ridge about 100 m east of road.
7222950/1630000

Fine-grained, light grey to brownish and dark green strongly foliated volcanic rocks are exposed in several outcrops along the ridge. These rocks are considered to have been rhyolites originally, but minor mafic dykes and possibly even lenses occur. Sericitic pods are interpreted as relicts of pumice, indicating the volcaniclastic nature of the rocks. Volcanic rocks with poorly preserved porphyritic textures, occurring in the wider area, are interpreted as subvolcanic intrusions. The dominant structural feature S1 is folded by F2 around shallowly plunging fold axes and subsequently folded by a later deformation phase (D3) with steep fold axes. A spaced cleavage (S3) represents the latest deformation in these rocks.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	0-40	-	-	2.5/2.2/6.1

The volcanic rocks are generally altered, with sericite as the main alteration mineral, but chlorite-rich zones also occur. The alterations are probably related to hydrothermal processes, but there is no direct relationship between hydrothermal alteration and ore formation in the Kristineberg area.

b. The Kristineberg mine

UJB970074. View from road.
7220700/1630000

Kristineberg is the largest of Boliden Mineral AB's mines in the Skellefte District, producing about 550,000 tons of massive sulphide ore per year. The ore grades are 1 ppm gold, 2 ppm silver, 1% copper, 3.2% zinc and 0.4% lead. The ore was discovered in 1918 and the mine has been worked since the 1940s. A concentrator was situated at Kristineberg until the 1980s, but the ore is now transported to the concentrator at Boliden.

c. Kolbäcken

UJB930050. Outcrop on roadside.
7220050/1629650

This outcrop, showing a grey, fine-grained, felsic volcanic rock, is the only example in the Kristineberg area of a bedrock that is not strongly altered. This volcanic rock, with few or no distinct textures, is interpreted as an ash-rich volcaniclastic rock.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	0–10	2675	-	-

3:2. Säter (23I 3f): Andalusite-altered felsic volcanic rock (Skellefte Group).

UJB930118. Outcrop close to road.
7216580/1628150

These light grey, rather brownish andalusite-bearing rocks are interpreted as volcaniclastic rhyolites, though there are no primary textures preserved. A distinct tectonic foliation (S1) is folded by F3. First-generation andalusite crystals are oriented parallel to S1, indicating that the clay alteration which produced this andalusite generation pre-dates the main deformation phase. It is regarded as syngenetic. Large porphyroblasts of a second generation of andalusite, post-dating the main deformation phase, were probably generated by contact metamorphism from the intrusion of Revsund granite south of Säter.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	15	-	-	2.9/4.1/8.8

The bedrock in the Kristineberg area normally shows alteration to a varying degree, and primary textures are normally not preserved. Around Säter, the bedrock displays an amphibolite facies paragenesis, dominated by andalusite and cordierite, passing into a chlorite-sericite dominated greenschist paragenesis north of Kristineberg. Thermometric analyses in the Säter area of biotite-tourmaline indicate metamorphic temperatures of c. 600 °C south of Kristineberg. In this area, subeconomic zinc dissemination with some copper, gold, and silver (Mörkliden) is related to the chlorite-sericite alteration.

3:3. Vargbäcken, Granselliden (23I 5d): Fine-grained turbidites of the Vargfors Group, skarn, gold mineralization in a dioritic intrusion within the turbidites, sills of magnesium basalt.

a. "South of the road junction"

UJB950072. Outcrop on roadside.
7226470/1618040

Thin-bedded (2–10 cm), fine-grained turbidites show cross-bedding and erosional surfaces. Skarn lenses with amphibole porphyroblasts occur in these rocks.

A general feature of the turbidites in the Vindelgransele area is "coarsening upwards" with correlated increase in bed thickness within the sequence. Deposition of single thick turbidite units occurred unsystematically within a sedimentary basin, which was generally dominated by deposition of fine-grained, thin-bedded sediments. This occurrence of different facies types is typical of distal or lateral environments in a turbidite system and can be interpreted in two different ways: (1) the existence of two different sources and deposition within an elongated basin, or (2) the existence of a single source which, unsystematically, was affected by earthquakes displacing larger quantities of sediments.

b. Road to Granselliden

UJB950075. Outcrops along road and gold prospect.
7225750/1618400

The Vargbäcken gold mineralization is hosted by an intrusion of grey, fine- to medium-grained quartz monzodiorite within the turbidite sequence. Quartz veins, about 1 cm wide, are oriented in two principal directions. Sulphides are rare, and the alteration of the intrusion is not very strong.

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
—	80	2919	-	2.1/1.9/4.4

The dioritoids in the Vindelgransele area normally occur as several 100 m thick sills with weakly developed magmatic layering. Their stratigraphic position is uncertain; they seem to truncate S0 and S1 but are folded by F2 within the larger anticlinal structure at Vindelgransele. These dioritoids are host rocks for several gold mineralizations in the form of quartz veins (Middagsberget, Fäbodliden and Vargbäcken). Gold-bearing quartz veins also occur within the surrounding turbidites.

3:4. Rågobäcken, Vindelgransele (23I 5c): Thick arenitic layers within greywackes of the Vargfors Group, sedimentary structures.

AFT940160. Short walk, crossing river Rågobäcken, rubber boots recommended.
7227720/1613680

Grey, arenitic and well preserved turbiditic greywackes of the Vargfors Group show graded bedding with way-up to the north. Synsedimentary deformation structures and mud dykes can be observed. The arenitic layers are rich in silica concretions, normally aligned to bedding planes.

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
—	30	-	-	2,5/2,8/7,7

The turbidites in the Vindelgransele area occur in an anticlinal structure with felsic volcanic rocks of the Skellefte Group in the core. South of river Vindelälven, way-up is consequently towards west and north-west. The thickness of the turbidite sequence including the magnesium basalt sills is estimated here to almost 6 km. Higher up in the sequence, thick arenitic units (bed A in a Bouma sequence) become more frequent. The material in the arenitic layers is dominated by rounded quartz grains and some plagioclase, particularly in the coarsest layers.

The turbidites were probably deposited in a marine delta environment. Increasing number and bed thickness of arenitic layers toward the south-west indicate a material source south-west of the Skellefte District, with sediment transport to the north-east. The predominance of quartz and feldspar over lithic volcanic fragments indicates a continental derivation.

3:5. Kovallberget (23H 1i): Monomict conglomerate with fragments of a fine-grained, felsic volcanic rock, Bothnian Supergroup.

GSO940138 and 0137. Short walk to outcrops in woods north-east of road, about 5 km south-east of Gunnarn.
7208650/1591430

On mount Kovallberget, three different rock units are exposed: (1) debritic conglomerate with sandstone beds, (2) sandstone, and (3) volcaniclastic rocks. Most of the clast material within the conglomeratic layers is derived from light grey, fine-grained, felsic volcanic rocks. The conglomerate-dominated lower part of the sequence is overlain by a 25–30 m thick unit of sand- and mudstones. Within this unit, the layer thickness normally

does not exceed 0.5 m, and the particular layers are normal-graded. Both the conglomerate-dominated unit and the sand–mud unit have been deposited within a turbiditic environment, where the conglomerates represent channel fillings. The third unit (c. 10–15 m thick) at Kovallberget consists of a light grey, felsic volcaniclastic rock without distinct layering. This rock is probably the result of an ash eruption deposited as a suspension deposit in a marine environment.

In this area, there are several magnetic anomalies caused by dolerite dykes with a north-easterly strike. These anomalies overlap the weaker banded anomaly pattern that is probably caused by the metasedimentary rocks. North of the excursion stop, there is a distinct gravimetric minimum coinciding with a magnetically homogeneous area.

3:6. Björkliden (23H 2h):
Polymict conglomerate as lenses in fine-grained, distal turbidites, Bothnian Supergroup.

TEN960028. Short walk up hill.
7210310/1582820

The outcrops at Björkliden expose a sequence of mainly fine-grained, turbiditic, graphitic, almost black shales with intercalations of coarse clastic, debritic conglomerates. The latter are dominated by granitoid clasts and clasts of grey sandstone. Grey basaltic to andesitic volcanic rocks occur in small quantities, and clasts of greenstone and layered gabbro are rare. The matrix in these mainly clast-supported conglomerates consists of granitic gravel and turbiditic sand- and claystone or, in places, of mafic volcanogenic silt- and sandstones.

Toward the north-east, the conglomerate horizon is overlain by a right-way-up sequence of fine-grained, thinly bedded and normal-graded turbidites, which indicates that the conglomerates were deposited in a turbiditic environment. The fine-grained sedimentary rocks are interpreted as distal turbidites, which moved more or less parallel to the axis of an oblong depositional basin, whereas the coarse clastic rocks were deposited by mass flows directly into the basin, i.e. perpendicular to the basin axis. In that way they could be deposited in areas normally dominated by a distal turbiditic setting.

The magnetic susceptibility varies from 5 to 600 × 10^{-5} SI.

3:7. Storträsket (23H 2h):
Late to post Svecokarelian leucogranite with tungsten-mineralized quartz veins.

TEN940011. About 4.5 km west-southwest of Gunnarn, short walk along "truck trail".
7212020/1584330

Mineralized quartz veins within a leucogranite contain wolframite, scheelite, and molybdenite. Aggregates of pyrrhotite-pyrite±chalcopyrite occur within the host rocks. Approximately 100 m to the north-west, the quartz veins cut a grey, medium-grained to coarsely medium-grained granite (albite-microcline-quartz-muscovite) and hornfels-altered metagreywackes.

The quartz veins strike north-northeast (015/90–020/90), as do other greisen-like tungsten-mineralizations of this region. Mineralizations within the late to post Svecokarelian biotite-muscovite granite north of Storuman show similar orientations.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
Leucogranite	0	-	-	2,8/14,2/18,5
Metagreywacke	10	-	-	-

3:8. Haga at river Umeälven (23H 3d):
Turbiditic greywackes of the Bothnian Supergroup, isoclinal fold structures.

JPN940056. Outcrops along river close to the road, about 4 km east of Forsvik.
7216300/1573420

The main rock types in these outcrops are parallel laminated turbidites with 2–30 cm thick layers of sand-, silt-, and claystone. Turbidite beds, up to one or even several metres thick, occur in places. The proportion sand to silt/clay varies between 2:1 and 3:1. Most of the beds are graded; cross-bedding is absent. Two or three deformational events and amphibolite facies metamorphism have affected the bedrock of this area. The turbidite sequence is isoclinally folded around horizontal axes, producing way-up structures in opposite directions in these outcrops. The main schistosity is normally parallel with bedding, steeply dipping and striking east-northeast (S0/S1, 140–160/90). S2 strikes 290–310 and is best developed within the argillitic layers.

The occurrence of several deformation phases is also shown by the complex magnetic pattern of this area.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
Argillitic layers	30	-	-	-
Arenitic layers	15	-	-	-

The turbiditic sequence generally represents distal depositional environments with intercalation of some thick beds with proximal character. The mineralogical composition of these turbidites is dominated by quartz, indicating a continental source for most of the sediments.

DAY 4

4:1. Ersmarksberget, "Blaikengruvan" (24H 0c): Zinc-gold mineralization close to lake Storjuktan.

TNT940207
c. 7251800/1563500 and 7252000/1563370

The Ersmarkberget mineralization consists of gold- and zinc-bearing zones in black mudstone in the contact zone of a light grey, fine- to medium-grained, weakly porphyritic tonalite (the Juktan dome). The exploration company ScanMining AB has carried out drilling, trenching, and trial mining and outlined two principal and separate ore zones within the same ore system. The larger zinc-lead-silver-gold zone has a probable ore reserve of 6.6 million tonnes, with zinc grades around 2%, whereas the smaller gold zone contains 0.9 million tonnes with 3.7 g/t gold. The mineralization in the zinc zone consists of fissure fillings of quartz, carbonate, red sphalerite, and galena.

The tonalite is anomalously low in potassium, uranium and thorium, and show low magnetic susceptibility. It forms one larger pluton, surrounded by several small, deformed dyke-shaped intrusions along the pluton contact, all with the same petrophysical signature. Farther north-west, a larger granodiorite–diorite intrusion crops out.

Sampling for petrophysical studies was carried out in an area of c. 500 m in diameter around the mineralization:

Felsic intrusive rocks:

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
4615559	9	2666	-	-
4615604	8	2674	-	-
4615597	8	2665		
4615606	16	2686		
4615558	7	2654		
LG81223	146	2759	8	
CAT990122	2	-	-	0.9/0.4/1.1

Tonalite

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
4615578	51	2795	-	-

4:2. Dobblonbäcken (24H 5b): Gold and silver mineralization, potassium alteration, and disseminated sulphides in rocks of the Dobblon Group.

CAT980265-268. Outcrops at opposite side of the minor river Dobblonbäcken, rubber boots recommended.
7276800/1655300

The gold at Dobblonbäcken, up to 4 ppm, was found in local boulders, together with arsenopyrite, sphalerite, chalcopyrite, and galena. Ground measurements showed a concentrated IP anomaly covering at least 6000 m^2. Five holes with a total length of about 500 m were drilled in this area and one showed a gold concentration of 0.52 ppm over a length of 37 m. The highest silver concentration in any drill hole was 50 ppm.

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
CAT980265	10	-	-	6.1/5.9/17.7

In the area of map sheets 24H Sorsele, linear magnetic anomalies occurring in areas with granitic bedrock seem to be related to formation of magnetite by hydrothermal processes. However, the relationship between these anomalies and the gold mineralizations is uncertain.

4:3. Björnknösen (24H 5b) Polymict conglomerate of the Dobblon Group.

GBA000107. Outcrops along road and on low hills south of road.
7276700/1559000

The conglomerate at Björnknösen hill shows internal layering with 5–50 cm thick, clast-supported layers. It is polymict, with clasts of volcanic rocks, coarse-grained porphyritic granite, jasper, and brownish red, subaerial sandstones. The clasts are 0.5 to 20 cm in diameter and mostly rounded to well rounded, but angular clasts occur subordinately. This coarse clast material occurs in channels, in places with recognizable erosion surfaces at the base. These channels are separated by beds of stratified volcanogenic sandstones, up to 50 cm thick. Bedding strikes east–west with a dip of about 60 degrees to the north. Younging towards the north is indicated by the erosion surfaces. The conglomerate is underlain by a uranium-mineralized, lithophysae-bearing ignimbritic rhyolite.

Farther east, a moderately north-dipping sequence of conglomerates and underlying arkosic sandstones rests on a metamorphosed and tightly folded turbidite sequence (Paksjo Group). The conglomerates are domi-

nated by felsic, volcanogenic material and show no or only subordinate internal layering and are therefore interpreted as debritic deposits. The underlying sandstones contain beds with low angle cross-bedding which indicates deposition within a beach environment. North-east of Skravelberget hill (7276880/1562150) there are two distinctly different types of monomict conglomerates. One consists of rounded granite clasts within a matrix of granitic grit; the other is composed of rounded clasts of turbiditic greywackes of the Paksjo Group, i.e. the basement to the Dobblon Group in the eastern part of the Dobblon area.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
LK81538	24.5	2779	0.31	-

The bedrock in the Björnknösen area shows weak radiation and magnetization. The outcrops are situated on a gravity gradient which defines the border between granite-dominated areas in the south and south-east and volcanic rocks of the Dobblon Group in the north. Linear, north-easterly striking magnetic anomalies indicate dolerite dykes with increased magnetization. These dykes were observed by Einarsson (1979) in outcrops north-west of Vällingträsket.

4:4. Osaberg quarry (24H 6e): Quarry in operation within rhyolites of the Dobblon Group (Gippervare Formation).

APS990277. Quarry at end of road.
7282020/1571850

Quartz-feldspar porphyritic rhyolites are overlain by red to brownish red feldspar porphyritic rhyolites. Phenocrysts of the latter are commonly euhedral and consist of albitic plagioclase or microcline. Both rock types belong to the Gippervare Formation within the Dobblon Group. They were dated (U-Pb, zircon) at 1803±15 Ma by Skiöld (1988).

The quarry is situated between distinctly east-north-east striking magnetic anomalies in the north, probably caused by felsic volcanic rocks and areas with weakly magnetized rhyolites in the south.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
CAT990188	100-8000	-	-	3.3/10.5/18.4

4:5. Kallbäckberget (24H 5h): Karesuando–Bure deformation zone.

TNT940517 (alt. 514), CAT980222. 4 km west of Heden, outcrops along road.
7275260/1587480 (alt. 7275100/1587640)

The outcrops exhibit strongly foliated mafic volcanic rocks and volcanogenic conglomerates of the Arvidsjaur Group. The foliation strikes north-northeast (020/90) and shear sense indicators point to "west side up" for the latest movement. In this area, the Karesuando–Bure deformation zone is 500–600 m wide. It can be traced on the aeromagnetic map from here via Gällivare to Karesuando in northernmost Sweden.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
CAT980222	270	2920	0.32	1.5/2/2.5
CAT980223	34	2753	-	2.7/2.8/7.8

Susceptibility is low in the strongly sheared rocks, but can reach up to $12{,}000 \times 10^{-5}$ SI in tectonically less affected or unaffected lenses.

The anomalies are predominantly oriented parallel to the strike of the foliation (020/90). The electric conductors, indicated in VLF data, are irregularly spaced and discontinuous. This indicates that the deformation zone does not contain crushed, mica-altered or water-bearing continuous zones. If the zone contains such zones, they are partly very thin.

4:6. Skidnäs quarry (24I 3d): Ledfat conglomerate (Conglomerate Formation of the Ledfat series, Arvidsjaur Group).

UJB980009. Quarry between main road and Ledvattnet of river Skellefteälven. Short walk.
7267380/1617850

The Skidnäs quarry and adjacent outcrops yield excellent opportunities to study the Ledfat conglomerate, one of the coarse clastic deposits within the Vargfors Group.

This polymict conglomerate is mostly clast-supported, poorly to moderately sorted and shows layering. The clasts, especially those exceeding 5 cm in diameter, are rounded to well rounded and normally have a high sphericity. The clast material comprises grey, finely medium-grained to medium-grained granite, coarse feldspar porphyritic grey granite, grey to reddish grey and red to brownish sandstones, jaspilite, quartz and brownish red feldspar porphyritic volcanic rocks. Some clasts of finely medium-grained granite exhibit a penetrative foliation. Epidote and amphibole

are found in the matrix; the clasts are locally cemented by carbonates.

The sedimentary rocks at Ledfat have generally low magnetic susceptibility (<500 × 10^{-5} SI). Densities range between approximately 2640 and 2800 kg/m^3, depending on the composition of the sedimentary rocks. The density increases inversely with decreasing potassium content. Basic dykes cut through the Ledfat series. The basic dykes are interpreted to originate from gabbroids, which are presumed to lie below the sedimentary rocks.

The Conglomerate Formation is underlain by a steeply dipping, thick sequence of fluvial red arkoses with ubiquitous cross-bedded units. Both the arkoses and the conglomerate are intruded by late to post Svecokarelian gabbros and granites. At Gråberget, about 5 km south of Skidnäs, a copper mineralization occurs in contact with a granitic dyke (cf. page 143).

Besides this larger occurrence around and south-west of Ledvattnet, conglomerates of Ledfat type occur south of lake Bockträsket and along river Malån, 10–15 km south of Ledvattnet. The Ledfat conglomerate can be correlated with the youngest polymict conglomerate in the Bure area, with conglomerates at Blåviksjön (7192780/1606930) and Björkliden along river Umeälven and probably with the Dödmanberg conglomerate of the Vargfors Group. The deposition of these conglomerates is considered to indicate relatively rapid uplift and erosion of parts of the crust during the volcanic activity of the Arvidsjaur Group. A granite clast of the Ledfat conglomerate from Setmyrliden was dated (U-Pb, zircon) at 1866±17 by Skiöld (1988).

4:7. Vittjåkk (24I): Arvidsjaur granite of the Perthite monzonite suite.

FRJ960101. Outcrop beside road to mount Vittjåkk, 7 km south-west of Arvidsjaur, immediately south of road tunnel.
7279250/1649930

The red, medium-grained, leucocratic alkali feldspar granite in this outcrop is dominated by quartz and microcline; subordinately, biotite, riebeckite, and albite occur. Accessory minerals are magnetite and fluorite.

The Arvidsjaur granite forms an almost circular pluton with a diameter of about 25 km around Arvidsjaur. According to geophysical modelling, this pluton is 3–5 km thick, with contacts dipping around 60 degrees inwards. The granite is intrusive into the surrounding volcanic rocks of the Arvidsjaur Group and other granites of the Perthite monzonite suite. The intrusive nature of the contact is indicated by xenoliths of the host rock in the granite, chilled margins, and granitic dykes (apophyses) in the host rock.

The Arvidsjaur granite is considered to be the youngest, most fractionated intrusion of the Perthite monzonite suite of southern Norrbotten and northern Västerbotten counties. A U-Pb zircon dating at mount Akkanålke, about 5 km south of this stop, yielded an age of 1877^{+8}_{-7} Ma (Skiöld et al. 1993).

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
JSN950059	1077	2594	0.03	4.1/7.4/16.8

DAY 5

5:1. Dyrasflygget (24J 8b): Flow-banded syngenetically folded rhyolites in cryptodomes, Arvidsjaur Group.

MFR980083. Outcrops behind a small hill just north of road, about 4.5 km north north-west of Akkavare.
7291660/1655240

The bedrock in the area around Dyrasflygget and mount Östra Såkevare consists of flow-banded, syngenetically folded rhyolites, occurring as cryptodomes in volcanic, partly polymict breccias. This type of bedrock seems to control the topography, with small hills representing the cryptodomes, and lower, smooth relief within the more easily weathered breccias.

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
CAT990013	2895	2645	-	5.1/4.7/14.6

To the west, flow-banding in the coherent rocks becomes more diffuse and irregular; the bands are interrupted by numerous small (<1 cm), partly resorbed fragments. Rocks of this type are interpreted as rheomorphic ignimbrites. A subvolcanic intrusion, consisting of a quartz porphyritic rhyolite or granite, is exposed in a brook south of Västra Såkevare. It is considered to be a shallow magma chamber, related to the above-mentioned succession of volcaniclastic rocks and cryptodomes.

5:2. Fågelberget (24J 2g): Composite dyke, feeder dyke of Arvidsjaur volcanic rocks within rhyodacites of the Skellefte Group.

KBK970102. Quarry, short walk up to cleaned area above quarry.
7263800/1680590

Two west-northwest striking dykes are exposed in the cleaned area above the quarry on the southern slope of

mount Fågelberget. The larger one, a composite dyke about 5 m wide, consists of a dacitic inner sheet surrounded by two basic, about 1 m wide outer sheets. A comagmatic origin of the inner dyke sheet and dacites of the Arvidsjaur Group to the west of this area is indicated by REE and trace element patterns. The dyke cuts through a tilted sequence of 1886±13 Ma (U-Pb zircon, SGU unpublished) old volcaniclastic rhyolites to rhyodacites of the Skellefte Group. The inner sheet has been dated at 1877±9 Ma (U-Pb zircon, SGU unpublished) which makes the intrusion coeval with deposition of the volcanic rocks of the Arvidsjaur Group. At least the inner sheet is therefore considered to be a feeder dyke for dacites of the Arvidsjaur Group, implying that Arvidsjaur volcanic rocks overlie rocks of the Skellefte Group, at least in places.

Rhyodacite–dacite (7263900/1680250)

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
CAT960034	2863	2718	-	2.3/8.2/11.3

Electric measurements (Thunehed 2000) show that volumes of weakly resistive rocks occur in connection with the north-northeast striking low magnetic anomalies in the central parts of map area 24J Arvidsjaur. These anomalies are interpreted to be caused by Skellefte Group volcanic rocks. Volumes of weakly resistive rocks are also situated below the Arvidsjaur volcanic rocks and it cannot be excluded that significant volumes of Skellefte Group volcanic rocks occur below the Arvidsjaur vokcanic rocks in this region.

5:3. Urikberget (24J 1i): Volcanic breccia within the Arvidsjaur Group, caldera formation.

KBK940035, CAT960025. Several outcrops south of road, about 1.5 km west of Hej.
7256030/1694750

A volcanic breccia is exposed in two north-striking and west-dipping strips in the eastern and western parts of Urikberget. East of the breccia, grey dacitic feldspar porphyritic lava occurs, also forming the matrix of the volcanic breccias. No distinct contact is exposed between the volcanic breccia and the lava. In the transition zone, irregular flow-banded fragments occur in the lava. The volcanic breccia is both clast- and matrix-supported and the contacts between fragments and the feldspar porphyritic matrix vary from diffuse to sharp. The clast material is angular to subrounded and consists mainly of elongated flow-banded fragments, vesicular mafic fragments, and vesicular grey–greenish dacite fragments with or without feldspar phenocrysts. Jigsaw fit texture occurs in parts where the reddish feldspar porphyritic matrix dominates. Here, the matrix is considered to be intrusive. In other parts of the breccia, the matrix consists of laminated siltstone and fine sandstone, and peperitic structures occur. An about 2 m wide breccia dyke can be studied in the outcrop area.

The breccia may have formed when a sequence of weakly lithified volcaniclastic rocks, mainly tuffs, was intruded and destabilized by dacitic lavas. Gravity-propelled transport is not excluded in this model, but is considered to be short, due to the shape of the fragments. Rapp (1996) suggested deposition and emplacement from syn-volcanic, gravity-driven volcaniclastic mass flows, which were contemporaneous with the emplacement of the grey dacitic feldspar porphyritic lava flow. Jigsaw fit texture is suggested to have formed by quench fragmentation of the hot lava fragments following deposition. The peperitic structures point to, at least in places, emplacement into water-saturated sediments. The breccia is considered to be related to a caldera formation (see stop 5:5, b) and different processes may have been involved in their generation and emplacement.

Sample name	susc (x 10^{-5} SI)	dens (kg/m^3)	Q-value	K%/U/Th ppm
—	20–50	-	-	2.7/5.2/8.3

5:4. West of Urikberget (24J 1i): Urikberget conglomerate, lens of polymict conglomerate within volcanic rocks, Arvidsjaur Group.

KBK940036 and 0160. Outcrop immediately north of road, about 1.7 km west of Hej. Several larger and better outcrops occur on the slope of Urikberget hill, farther north.
7256210/1694550

The Urikberget conglomerate comprises rocks of both intrusive and volcanogenic origin. It has a north–south extension of almost 5 km and is between 200 and 400 m thick. The clasts are 1–50 cm in diameter, mostly rounded to well rounded, and have a high sphericity. They consist of metagranodiorites and metatonalites of the Jörn GI suite and of lavas and lithified volcaniclastic rocks, mainly of the Arvidsjaur Group. The conglomerate is matrix-supported with a widely varying, commonly coarse-grained or gritty matrix. Clay minerals seem to be absent within this matrix.

The conglomerate lens consists of several, steeply dipping and westerly younging, unstratified and poorly sorted beds on the one hand and distinctly layered beds on the other. These features indicate that the coarse clastic sequence of the Urikberget conglomerate was deposited in an alluvial environment where debris flows were the dominant transport mechanism. Due to the

lack of clay minerals in the matrix, the occurrence of thick, unstratified units, and its inner framework, the Urikberget conglomerate is interpreted as a result of slope wasting in an unweathered volcanic terrain with relatively pronounced relief.

A metagranodiorite clast of Jörn GI type from the Urikberget conglomerate has been dated by U-Pb on zircon at 1893±4 Ma (SGU, unpublished). Overlying ignimbritic rhyolites and a related subvolcanic granitic intrusion yielded U-Pb zircon ages of 1878±2 Ma and 1879^{+15}_{-12} Ma respectively (Skiöld et al. 1993, Kathol & Persson 1997). These ages limit the period of intrusion, uplift, and erosion of metagranitoids of the Jörn GI suite and the deposition of the Urikberget conglomerate to c. 10–15 million years.

5:5. Boljerberget (24J):
Rhyolitic ash-fall tuffs and ignimbrites of the Arvidsjaur Group.

a. "Between the roads"
KBK940129 and 0135, CAT960026. Short walk toward Boljerberget hill to the north. Several outcrops in the area between the roads.
7256300/1693880

The ash-fall tuffs south of Boljerberget hill are characterized by west-dipping, centimetre to decimetre thick beds of very fine-grained to lapilli-sized volcanic material. Stratigraphic younging to the west is indicated by impact sags in fine-grained layers and the truncation of underlying layers. The air fall emplacement is indicated by good sorting, lamination, stratification, truncation of underlying layers, impact sags of ballistic clasts, and the lack of traction structures such as cross-stratification. An about 30 cm wide pebble dyke can be studied in one of the outcrops.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	1000–3500	-	-	3.6/7.6/10.5

b. Boljerberget hill
KBK940130, CAT960027. Continued walk to Boljerberget hill. Low cliffs at southern side of the top.
7256520/1693830

Welded ignimbrites are exposed at and around Boljerberget hill. These are lithophysae-bearing, quartz-feldspar porphyritic rhyolites with fiamme and eutaxitic textures. The matrix varies in colour from blue-grey to violet, due to differing oxidation states of iron. A steeply dipping bedding parallel foliation is defined by fiamme and the eutaxitic textures. In thin-section the rock contains broken crystals and eutaxitic and granophyric textures. The degree of welding is moderate to dense. The poor stratification, variable degree of welding, and the absence of reworked horizons of the welded ignimbrites are consistent with rapid emplacement, either from sustained flows or from a rapid succession of flows.

Both the ash-fall tuffs and the ignimbrites around Boljerberget hill are considered to form a 400–500 m thick compound cooling unit, emplaced in an intracaldera setting. Together with the comagmatic, 1879^{+15}_{-12} Ma (Kathol & Persson 1997) old Antak granite, these 1978±2 Ma (Skiöld et al. 1993) volcaniclastic rocks form a rhyolitic volcanic system within the volcanic rocks of the Arvidsjaur Group.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
CAT960027	19	2691	-	3.6/7.2/11.4

5:6. Grundträsket (23K 8b):
Strongly foliated gneiss with mafic volcanic rock of the Arvidsjaur Group as precursor?

FRS960027. Road cut north of Grundträsket.
7242190/1706020

This outcrop exposes strongly foliated gneiss, belonging to the "Brännbergsliden gneiss complex". The latter differs completely from the surrounding, well preserved rocks by its penetrative foliation. The gneiss has been dated (U-Pb on zircon) at 1872±7 Ma (Lundström & Persson 1999). The Brännbergsliden gneiss complex is truncated by post-deformational granite dykes, which at this place belong to the Perthite monzonite suite.

Sample name	susc (x 10^{-5} SI)	dens (kg/m³)	Q-value	K%/U/Th ppm
—	2000–8000	2832	0.17	1.7/3.4/5.0

ADDITIONAL LOCALITIES IN THE SOUTHERN PART OF MAP AREA

B1. Rönnliden (22I 1g):
Metagranitoid of the Knaften massif.

Outcrop on roadside.
7157100/1634980

Grey to greyish red metagranitoid of the Knaften massif is exposed along the road at Rönnliden. The Knaften metagranitoids are normally massive, but locally display magmatic foliation. Blue quartz crystals are common and pegmatitic parts occur. The metagranitoid from this locality has been dated (U-Pb on zircon) at 1954±6 Ma (Wasström 1993), which is interpreted as an intrusion age.

B2. Björnberget (22I 1i):
Quartz-feldspar porphyritic dykes, related to the Knaften metagranitoids.

Outcrops on roadside.
7155800/1642200

In this outcrop, quartz-feldspar porphyritic and more quartz-dominated dykes can be observed. Both types truncate strongly deformed pillow lavas but are themselves irregularly shaped. A quartz-feldspar porphyritic dyke yielded a U-Pb zircon age of 1940±14 Ma (Wasström 1996).

B3. Hästliden (22I 1i):
Pillow lavas of the Bothnian Supergroup.

Outcrops on roadside.
7156300/1641550

The pillow lavas in the Knaften area consist mostly of elongated pillows with glassy crusts, which occur in a primary sedimentary imbrication structure. The lavas contain only minor amounts of matrix between the pillows, which implies rapid deposition of the lavas. Well-preserved feldspar phenocrysts and minor amygdales and vesicles are common. Augite and possibly olivine are normally altered to amphiboles.

B4. Fagerliden (21K 6d):
Migmatite, veined gneiss of the Bothnian Supergroup.

LKS960029, LCK960015. Large, flat-lying outcrops on roadside.
7133750/1744600

This outcrop displays migmatites and veined gneisses of sedimentary origin and internal relationships between mesosome and leucosome. Cordierite, sillimanite and garnet are common in these rocks.

ADDITIONAL LOCALITIES IN THE LULEÅ AREA

L1. Måttsundsberget (24L 7g):
Subvolcanic intrusive breccia, previously interpreted as epiclastic conglomerate.

Several larger outcrops on slope of Måttsundsberget.
7286650/1782550

The Bälinge conglomerate (Åhman & Ödman 1952) at this locality and in the type area Bälingsberget was previously regarded, due to its content of fragments of Haparanda suite metagranodiorite, as an important marker horizon in the regional stratigraphy of Norrbotten. However, Mellqvist (1994) and Wikström et al. (1996a) observed numerous magma-mingling and magma-mixing phenomena between fragments and the matrix within these rocks. Furthermore, they found transitional rock assemblages, which they interpreted as clast-rich volcanic rocks. The authors therefore reinterpreted the Bälinge conglomerate as a subvolcanic magmatic hydraulic breccia, which affected the interpretation of the regional stratigraphy. A fragment from this locality was dated (U-Pb, zircon) at 1879±4 Ma by Wikström et al. (1996b). Besides this "Bälinge breccia", felsic volcanic rocks and Archaean gneisses are exposed in this area.

L2. Mittihedberget (24L 5g):
Archaean metagranitoid.

Several outcrops on the slope of Mittihedsberget.
7275250/1784600

In this locality, a feldspar porphyritic metagranitoid is overlain by conglomerate-like rocks containing granitoid clasts. The porphyritic metagranitoid was previously considered to belong to the c. 1.8 Ga Revsund suite (Åhman 1953). However, a U-Pb zircon dating of a metagranitoid clast gave an Archaean age of 2655±7 Ma (Lundqvist et al. 2000), and the metagranitoid itself was dated by the same authors some kilometres to the south of Mittihedberget at 2704±3 Ma. These rocks were the first Archaean rocks detected in the Luleå area. The conglomerate-like rocks are now interpreted as magmatic hydraulic breccias similar to those on Bälingsberget and Måttsundsberget.

L3. Fagervik (24L 4g):
Conglomerate with Archaean and Haparanda suite clasts.

Outcrops along coast.
7273250/1784350

At Fagervik, a mainly matrix-supported conglomerate with rounded to well rounded metagranitoid clasts is exposed in beautiful outcrops along the coast. The clasts show distinct contacts with the matrix, which is different from the intrusion breccias at Bälingsberget, Måttsundsberget, and Mittihedsberget. Radiometric datings of clasts from this conglomerate yielded both Archaean and Haparanda suite ages: 2706±6 Ma and 1903±5 Ma respectively (Lundqvist et al. 2000).

The matrix has been dated by the same authors at 1871±2 Ma.

L4. Gamla vattentornet, Piteå (24L 1c): Metagreywackes and veined gneisses of the Bothnian Supergroup.

Road cut.
7259450/1762750

This locality is situated in the transition zone between the metasedimentary sequences of the Bothnian Basin and the metagreywackes, resting on an Archaean basement. The metagreywackes at this locality are altered to veined gneisses with abundant veins, dykes, and minor massifs of migmatite granite. This granite contains inclusions of both older supracrustal rocks and foliated metagranitoids. A grey, fine-grained migmatite granite from this locality has been dated (U-Pb, monazite) at 1784±5 Ma (SGU, unpublished).

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Geological Survey of Sweden
Box 670
SE-751 28 Uppsala
Phone: +46 18 17 90 00
Fax: +46 18 17 92 10
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