SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ca AVHANDLINGAR OCH UPPSATSER I A4 NR 67

THOMAS LUNDQVIST, MATS WILLDÉN, PETER KRESTEN
AND KRISTER SUNDBLAD

THE ENÅSEN Au DEPOSIT AND THE ALNÖ ALKALINE COMPLEX

7th IAGOD SYMPOSIUM
AND NORDKALOTT PROJECT MEETING

EXCURSION GUIDE NO 9/10

UPPSALA 1986

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. Ca | AVHANDLINGAR OCH UPPSATSER I A4 | NR 67

THOMAS LUNDQVIST, MATS WILLDÉN, PETER KRESTEN
AND KRISTER SUNDBLAD

THE ENÅSEN Au DEPOSIT AND THE ALNÖ ALKALINE COMPLEX

7th IAGOD SYMPOSIUM
AND NORDKALOTT PROJECT MEETING

EXCURSION GUIDE NO 9/10

UPPSALA 1986

ISBN 91-7158-405-6
ISSN 0348-1352

AUTHORS

Thomas Lundqvist
Geological Survey of Sweden
Box 670
S-751 28 Uppsala
Sweden

Peter Kresten
Geological Survey of Sweden
Box 670
S-751 28 Uppsala
Sweden

Krister Sundblad
Geological Survey of Sweden
Box 670
S-751 28 Uppsala
Sweden

Mats Willdén
Boliden Mineral AB
S-936 00 Boliden
Sweden

Fotosats: ORD & FORM AB
Tryck: Offsetcenter, Uppsala 1986

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

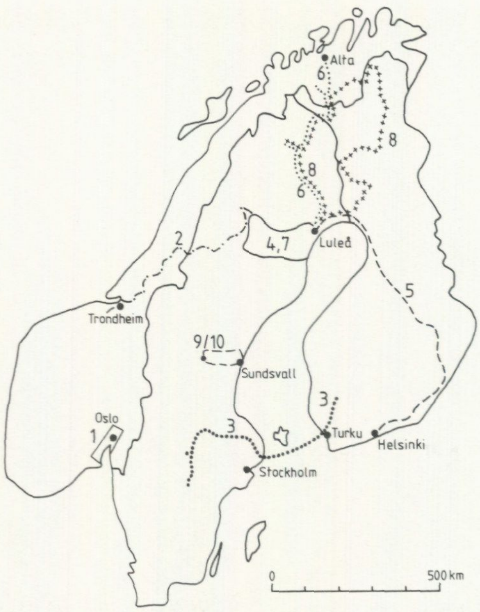
FOREWORD

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

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

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

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



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

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

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

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

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

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

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

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

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

IAGOD-excursions 1986

THE ENÅSEN Au DEPOSIT AND THE ALNÖ ALKALINE COMPLEX

CONTENTS

GEOLOGICAL EVOLUTION OF CENTRAL SWEDEN

Th. Lundqvist

The Enåsen gold mineralization is situated in central Sweden, within the Svecofennian part of the Early Proterozoic Svecokarelian fold belt (cf. Lundqvist 1979). The gold mine is in the northernmost part of Gävleborg County, about half a kilometre from the Västernorrland County border and c. three kilometres from the Jämtland County border.

The regional geology is known mainly as a result of mapping carried out by the Geological Survey of Sweden (SGU) and through investigations by Boliden Mineral AB, Swedish Geological (SGAB) and LKAB Prospektering. SGU maps on the scale of 1:200 000 are available for Gävleborg County (Lundegårdh 1967) and Jämtland County (Lundegårdh *et al.* 1984). A description of the former map has been published, and is under preparation for the latter. A third SGU map, of Västernorrland County (Lundqvist, in preparation), is planned to be published in 1986, and work on the description is progressing.

PRE-QUATERNARY GEOLOGY OF CENTRAL SWEDEN

The Proterozoic bedrock of central Sweden (Fig. 1) consists mainly of a sequence of metagreywackes, in the order of 10 000 m thick, which has been metamorphosed under low-pressure conditions in amphibolite or (subordinately) greenschist facies. Intercalations of basalts (amphibolites) form less than 5 % of the stratigraphic sequence and rhyolites are rare, the notable exception being Junsele (Rockliden) c. 200 km NNE of Enåsen.

In the Enåsen region, the metamorphosed greywackes pass southwards into more mature, argillitic metasediments, largely transformed into garnet-cordierite-sillimanite-bearing veined gneisses. In this transitional zone between the greywackes and argillites, there occur abundant arkoses (the Naggen "quartzite" etc.) which, except for the area around Naggen, c. 30 km east of Enåsen, have been metamorphosed and migmatized in high amphibolite facies. At Naggen, they stratigraphically overlie the metagreywackes in the north.

In western Medelpad, c. 20–30 km northwest of Enåsen, metamorphosed basalts and rhyolites occur. Although the stratigraphic relations are obscure in this region, a rhyolite appears to overlie a sequence of arkoses and argillites.

The metamorphosed greywackes and argillites of central Sweden occur between two regions with abundant acid metavolcanics, the Skellefte District in the north and Bergslagen in the south (cf. Magnusson *et al.* 1960, Lundqvist 1979). The acid volcanicity in the Skellefte District, which preceded the deposition of the central Norrland greywackes, has given rise to abundant sulphide mineralizations with chalcopyrite, sphalerite, galena, gold etc. (Frietsch 1980). In the Bergslagen region, iron and sulphide ores are intimately connected with acid metavolcanics (Frietsch, *op.cit.*).

The metamorphosed sedimentary and volcanic sequences of the Svecofennian part of the Svecokarelian fold belt lack an identifiable basement (cf. Rankama & Welin 1972, Lundqvist 1979). Although metaarkoses of e.g. Naggen type indicate a pre-sedimentary granitic basement, such a basement is as yet unknown from the region.

The above-mentioned sedimentary and volcanic rocks were intruded by voluminous calc-alkaline magmas giving rise to a suite ranging from ultrabasic to granitic in composition. In the greywacke region, tonalites and granodiorites are the dominating rocks among these early-orogenic, or primorogenic intrusions. In the southern border zone of the metagreywackes, around the Gävleborg-Västernorrland border, granitic compositions are, however, abundant. Gabbros at Kramsta and Gruvberget (75 km SSE and 70 km SE of Enåsen, respectively), belonging to these early-orogenic intrusions, contain concentrations of vanadium-bearing titaniferous magnetite, which are of economic interest (Lundegårdh 1967).

The main Svecokarelian folding and metamorphism in central Sweden post-dated the early-orogenic intrusions, and thus affected both these and the supracrustals. The folding, at least in the southern regions, involved two major phases (cf. Lundegårdh 1967), the first of these being characterized by N–S striking, easterly dipping axial planes and the second by E–W-oriented axial planes. The lack of key horizons in the large greywacke complexes, however, renders tectonic interpretations difficult. Metamorphism was of low-pressure type and involved large-scale migmatization, especially in the metasedimentary sequences, but to a minor degree also in the early-orogenic granitoids. In the metagreywackes, migmatization has occurred in three stages, the first involving the formation of veined gneisses mainly in relatively mica-rich layers, and the second, an intense production of raft migmatites, largely with a granodioritic neosome containing more or less rotated pieces of greywacke gneiss. A third step was later formed by (arteritic) injection and assimilation caused by the intrusions of the late-orogenic (serorogenic) granites and pegmatites (cf. below). Stages two and three post-date the major Svecokarelian deformation.

Intrusion of largely undifferentiated granites and pegmatites, referred to as late-orogenic or serorogenic, followed the migmatization and folding. These granites carry both biotite and muscovite, the latter being most prominent in non-migmatized areas. They cross-cut the migmatite structures and are mostly massive, although a foliation may be prominent in certain areas, especially in the marginal parts of the massifs. They have traditionally been regarded as anatectic, formed by melting processes at deeper crustal levels. However, as yet no modern isotope or trace element investigations have been carried out to support this view.

In the postorogenic stage, the bedrock was intruded by granitic magmas, which formed voluminous massifs mainly of coarse microcline-porphyritic granite, the Revsund granite. These magmas were essentially "dry", as pegmatites and aplites are rare. Hornfels alteration is in some areas prominent around the contacts, especially in the metasediments. Important contact minerals are almandite, cordierite, microcline, hypersthene, hercynite, and sillimanite. As a rule, the Revsund granite is little differentiated, but monzodioritic to monzonitic differentiates have been observed (Persson 1978).

West of the Enåsen area is a large granite massif (the Rätan granite), which was also formed by postorogenic intrusion. This granite is microcline-porphyritic, although the megacrysts are not so coarse as in the Revsund granite. Possibly associated with the Rätan granite is a big tholeiitic dolerite (or gabbro) massif at Turingen, 30–40 km northwest of Enåsen.

Three anorogenic massifs of rapakivi-type, referred to the sub-Jotnian, occur in the region under consideration. These are the Ragunda, Nordingrå and Rödön massifs.

The intrusions of the Ragunda massif (Kornfält 1976), 100–130 km NNE of Enåsen, started with gabbro, which was later intruded by syenite, quartz syenite, hornblende granite and biotite granite.

At Nordingrå, c. 180 km northeast of Enåsen, an early gabbro-anorthosite suite was followed by a small-porphyritic granite, in part with a granophyric groundmass (Sobral 1913, von Eckermann 1938). As is common in rapakivi associations, the iron-magnesium minerals characteristically show high Fe:Mg ratios. The U/Pb age of the anorthosite and the granite is 1578 ±19 Ma (Welin & Lundqvist 1984).

The small Rödön massif near Alnön at Sundsvall, c. 120 km east of Enåsen, consists of a coarsely porphyritic rapakivi granite accompanied by dikes of dolerite, in part porphyritic, and of granite porphyry, sometimes as composite dikes (Holmquist 1899).

At Nordingrå, the sub-Jotnian rapakivi gabbro-anorthosite-granite massif is overlain by a sequence of sandstone, shale and minor conglomerate, 60 m thick, referred to the Jotnian. The basal sedimentary layers consist of arkoses, beneath which the igneous rocks are weathered (Sobral 1913).

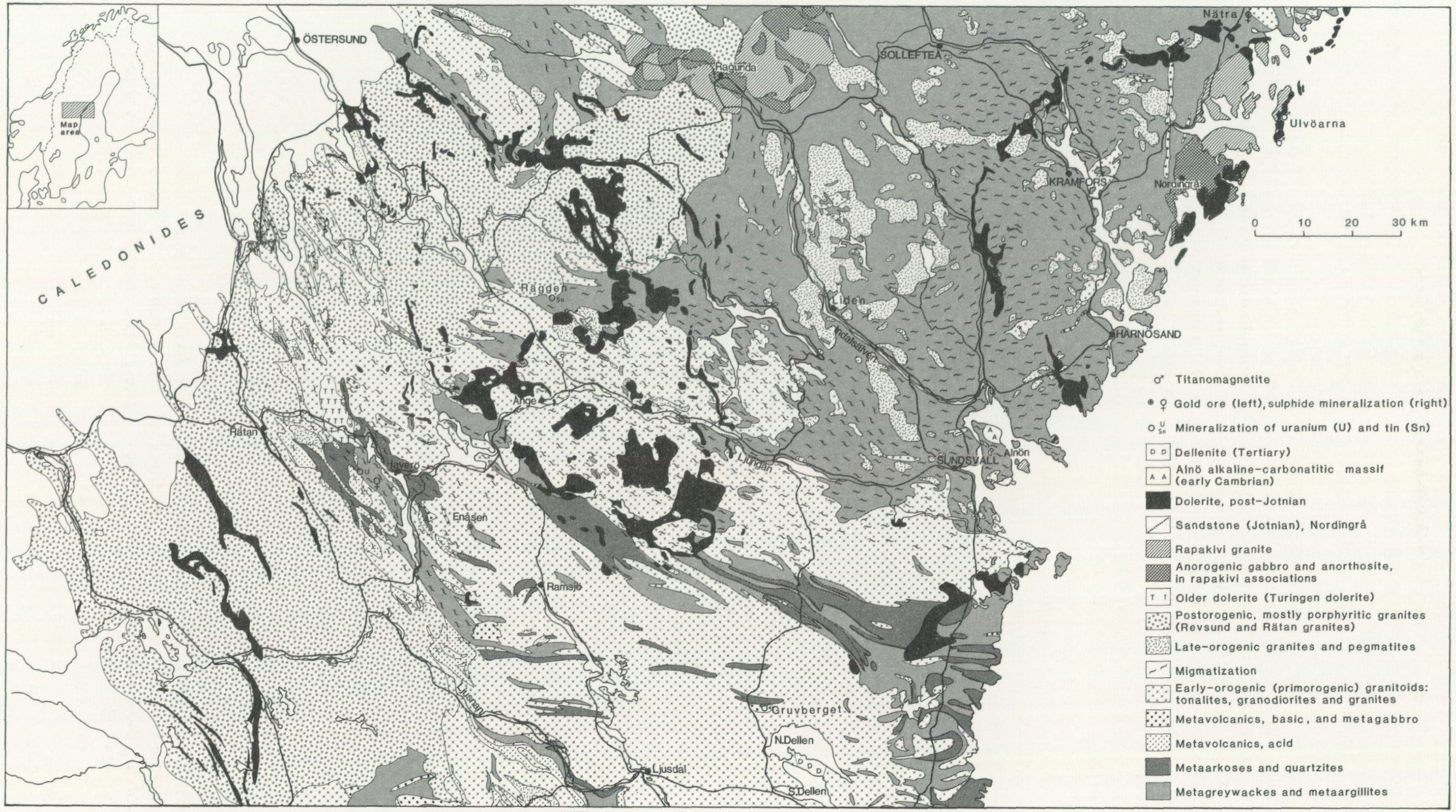


Fig. 1. Bedrock geology of central Norrland.

In central Norrland there occur abundant flat-lying sheets and steeply dipping, mostly narrow dikes of a dolerite of alkali basalt type referred to the post-Jotnian or Jotnian (cf. Gorbatschev *et al.* 1979). Radiometric dating by the K-Ar isochron method has yielded 1215 Ma (Welin & Lundqvist 1975, Welin 1979). At Nordingrå, a flat-lying dolerite of this group, with a thickness of c. 300 m, has intruded the sub-Jotnian rapakivi complex and the Jotnian sandstone formation (Sobral 1913). Parts of the sheet display beautiful layering (Lundqvist & Samuelsson 1973, Larson 1973, 1980). On Ulvöarna, such parts of the dolerite show layers of vanadium-bearing titaniferous iron ore, consisting of magnetite, ulvöspinel and ilmenite with minor silicates. The mineral ulvöspinel was first identified in samples from a small mining pit on Södra Ulvön (Mogensen 1946).

Surrounding the Nordingrå massif is another, lopolithic sheet of similar dolerite, having a diameter of c. 10 km. All the dolerite sheets sometimes contain monzonitic to granitic differentiates at high levels in the flat-lying sheets. These differentiates were probably formed by melting of the crust at deeper levels, caused by the rising dolerite magma. Local (*in situ*) contact mobilization of wall rocks has also been observed.

The Alnö alkaline-carbonatitic complex and related dikes near Sundsvall were formed at the beginning of Phanerozoic time, c. 550–600 Ma ago, see Kresten, pp. 20–21, this volume.

In the Bothnian Sea, from the latitude of the town of Härnösand and southwards, there occur Cambro-Ordovician sedimentary rocks, as revealed by boulders on the shores and by investigations of the sea bottom (Hörnsten 1959, Axberg 1980). In the west, the Precambrian rocks are covered by the Caledonian sequences.

Finally, a possible meteorite impact at Dellensjöarna, c. 80 km ESE of Enåsen, should be mentioned. The so-called dellenite or Dellen "andesite" of Tertiary age (in fact, a rhyolite to dacite) was earlier considered to be of volcanic origin (Redaelli 1957, Lundegårdh 1967). Later, however, it has been suggested that the dellenite was formed by impact melting (Fredriksson & Wickman 1963, Svensson 1968).

Table 1 summarizes the geological evolution of central Norrland.

TABLE 1. Geological evolution of central Norrland

Age	Rock or event	
Quaternary	Pleistocene glaciation (till, clay etc.)	
Tertiary	Dellen "andesite" (=rhyolite dacite), a possible astrobleme	
Cambrian-Ordovician	Sedimentary rocks (limestone etc.) in the Bothnian Sea	
C. 550–600 Ma	Alnö alkaline and carbonatitic rocks	
1215 Ma	Post-Jotnian dolerites (Nordingrå etc.)	
	Jotnian sandstone (Nordingrå)	
	Anorogenic massifs of rapakivi type:	
C. 1580 Ma	Nordingrå: Gabbro, anorthosite, granite	
	Ragunda: Gabbro, minor anorthosite, granite, quartz syenite and syenite	
	Rödön: Granite with dikes of granite porphyry and dolerite	
C. 1650 Ma	Postorogenic granite (Rätan granite)	
	Turingen dolerite	
C. 1750 Ma	Early postorogenic granite (Revsund granite)	
C. 1800 Ma?	Late-orogenic (serorogenic) granites and pegmatites (Härnö granite and pegmatites)	
C. 1800–1850 Ma	Major Svecokarelian folding and metamorphism (migmatization etc.)	
C. 1850–1900 Ma	Early-orogenic (primorogenic) intrusions: Granodiorite, tonalite and granite with minor ultramafite, gabbro and diorite	
	Western Medelpad	Västernorrland County except for western Medelpad
C. 1850–1900 Ma	Metarhyolite Metaargillite and metagreywacke intercalated with metaarkose, metabasalt and minor metarhyolite	Naggen metaarkose Metagreywackes with intercalations of metabasalt and minor metarhyolite
	Basement unknown	

METALLOGENY OF CENTRAL SWEDEN

K. Sundblad

Although the distribution of the major rock units in the Proterozoic of central Sweden is fairly well known (Lundegårdh 1967, Lundegårdh *et al.* 1984, Lundqvist, in preparation), our knowledge of the metallogeny of the area is very limited and uncertain. This is mainly due to the fact that this area lies outside the classical ore provinces of Bergslagen and the Skellefte District and thus, although several economic-subeconomic ore deposits are known, the area has never been of major interest for economic geologists. However, during the last decade several prospecting companies have shown a newly-awakened interest, partly due to changes in the metal prices on the world market and also because earlier unexpected ore types and metals have been found in this part of Sweden.

Very little has been published on the ores of the area and the few publications available are, in most cases, pre-1960. In consequence, most of the present knowledge on the ore geology of central Sweden is scattered in numerous unpublished reports to the various prospecting companies active in the area, i.e. Boliden Mineral AB, Swedish Geological (SGAB) and LKAB Prospektering. This chapter will, therefore, be an attempt to summarize all available information on the metallogeny of central Sweden.

MINERALIZATIONS HOSTED IN EARLY PROTEROZOIC SUPRACRUSTAL ROCKS

Mineralizations of Bergslagen affinity

As can be seen on Fig. 1, a zone of Early Proterozoic acid and mafic metavolcanics can be followed from the Caledonian Front south of Östersund (Svenstavik) towards the Ljusdal area in the southeast. These metavolcanics are hosts for several subeconomic massive sulphide deposits and can be further traced towards the south into the classical ore-bearing province of Bergslagen. Two deposits hosted in metavolcanics are worth mentioning in this context: Tjärnberget and Enstern (Fig. 2), both investigated by Boliden Mineral AB. The Tjärnberget deposit is situated 40 km south of Östersund between the lakes Storsjön and Näkten and was discovered in 1973. The Enstern deposit lies 50 km further to the southeast, about 40 km WSW of Ånge, and has been known since the 1930's. No published data are available for these two deposits and the following is based on information received from P. Harström, Garpenberg, pers. comm. 1986. Both deposits are stratabound, metamorphosed Zn(-Cu-Pb)-bearing deposits hosted in metavolcanics of dominantly mafic composition. Both massive and disseminated ore types exist, and the most important type is a ball ore textured massive sulphide ore with pyrite, pyrrhotite and sphalerite with subordinate chalcopyrite and galena.

Furthermore, a third deposit, Snuggen, located about 25 km southwest of Ljusdal, has been briefly described by Blomberg (1895) and Hedström (1901). In this deposit pyrrhotite, pyrite, chalcopyrite and gahnite (zinc spinel) have been found in a grey, garnet-bearing gneiss.

Although very little is known about genetical relationships between host rocks and the ore deposits in the Svenstavik-Ljusdal area, it appears possible that the association of metamorphosed supracrustal rocks and sulphide ores of this kind represents the northernmost prolongation of the ore-bearing formations of the Bergslagen district.

Mineralizations of uncertain origin

Uranium deposits in the Bodsjön area. Several small uranium mineralizations have been investigated by SGU/SGAB in the Bodsjön area, 40 km WSW of Ånge. Published material is not available for these deposits, and the following information has been received from L.-O. Forsberg, Luleå, pers. comm. 1986. The dominant type of uranium mineralization occurs as pegmatoid bodies hosted in migmatized argillites in a metasedimentary sequence of upper amphibolite facies characterized by arenitic and argillitic rocks with intercalations of metasediments of iron formation affinity. The pegmatoid bodies, which are typically a few hundred metres in length, are characterized by quartz, feldspar and biotite. The only existing primary uranium mineral, uraninite, occurs as discrete crystals preferably intergrown with biotite. The U-content in the pegmatoid bodies varies from a few hundred ppm to a few thousand ppm. However, even the largest body, the Sågtjärnen deposit, has not a sufficiently high grade and tonnage for economic feasibility. Neither the genesis nor the age of the deposit is satisfactorily known, but the metamorphism is considered to have been an important factor in relation to the ultimate concentration of the uranium.

The Enåsen Au deposit. The Enåsen Cu-Zn-bearing Au deposit is also hosted in metamorphosed supracrustal rocks approximately equivalent in age to those hosting the massive sulphide deposits of "Bergslagen affinity". It is probable that the setting in these (metamorphosed) supracrustal rocks is a relevant factor for the interpretation of the genesis of the Enåsen deposit. However, influence of geological processes occurring after the deposition of the supracrustal rocks cannot be excluded as important factors for the origin of the Enåsen deposit. Further details on the deposit are presented by Willdén on pp. 14–17.

MINERALIZATIONS IN EARLY PROTEROZOIC MAFIC OR INTERMEDIATE INTRUSIONS

V-Ti-bearing magnetite ore in the Kramsta and Gruvberget areas

In the Ljusdal area, a number of lens-shaped bodies of the early-orogenic generation of V-Ti-bearing mafic intrusions occur. The deposits of V-Ti-bearing magnetite ore in these intrusions have been described by Lundegårdh (1957), and complementary information has been received from F. Ros, Uppsala, pers. comm. 1986. The mafic intrusions range in composition from gabbro via norite to hornblende-gabbro. The highest concentrations of V and Ti are usually found in the basal parts of the intrusions and are mineralogically composed of vanadiniferous magnetite and ilmenite. The most important of these subeconomic deposits are situated at Kramsta, 15 km south of Ljusdal and at Gruvberget, 25 km northeast of Ljusdal (Fig. 2). At Gruvberget, an ore potential of 15 million metric tons at a grade of 0.26 % V has been proven.

Ni-Cu-bearing ore at Nätra

The Ni-Cu deposit at Nätra (Förnätra) is situated 14 km southwest of Örnsköldsvik in the northeastern part of Fig. 1. The deposit, which has been known since the 19th century, was first described by Lundbohm (1899) and has also been examined by Grip (1961) and Nilsson (1985). The ore consists of pyrrhotite, pentlandite and chalcopyrite and the grade has been estimated at about 0.5 % Ni, 1.0 % Cu and 19 % S. The geological setting is the western border zone of an early-orogenic massif of tonalite to quartz diorite. The Ni-Cu deposit occurs in association with a sheet-like inclusion or dike of amphibolite in the tonalite. Sheet-like inclusions of metagreywackes also occur.

Li-Sn-Ta MINERALIZATIONS IN EARLY PROTEROZOIC PEGMATITES

Until recently, very few occurrences of Li and Sn mineralizations were known in Sweden, but during the last six years numerous occurrences of Li-Sn-Ta-bearing pegmatites have been located in central Sweden. The discovery of these Li- and Sn-bearing pegmatites has thus revealed an earlier unknown aspect of the metallogenesis of the Proterozoic in Sweden. No mineralization has yet been subject to mining, but the Järkvissle deposit is potentially of economic interest for its Li- and Sn-contents. The grades of the mineralizations lie around 0.8 % Li, 0.1 % Sn and 100 ppm Ta (Fredriksson & Tuuri 1986). Other prospects of interest are Räggen (Sn), Hälleberget (Sn), Stockberget (Ta, Sn) and Orrvik (Li), see Fig. 2.

All of the Li-Sn-Ta deposits occur in muscovite pegmatites of the late-orogenic Härnö granite generation, crosscutting relatively low-grade metagreywackes. Spodumene, petalite, cassiterite and columbite-tantalite are the economically most interesting minerals. In addition, beryl and Li-phosphate are commonly found (Fredriksson & Tuuri 1986, Smeds & Tuuri 1986). Furthermore, the rare occurrence of herzenbergite is also noted (Smeds 1984).

It is of interest to note that earlier reported occurrences of tin in Sweden also are hosted in pegmatites and have an ore paragenesis similar to those mentioned above. Thus, in the classical pegmatite on Utö, south of Stockholm, where Li was first discovered in 1817 by Arfwedsson in petalite, there occur amblygonite, spodumene and lepidolite in addition to petalite. Nordenskiöld (1877) also reported cassiterite and minerals in the columbite-tantalite series. In another classical Swedish pegmatite locality, Varuträsk, northwest of Skellefteå, among others the following minerals have been reported: lepidolite, amblygonite, spodumene, petalite, beryl, pollucite, cassiterite, columbite, tantalite and Mn-tantalite (Quensel 1952).

V-Ti-BEARING MAGNETITE ORE IN MIDDLE PROTEROZOIC MAFIC INTRUSIONS

The youngest ore deposits in the Proterozoic of central Sweden are found in Jotnian (c. 1200 Ma) dolerite sheets in the eastern and central parts of Fig. 1. These deposits consist of V-Ti-bearing magnetite ore and have been found at several places on the islands between Örnsköldsvik (north of Fig. 1) and Härnösand. The richest concentrations occur on the Ulvöarna islands, where about 50 000 metric tons of ore have been extracted from the Grundhamn deposit. The latter has been described by Sobral (1913), Mogensen (1946) and Magnusson (1953). The ore consists mineralogically of titanomagnetite, ulvöspinel, ilmenite and minor olivine and plagioclase. It occurs as impregnations in at least three horizons in the flat-lying dolerite.

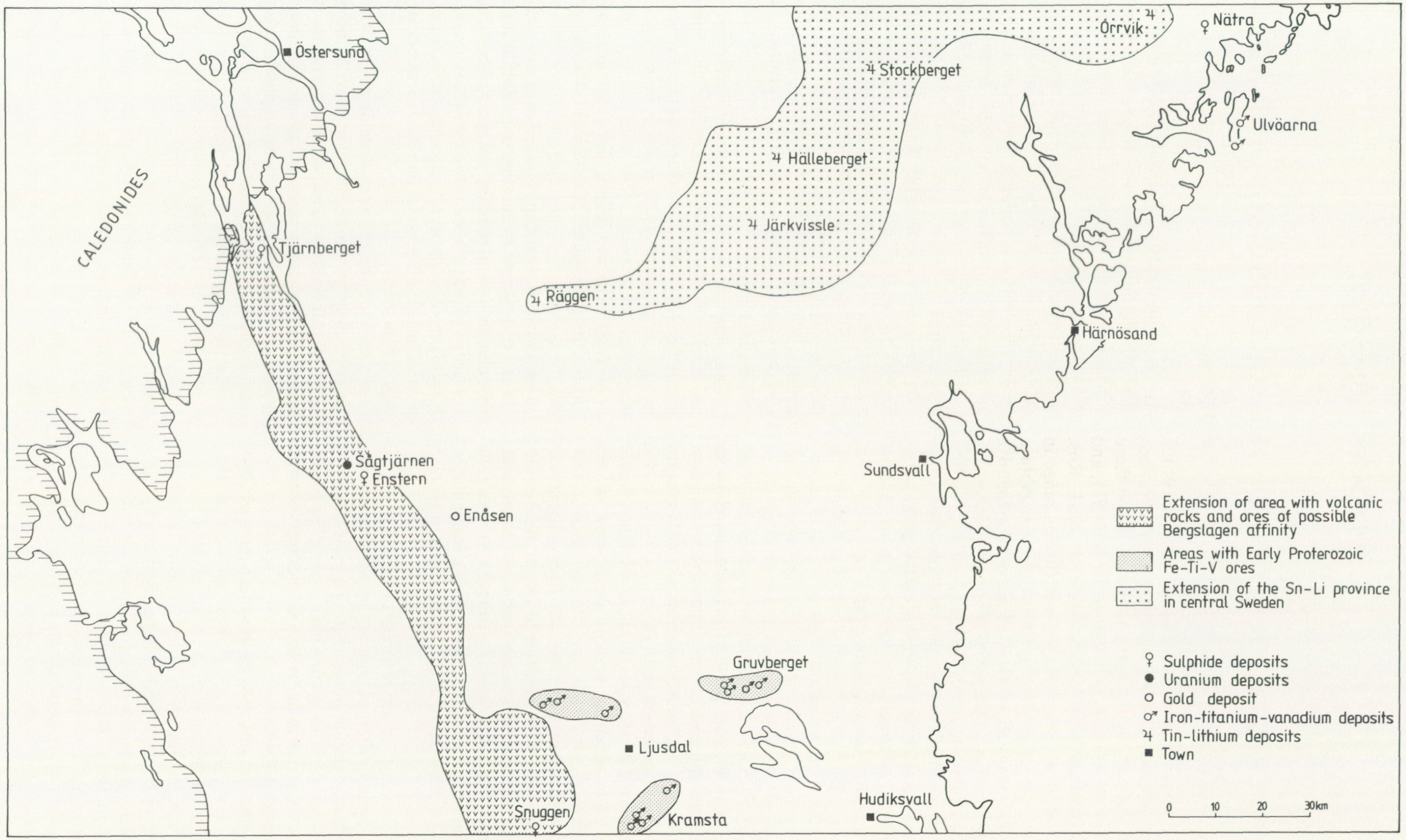


Fig. 2. Metallogenetic provinces of the Proterozoic in central Sweden. For background geology, see Fig. 1.

PROTEROZOIC GEOLOGY OF THE SURROUNDINGS OF ENÅSEN

Th. Lundqvist

As stated above, the Enåsen gold deposit is situated in the southern border zone of the metagreywackes of the Härnö formation. The nearest region with metagreywackes of normal type is at Östavall, c. 15 km NNE of Enåsen. Here, the metamorphic grade is, in part, low (low amphibolite to high greenschist facies). Compositionally, the arenitic beds of the greywackes mainly consist of quartz (c. 40 %), plagioclase of oligoclase composition and minor microcline (total feldspar content c. 40 %) and mica, mostly biotite (c. 20 %). Microcline is more frequently seen in thin sections from the Östavall area than in samples from the major greywacke region to the north, although the difference is not great. Tourmaline is a typical accessory mineral.

Phenoclasts of oligoclase and quartz together with small clasts of greywacke metasediments show upwards decreasing size and frequency (graded bedding). Another typical structure is formed by decimetre-sized, rounded or elongated concretionary bodies consisting of various calc-silicates (diopside, hornblende, An-rich plagioclase, Ca-rich garnet, epidote, prehnite, etc.). They apparently represent diagenetically formed carbonate concretions metamorphosed into calc-silicate assemblages.

The low-metamorphic metagreywackes usually contain less than 10 % of intercalated argillitic beds, now in the form of mica-schists, phyllites and slates. Quartz and mica (biotite>muscovite) predominate over oligoclase. Greenschist facies slates contain chlorite. As in the arenitic beds, tourmaline is a typical accessory mineral. North and east of the Östavall area, the metagreywackes have largely been transformated into veined gneisses and raft migmatites (cf. map, Fig. 1). Almandite is a frequent constituent of these migmatites.

In the Haverö area, c. 15 km northeast of Enåsen, metagreywackes of slightly different type are found intercalated with metaargillites, amphibolites etc. These metagreywackes are characterized by somewhat higher plagioclase and lower biotite contents than the normal metagreywackes east and northeast of Haverö.

The metaargillites occurring in the northern parts of Gävleborg County, and continuing northwestwards to the Haverö area, seem to be linked with the more northerly metagreywackes by a facies transition. They are usually strongly metamorphosed and migmatized in uppermost amphibolite facies, and mostly appear as garnet-sillimanite-cordierite-bearing veined gneisses. The paleosome is dominated by quartz and biotite, with minor plagioclase, microcline etc.

Metaarkoses with more subordinate quartzitic horizons are mainly located in the transitional zone metagreywackes–metaargillites. Where best-preserved, near Naggen, they display beautiful bedding, in part graded or discordant, and a blastopsammitic texture of more or less rounded quartz and microcline grains (cf. Lundegårdh 1960). The latter vary from mm-size down to almost aphanitic in certain layers. Subordinately, sodic plagioclase, muscovite, and biotite occur; accessories are opaques, tourmaline, zircon, etc. Not uncommonly, hornblende, epidote, bytownite and other Ca-silicates are present, indicating pre-metamorphic carbonate cement.

In the region northwest of Enåsen (the Haverö-Enåsen region) the arkoses are mostly metamorphosed to strongly migmatitic rocks in uppermost amphibolite facies. Sillimanite and cordierite coexisting with microcline are typical of these metaarkoses. Magnetite is also a characteristic constituent, both in the metaarkoses and associated supracrustal rocks, and gives rise to pronounced positive anomalies on aeromagnetic maps.

Thus, high-grade counterparts of the Naggen metaarkose are dominated by quartz, microcline and sillimanite. The microcline is both of detrital and metamorphic origin, in the latter case formed by the reaction muscovite + quartz → microcline + sillimanite. The gold-bearing quartzite at Enåsen could represent such a high-grade metaarkose, which has lost its potassium (microcline) content by metasomatism. It is, however, not clear whether this metasomatic alteration was essentially synsedimentary–synvolcanic, or related to regional metamorphism. The latter appears less probable in view of the fact that most rocks of the region do not seem to have been strongly metasomatically altered. Possibly the original potassium content in the metaarkose is now included in the microcline-enriched zone of the hanging wall (cf. below).

A peculiar quartz rock at Kölaberget, c. 10 km WNW of Enåsen, may be genetically linked with the gold-bearing quartzite. It mainly consists of coarse- to fine-grained quartz, with few structures to support a sedimentary origin; in part it resembles vein quartz. In addition, sillimanite, in part as compact aggregates and, more subordinately, topaz as scattered crystals or as fist-sized aggregates are also present. Minor constituents are pyrophyllite, andalusite and rutile (U. Hålenius, pers. comm. 1980). The origin of this quartz rock is obscure; it is tentatively suggested that it was formed by pneumatolytic to hydrothermal mobilization and potassium leaching from a metaarkose of Naggen type.

In the Haverö area, various metasedimentary rocks which are transitional in mineralogy between (mica- and plagioclase-poor) metaarkoses and (plagioclase- and biotite-rich) metagreywackes occur. A fairly common type of metasediment is an arenite mainly consisting of quartz and bytownite with minor biotite. It is intercalated mainly with the metagreywackes and with rocks transitional between metagreywackes and metaarkoses. Such metaarenites also occur in the large areas of metagreywackes belonging to the Härnö formation, but are then quantitatively much less important.

Minor crystalline limestone is present in the Haverö area. Together with the calc-silicates found in various metasedimentary rocks it indicates a small but significant carbonate deposition. This deposition, although quantitatively subordinate, was more important than in the thick greywacke sequences to the north.

Both acid and basic metavolcanics occur in the surroundings of Enåsen. The latter are mainly altered to amphibolites or amphibolitic gneisses, but in part the metamorphic grade was high enough to cause crystallization of ortho- and clinopyroxene instead of hornblende (granulite facies).

The acid metavolcanics are mainly reddish fine-grained gneisses dominated by quartz, microcline and sodic plagioclase. In a minor area (Hortesberget west of Haverö), a porphyritic texture has been preserved. The acid metavolcanics frequently carry magnetite and thus give rise to positive anomalies on the aeromagnetic maps. In addition to clearly metavolcanic rocks of rhyolitic composition, the maps, Figs. 1 and 6, also include rocks of more doubtful origin under the heading "acid metavolcanics". The most important of these is situated c. 10 km west of Enåsen. It is a fine- to finely medium-grained, greyish-red rock of apparently greater homogeneity than the similarly composed unmistakable acid metavolcanics. It could represent a subvolcanic intrusion or, perhaps, an advanced differentiation stage of the early-orogenic (primorogenic) magmas.

The volcanic and sedimentary rocks have been abundantly intruded by various magmas of primorogenic (early-orogenic) age. Predominant compositions are granitic, granodioritic and tonalitic, but minor gabbro (in part ultramafic), diorite and quartz diorite also occur.

Early-orogenic granites are very sparse in the vast greywacke areas of the Härnö formation. They are, however, abundant near the belt of metaarkoses of Naggen type. In part, the granites are very rich in perthitic microcline (K_2O c. 7 %), which may form (deformed) megacrysts. Almandite, cordierite and sillimanite are characteristic constituents, whereas biotite is subordinate or lacking. The quartz is often platy, similar to that occurring in granulites. The Al_2O_3 excess probably indicates assimilation of argillitic metasediments. Field observations suggest that the granites are intrusive into the Naggen metaarkose and the metagreywackes, although the possibility of metamorphic mobilization along the granite–metaarkose contact cannot be excluded as a cause of intrusive features near Naggen.

Some primorogenic granodiorites are even-grained, others are megacryst-bearing (microcline). South to southeast of Enåsen is a vast massif of reddish grey to grey so-called Ljusdal granite, which is a granodiorite to granite carrying abundant microcline megacrysts. Also north of Enåsen and Naggen megacryst-bearing, grey granodiorites are abundant. The megacrysts can frequently be seen to belong to two different generations, the older of which has been deformed to elongated augen. The younger megacrysts are rectangular and cut across the foliation.

As the major phases of deformation post-date the primorogenic intrusions, the latter are usually more or less strongly foliated or lineated. Also, the regional Svecokarelian metamorphism, which has in large areas involved migmatization, has affected the primorogenic intrusions as well as the supracrustals. The former, however, generally resisted mobilization better than the latter, and have been migmatized mainly in the marginal parts of the massifs and in areas with abundant supracrustal xenoliths. A special type of recrystallization, observed in the Ljusdal "granite", involved post-tectonic recrystallization to megacryst-bearing granodiorites and granites closely resembling the post-orogenic Revsund granite in the north (Lundegårdh 1967).

The late-orogenic (serorogenic) granites and associated pegmatites, which are abundant in the main greywacke areas in the north, are very sparsely represented in the surroundings of Enåsen, where primorogenic granodiorites and granites predominate. Their distribution may be related to the fact that generation of these granitic, supposedly anatectic magmas was greatly facilitated by the occurrence of mica-rich, especially muscovite-rich, metasediments such as the argillitic intercalations in the metagreywackes.

The major Svecokarelian regional fold phases resulted generally in steeply inclined bedding and foliation planes. Although no detailed structural analysis has been carried out, it seems evident that the deformation in an east–west belt through southern Medelpad and northern Hälsingland involved two major phases. The interpretation given by Lundegårdh (1967) for the Hälsingland region (in the Gävleborg County) and by Stålhös (1981) for the Svecofennian region south of Stockholm may thus be valid here also: namely an early east–west compression created north–south trending folds, overturned with an easterly dipping axial plane. A later NNE–SSW compression gave rise to the predominating WNW structural trends and the persistent gently ESE plunging lineations and fold axes. Probably the voluminous early-orogenic massifs caused a heterogeneous strain pattern, as they were more resistant to the regional deformation (cf. Stålhös 1981).

THE ENÅSEN GOLD DEPOSIT

M. Willdén

The Enåsen gold mine is an open pit operation run by Boliden Mineral AB. Prospecting activities in the 1930's indicated a number of minor copper mineralizations in the area. Further investigations in the 1950's proved the presence of gold. Rising gold prices in the mid-seventies brought attention to the area as a potential gold producer, and in 1983 Boliden decided to bring the deposit into production. The ore reserve is 1.1 Mt with 2.2 g/t Au, 4 g/t Ag and 0.2 % Cu. The designed ore production for the mine and concentrator is 200 000 t/y.

GENERAL GEOLOGY

The immediate vicinity of Enåsen is dominated by highly metamorphic supracrustal rocks of Early Proterozoic age (cf. pp. 12–13), consisting of various metasedimentary arenaceous and argillaceous formations, usually grey in colour and garnet-bearing. Basic metavolcanics and skarn (Ca-silicates) are intercalated in this sequence. The supracrustals are surrounded by grey and reddish, gneissic granitoids of granodioritic to granitic composition.

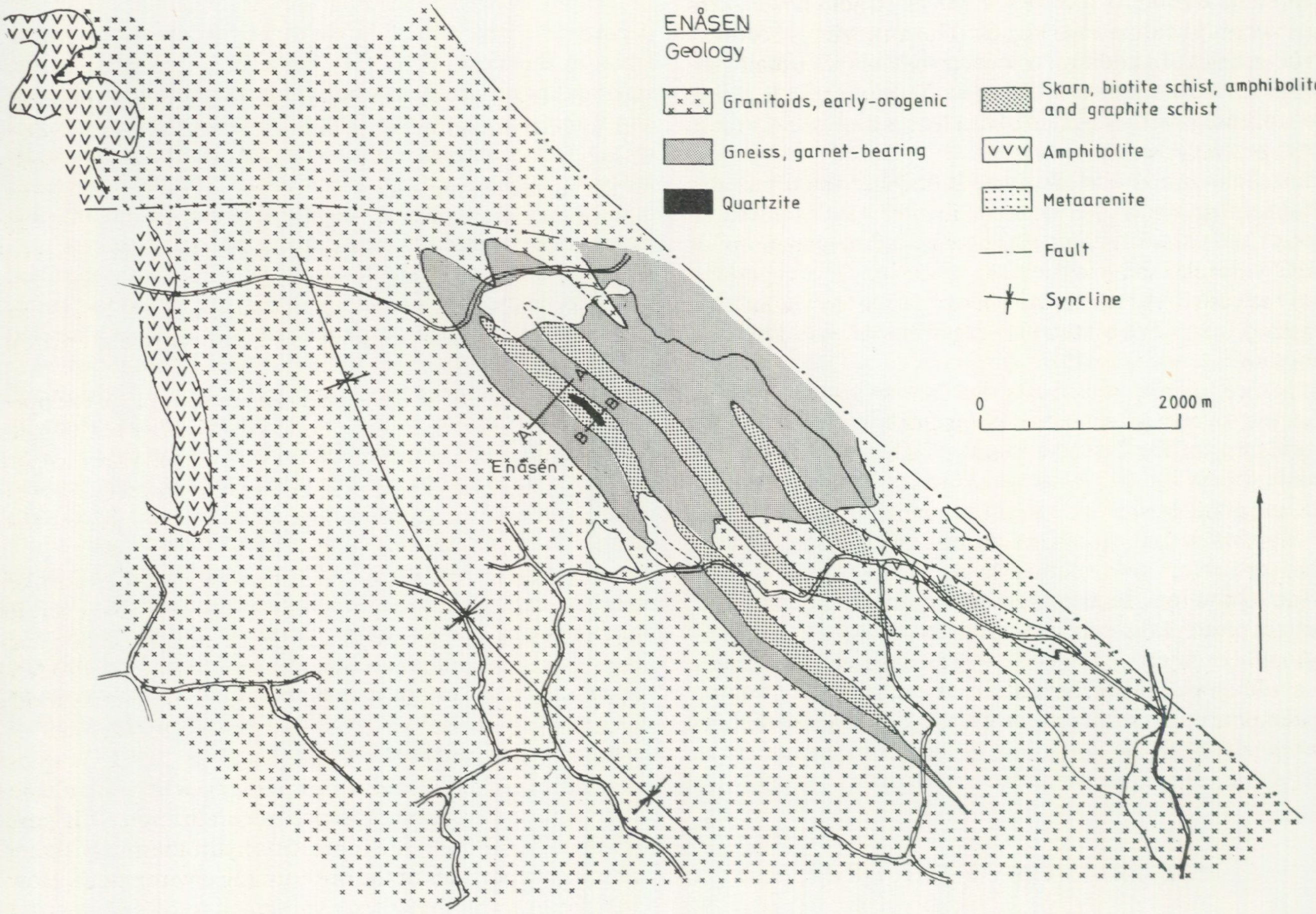


Fig. 3. Geology of the immediate surroundings of the Enåsen gold mineralization. Profiles A and B are shown in Figs. 4 and 5, respectively.

Tectonically, the area is dominated by a major NW–SE trending synform interpreted as a syncline. (Fig. 3). The syncline is indicated by the distribution of sedimentary gneisses and related granitoid rocks. The plunge of the synclinal axis is undulating and almost horizontal. The Enåsen mine site is located on the western flank of an anticlinal structure developed within the syncline. The plastic nature of the deformation is indicated by, in addition to folding, the presence of pinch and swell structures. The northeastern part of the area is cut by an extensive NW–SE striking fault zone, the exact displacement along which is unknown. Another fault of less magnitude occurs in the northern part of the area.

GEOLOGY OF THE ENÅSEN DEPOSIT

The local geology of the Enåsen deposit is characterized by NW–SE trending isoclinal folds overturned, and to some extent probably overthrust, to the northeast. Mining activities are confined to the northwestern part of a fold structure dipping gently to the southwest (Figs. 4 and 5).

According to the interpretation of the stratigraphy, a sheared quartzitic rock, which is the main gold host, forms the lowermost formation (Fig. 5). The quartzite is normally 10–20 m thick. In addition to quartz, sillimanite usually is a conspicuous component of the rock. The quartzite is white, but a diffuse layered structure with lenses rich in biotite and cordierite may occur.

The quartzite is overlain by a sequence which includes biotite schist, skarn gneiss, amphibolite and, to a limited extent, limestone and graphite schist. Impregnations of $CuFeS_2$ and FeS may occur in the sequence. This is particularly the case in the open pit, where a 1–3 m thick zone with copper ore is mined on the hanging wall of the gold-bearing quartzite.

The ore-bearing rock units are followed upwards by a thick pile of greyish, garnet-bearing gneisses which are frequently migmatized and transformed into a granitoid component. In the transitional zone between the copper ore mentioned above and the gneiss sequence, there is normally a well-marked horizon characterized by the occurrence of elongated layers with red K-feldspar.

The folded rock sequence is cut by sheets of aplite, which roughly parallel the gently dipping fold planes.

A number of minor faults have been observed in the mine area, obliquely cutting the strike of the rocks. The faults are contemporaneous with, or post-date, sets of diabase dikes of probable Jotnian age.

DESCRIPTION OF THE ORE

The ore body is about 350 m long and 5–25 m wide. It dips about 30° to the southwest and the average depth is 50 m. Two types of ore can be distinguished, namely quartzite ore and copper ore. The latter is considered to be a marginal ore and is mined only where in contact with the quartzite ore (i.e. on the hanging wall in the open pit).

The quartzite ore consists of weakly sulphide-impregnated portions of quartzite rock carrying gold. Chalcopyrite is the dominating sulphide together with pyrrhotite and pyrite. The sulphur content is normally less than a few per cent. The average grade is 4 g/t Au with 0.2 % Cu. The gold distribution is irregular, however, and scattered sections containing 20 g/t Au have been observed.

The gold occurs mainly as native gold associated with sulphides and quartz, or as native gold and gold tellurides with sulphosalts (Nysten and Annersten 1984). In addition to the sulphide and telluride components, topaz and rutile seem to be related to the ore paragenesis.

The copper ore of the hanging wall deposit consists of chalcopyrite and pyrrhotite. The average grade is 0.6 % Cu with 0.8 g/t Au and 5 % S. The richest mineralization occurs in a pegmatitic rock composed mainly of greenish feldspar. As mentioned above, the colour of the feldspar turns rapidly red where entering the lowermost part of the overlying gneiss sequence. Other gangue minerals characterizing the copper mineralization are garnet and cordierite.

ORE GENESIS

Various suggestions have been put forward to explain the origin of the gold mineralization at Enåsen. One obvious obstacle when attempting to construct an ore genetic model is the high metamorphic state of the bedrock in the area, since spatial as well as petrographic criteria clearly indicate that the mineralization is pre-metamorphic in age. Recent geological investigations have shed light on the pre-metamorphic evolution of the area, which might have some bearing on the understanding of the ore-forming environment.

The rock unit hosting the gold mineralization is developed below a sequence including basic volcanics and lithologies carrying copper and iron sulphides (Fig. 5). The complex sulphide mineralization has been interpreted as volcanogenic and formed in a syntectonic environment also producing basic volcanic rocks.

The sheared and elongated state of the quartzite makes more detailed spatial interpretations difficult. However, its appearence below a complex sulphide mineralization suggests that it was formed by similar processes. A hydrothermal origin is also indicated by the sulphide and telluride mineralogy and the presence of rutile and topaz.

Stratigraphic and tectonic relations (Figs. 4 and 5) suggest that the gold mineralization took place prior to or simultaneously with the complex sulphide mineralization. It is possible that the ore quartzite represents hydrothermally altered subvolcanic portions of the ore-forming environment. However, the exact nature of the parent rock is still unknown (cf. also p. 12 above). Therefore, further investigations are essential in order to define the ore-forming environment more precisely.

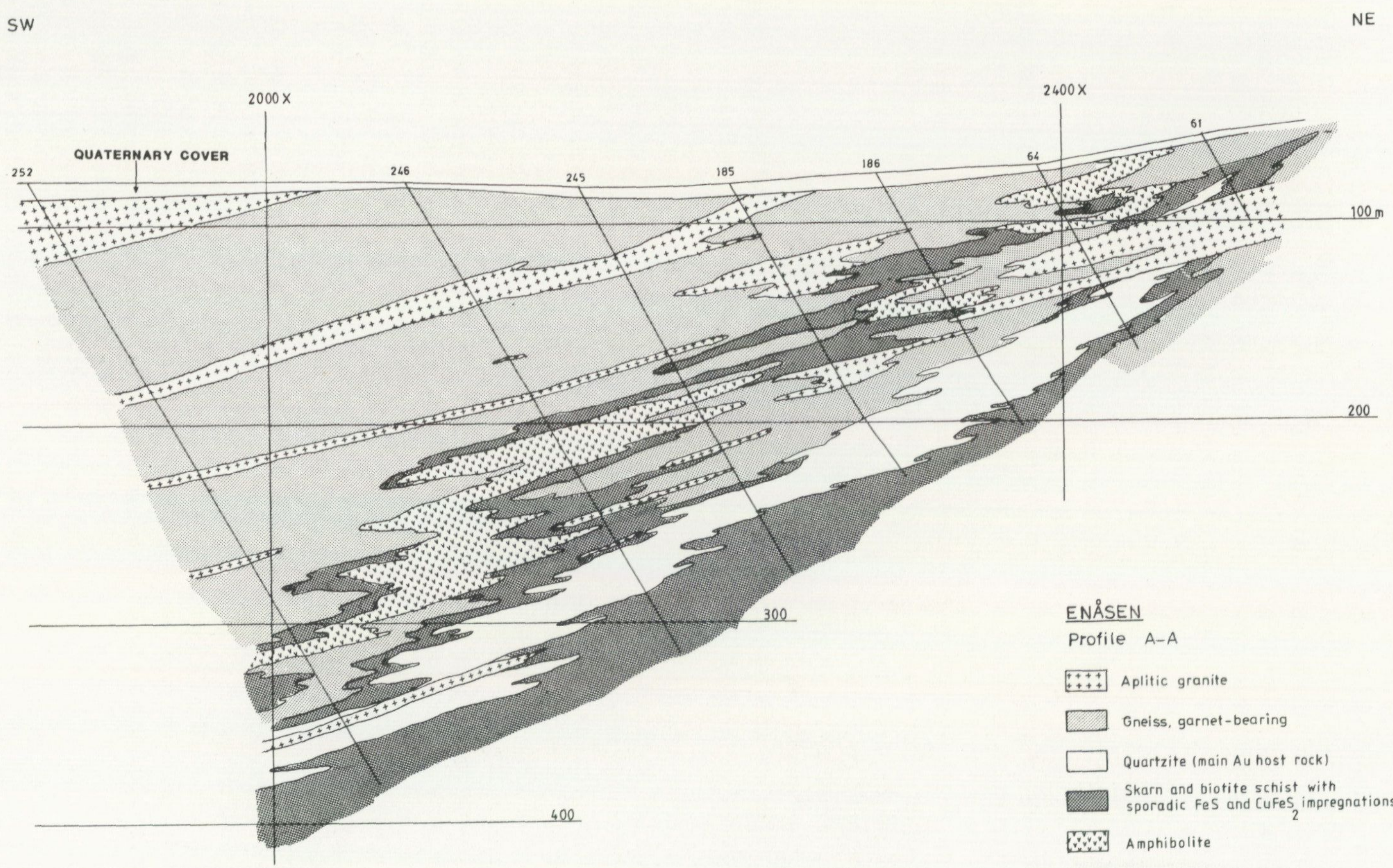


Fig. 4. Profile A at Enåsen. See Fig. 3.

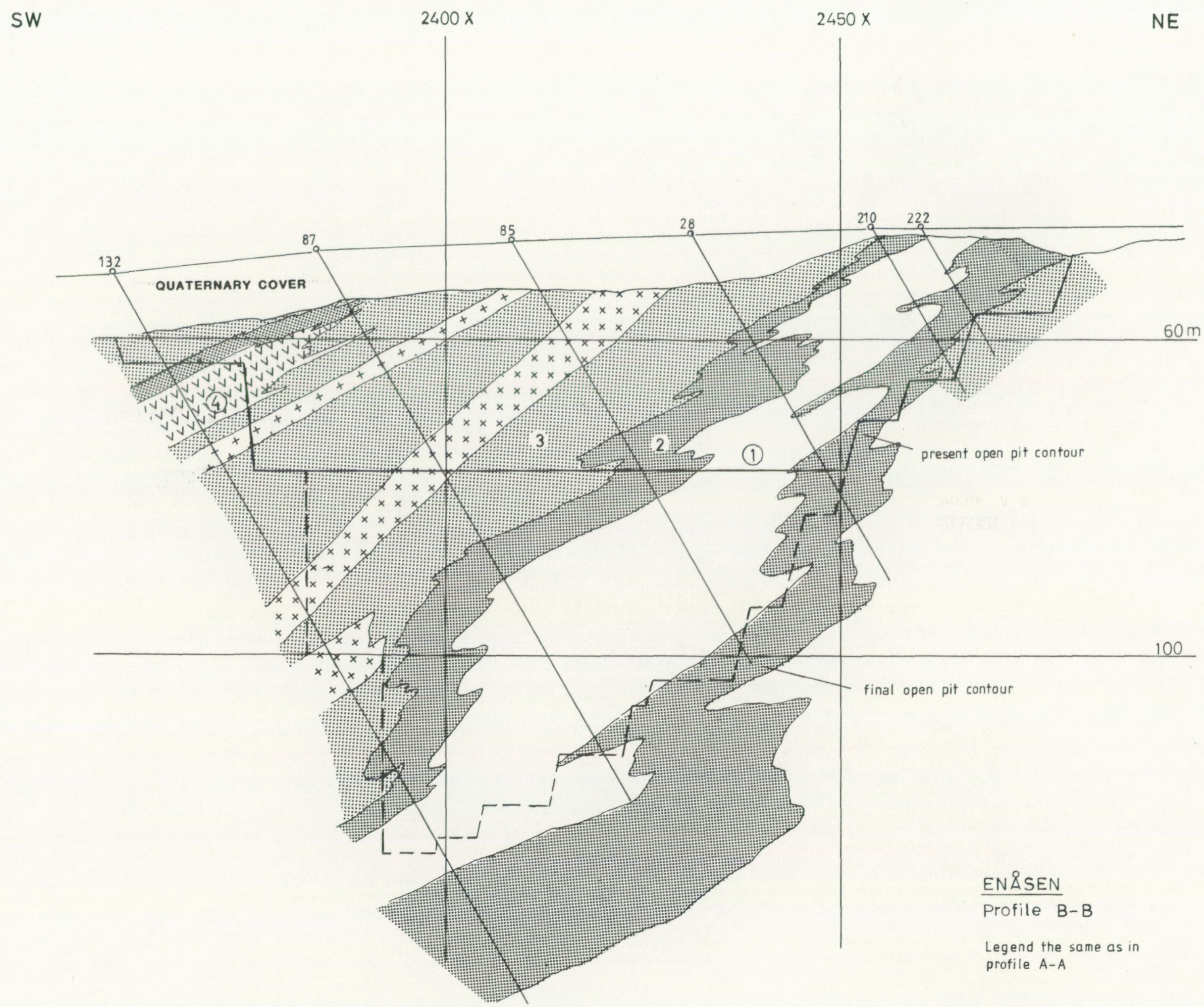


Fig. 5. Profile B at Enåsen. See Fig. 3.

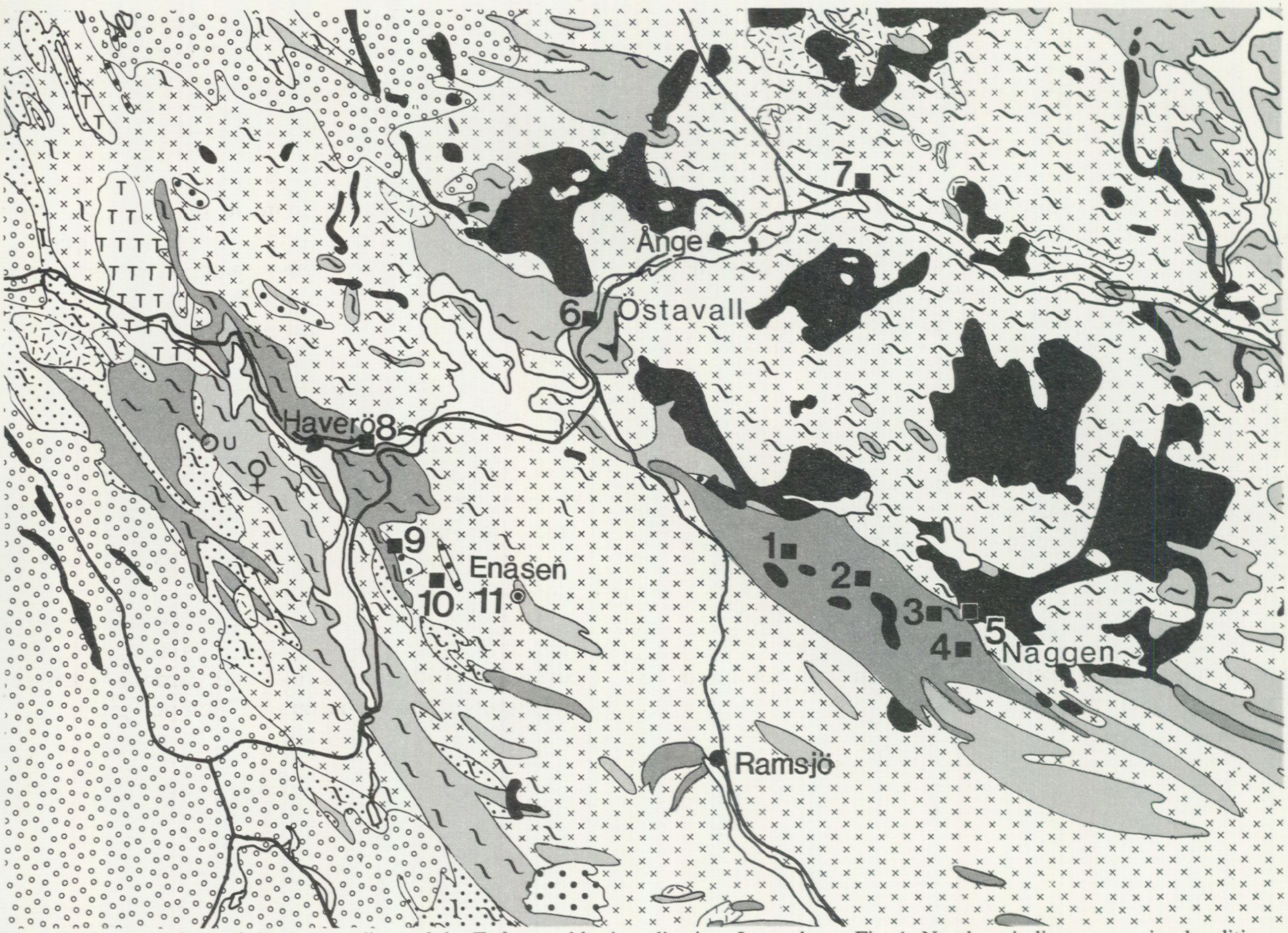


Fig. 6. Bedrock geology of the surroundings of the Enåsen gold mineralization. Legend, see Fig. 1. Numbers indicate excursion localities.

STOP DESCRIPTIONS

ENÅSEN AND SURROUNDINGS

Th. Lundqvist and M. Willdén

The excursion in the Enåsen area will concentrate on both regional setting (stops 1–10) and details within the Enåsen gold deposit (stops 11:1–11:4). The excursion route is indicated in Fig. 6.

Stop 1. – East of Lake Vandeln. Naggen metaarkose with primary bedding and clastic texture. The bedding in part shows weak grading.

Stop 2. – Northwest of Lake Lillnaggen. Naggen metaarkose with beautifully preserved clastic texture. The bedding is in part graded. Chemical analysis shows 86 % SiO_2 and 4.8 % K_2O. The microcline content is c. 30 %. Minor biotite, tourmaline and sericite occur. The latter is probably in part secondary after An-rich plagioclase. Accessories are epidote, opaques, apatite, zircon, sphene, etc.

Stop 3. – Naggen village. Naggen metaarkose, recrystallized, with tourmaline-bearing granitic schlieren.

Stop 4. – County border southeast of Naggen. Strongly recrystallized, "granitoid" Naggen metaarkose.

Stop 5. – Northeast of Naggen village. Dolerite forming a sheet-like intrusion in the Naggen metaarkose and surrounding granites. The dolerite, which is of alkali-basalt type, consists of labradorite (c. 60–65 %), augite (c. 10–15 %), olivine (c. 10–15 %), and minor biotite, titanomagnetite/ilmenite, apatite, K-feldspar, etc.

Stop 6. – Järnvägsforsen, on the river Ljungan. Metagreywacke with a well preserved bedding, in part graded, relict clastic texture and calc-silicate lenses (concretions). The clastic texture is macroscopically evident through mm-sized grains of oligoclase and quartz together with small clasts of metagreywacke and slate/schist. The modal composition of the feldspar-rich layers is here c. 40 % quartz, 35 % oligoclase, 5 % microcline, and 20 % biotite.

Stop 7. – Tälje, road E 75. Foliated primorogenic (synorogenic) granodiorite with both deformed and undeformed microcline megacrysts. Serorogenic (late-orogenic) granite and pegmatite form cross-cutting dikes. A narrow dolerite dike is also seen.

Stop 8. – Säter. Metaarkose transformed into veined gneiss and carrying abundant sillimanite. This rock is a high-metamorphic (high amphibolite facies) counterpart to the Naggen metaarkose. A few hundred metres to the west is an exposure of a reddish, veined, metaargillitic gneiss carrying bluish cordierite, almandite, and sillimanite.

Stop 9. – Kölaberget ("Glassberget"). A coarse- to fine-grained quartz rock carrying abundant sillimanite and topaz with minor andalusite, muscovite, biotite, and pyrophyllite, the latter secondary after sillimanite. This rock possibly represents a more advanced alteration stage of a metaarkose than the Enåsen gold-bearing sillimanite quartzite.

Stop 10. – Lake Öster-Sotsjön. Foliated granite belonging to the primorogenic (early-orogenic) suite. Strongly deformed microcline megacrysts occur.

Stop 11. – The Enåsen mine. A section through the ore zone will be examined in the open pit. The stops are listed from the foot wall of the ore to the hanging wall (Figs. 4 and 5).

11:1. Ore quartzite.

11:2. Gneiss, coarse-grained and impregnated by $CuFeS_2$ and FeS (the marginal ore). The rock covers the hanging wall of the ore quartzite in the open pit. The mineralized gneiss has a restricted extent, and outside the open pit it is normally replaced by biotite-rich schists and various skarn-bearing gneisses.

Rocks similar to those in the hanging wall of the quartzite are developed also on the foot wall side. In the open pit they are represented mainly by biotite-rich schists.

11:3. Gneiss, garnet-bearing and partly pegmatitic. The contact to the mineralized gneiss below is distinct and characterized by the presence of reddish, elongated layers rich in microcline.

In the northern part of the open pit the folded gneiss sequence is cut by aplite dikes.

11:4. Amphibolite, overlain by biotite-rich schist that locally may be slightly graphitic. The sequence can be correlated with the schist and various gneisses enveloping the ore quartzite in the open pit.

THE ALNÖ ALKALINE AREA

P. Kresten

GEOLOGICAL BACKGROUND

The Alnö complex near Sundsvall, along the Bothnian coast of Sweden, provided the starting point for studies of carbonatite petrology and for 100 years has maintained its position as the classic locality. The first comprehensive study (Högbom 1895) demonstrated that the carbonatites had to be regarded as having crystallized from magmas; Stutzer (1907) considered them to be the extreme differentiation products of a nepheline-syenitic magma. The rocks of the complex became renowned through the papers of von Eckermann, in particular the "Alnö Memoir" (1948).

Rb-Sr age determinations show that the main intrusive event took place at about 560 Ma (Brueckner & Rex 1980). K-Ar age determinations indicate that the volcanic activity in the area commenced at about 610 Ma and continued to about 530 Ma. In addition, spurious 380 Ma K-Ar ages occur.

The area is situated at the intersection of several deep crustal faults: the Norrland line (NNE–SSW), the Mjällån fault zone (N–S) and the Indalsälven fault zone (NW–SE). The principal wall rocks of the intrusions are metagreywackes and various types of granite (cf. map, Fig. 1).

Recent studies (Kresten 1976, 1979) demonstrate the existence of several intrusions of different ages and with particular characteristics within the Alnö area.

The oldest intrusions are the pyroxenites, uncompahgrites and kimzeyite-bearing sövites of the Söråker intrusion, on the mainland north of Alnö island. They form a ring-complex measuring 1×2 km across. The intrusion and its fenite aureole are very poorly exposed.

The northern ring-complex at Alnö is situated along the northeastern shore of the island and on the small islands off the coast (see detailed map, scale 1:10 000, in Lundqvist, in prep). It is composed of pyroxenites, ijolites, nepheline syenites and perovskite-bearing sövites, all of which seem to have been emplaced contemporaneously. Field observations demonstrate limited miscibility of alkaline and carbonatitic magmas, as well as an emplacement of the rocks by laminary flow. The northern ring-complex is surrounded by a complicated breccia which includes alkaline rocks, carbonatites and fenitized wall rocks. The sövite of the northern ring-complex is intruded by late ijolite. By contrast, the sövites of the main intrusion always post-date the alkaline plutonic rocks. Thus, the northern ring-complex is regarded as a predecessor of the main intrusion further to the south.

The main intrusion at Alnö island consists of pyroxenites (small plugs as well as fragmented ring-dykes), ijolites to melteigites and, finally, nepheline syenites. The alkaline intrusions are surrounded by a fenite aureole, as a result of the interaction of a volatile phase from the ijolite magma with the wall rock. Some of the high-grade fenites show intrusive behaviour. Late intrusions of commonly pyrochlore-bearing sövites form an anastomosing pattern (see detailed map, scale 1:10 000, in Lundqvist, in prep). The sövites have caused local fenitization of the wall-rock, of older fenites as well as of pre-existing alkaline plutonic rocks. The Båräng vent, west of the main complex, is made up entirely of sövites and fenites.

The latest major intrusive phase seems to be the Sälskär volcanic breccia northwest of the main complex, measuring about 1×1.5 km. As there are no exposures, information on the size and shape of the vent is provided by magnetometry and information on the geology by local boulders. They consist of (olivine-)melilitites, brecciated by a lapilli-rich apatite-pyrochlore-carbonatite. The Sälskär vent is one of the rare examples of carbonatite explosive vents.

The plutonic intrusions have been accompanied by a large number of dikes. In an area of about 1 000 km^2, some 1200 dikes have been mapped. Alkaline dike rocks cover the compositional range of the alkaline plutonic rocks. In addition, alkali trachytes are found, representing both primary magmas and products of fenite partial melting. Melilitite dikes are scarce. Alnöitic lamprophyres, some of which are melilite-bearing, are common. With increased contents of olivine and phlogopite, the alnöites grade into kimberlitic alnöites, which form dikes or diatremes, often crowded with ultramafic xenoliths. Carbonatite dikes are either mainly calcitic (alvikites) or dolomitic (beforsites). Rocks transitional in composition between carbonatites and lamprophyres or trachytes occur.

Through most of the period of magmatic activity in the area, dike rocks have been emplaced. Only the kimberlitic alnöites and the Sälskär breccia are devoid of intersecting dikes. The model of dike emplacement given by von Eckermann (1948) has been revised (Kresten 1980).

So far, more than 100 different mineral species have been reported from the Alnö area. Most of them are found in carbonatites, notably the sövites and the beforsites. Among the more unusual minerals found, tazheranite, (niobo-)zirconolite, brockite, (ferro-)synchisite, auerlite, beckelite and hydroandradite may be mentioned.

Accordingly, the geochemistry of the Alnö rocks is characterized by variable but often high contents of e.g. Ba, Sr, Nb, Zr, Y, REE, Th and U. Particularly in the late-stage deposits – late ferrobeforsites and hydrothermal veins – spectacular concentrations of some elements are found.

Despite these finds, the economy is disappointing. In some pyroxenites and sövites, local concentrations of titanomagnetite occur and have been the objectives of small-scale mining. The very late-stage hydrothermal baryte dikes and veins were quarried during World War II. Minor quarries for lime have been taken up in the sövites. Small, uneconomic apatite deposits are found, mainly in sövites. Some of the sövites, e.g. the pyrochlore-rich sövites of the Båräng vent, are enriched in niobium (to 3000 ppm), the rare earth elements (to 1500 ppm) and uranium (to 200 ppm), but the volumes are too small. The nepheline syenites are too impure to be of use in aluminium production. The reported occurrences of diamond in the kimberlitic alnöites (Kresten & Nairis 1982) still require further confirmation; subsequent tests have been negative.

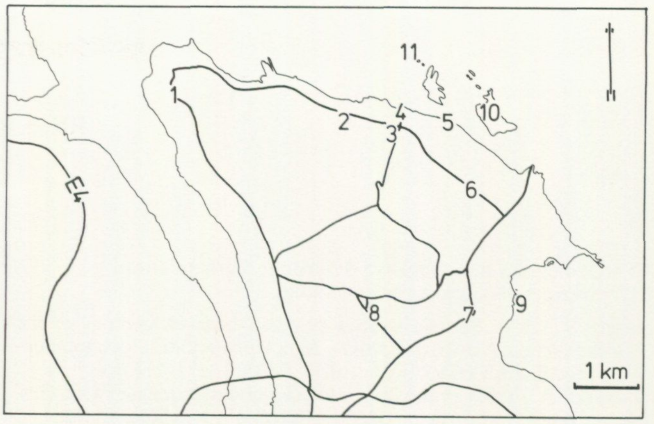


Fig. 7. Localities for the Alnö excursion.

STOP DESCRIPTIONS

Stop 1. – Alnöite breccia at Hovid. The road-cutting exposes an alnöite dike, about 20 m wide, which rapidly tapers off in width along strike. Fragments of granites, gneisses, diabase and sövite are found. Rare deep-seated granulites and eclogites have been found, but no upper mantle xenoliths. Megacrysts include titanomagnetite, chromian diopside, phlogopite and large (to 20 cm) titanian pargasite. Fenitization of the wall rock (veined metagreywacke gneiss) is restricted to some metres. The alnöite breccia is intersected by several carbonatite dikes.

Stop 2. – Road-cutting north of Hartung. Initial fenitization of the metagreywackes is evidenced by the appearance of aegirine and alkali amphibole, as well as by plastic deformation of the rock. Further to the south, fenitization becomes more intense. A number of alkaline and carbonatitic dikes are seen.

Stop 3. – Road-cutting at Hörningsholm. Dikes of nepheline syenite cross-cutting ijolite series, differentiated into urtite to pyroxenite.

Stop 4. – Hörningsholm. In the field, exposure of sövite-pegmatite showing oriented intergrowth between calcite and aegirine-augite. Along the shore, large sövite dike, belonging to the northern ring-complex, as well as pyroxenites.

Stop 5. – Shore east of Hörningsholm. Rock units of the northern ring-complex: melteigite and sövite dike with fragments of pyroxenite and various high-grade fenites.

Stop 6. – Alnöite at Näset. One of the two original type localities of alnöite: megacrysts of phlogopite and some clinopyroxene in a fine-grained melilite-bearing matrix.

Stop 7. – Ås. Biotite-sövite with abundant fragments of alkaline rocks and well-developed flow structure.

Stop 8. – Abandoned sövite quarry south of Smedsgården. High-grade fenite with magnetite dike, wollastonite-rich contact zone and massive sövite dike.

Stop 9. – The jetty at Ås. At the jetty, and along the shore, the whole variety of Alnö rocks is seen in boulders. In the jetty, boulders of jacupirangite and sövite-pegmatite are most conspicuous. The outcrops south of the jetty show high-grade fenites invaded by sövite and a variety of dike rocks.

Stop 10. – Långharsholmen and nearby skerries. In the southeast, contact breccia comprising fenites, sövite and alkaline rocks. To the northwest, sövite dike (see localities 4 and 5) with intercalated alkaline rocks, mainly pyroxenite and ijolite. At the northwestern point of the island, intrusion of younger ijolite. The skerries north of Långharsholmen are made up of sövite and little pyroxenite, with spectacular dikes and blebs of sövite-pegmatite.

Stop 11. – Västra Sälskär. Sövite displaying flow structure, in contact with pyroxenite. Boulders of the Sälskär volcanic breccia.

Note that visits to localities 10 and 11 will depend upon weather conditions.

REFERENCES

GFF=Geologiska Föreningens i Stockholm Förhandlingar
SGU=Sveriges geologiska undersökning

Axberg, S., 1980: Seismic stratigraphy and bedrock geology of the Bothnian Sea, Northern Baltic. – Acta Universitatis Stockholmiensis, Stockholm Contr. Geol. vol. XXXVI:3, 153–213.

Blomberg, A., 1895: Praktiskt geologiska undersökningar inom Gefleborgs län... utförda genom SGU 1889–1893. – SGU C 152.

Brueckner, H.K. & Rex, D.C., 1980: K-A and Rb-Sr geochronology and Sr isotopic study of the Alnö alkaline complex, northeastern Sweden. – Lithos 13, 111–119.

Eckermann, H., von, 1938: The Anorthosite and Kenningite of the Nordingrå-Rödö region. – GFF 60, 243–284.

– 1948: The alkaline district of Alnö Island. – SGU Ca 36.

Fredriksson, G. & Tuuri, E., 1986: Rare element pegmatite prospects in Västernorrland and Jämtland, north-central Sweden. – Abstract 17e Nordiska Geologmötet, Helsinki.

Fredriksson, K. & Wickman, F.E., 1963: Meteoriter. – Svensk Naturvetenskap 16, 121–157.

Frietsch, R., 1980: The ore deposits of Sweden. – Geol. Surv. Finland, Bull. 306.

Gorbatschev, R., Solyom, Z. & Johansson, I., 1979: The Central Scandinavian Dolerite Group in Jämtland, central Sweden. – GFF 100, 177–190.

Grip, E., 1961: Geology of the nickel deposit at Lainijaur in northern Sweden. – SGU C 577.

Hedström, H., 1901: Gahnit från Snuggens Koppargruva i Helsingland. – GFF 23, 42–44.

Högbom, A.G., 1895: Über das Nephelinsyenitgebiet auf der Insel Alnö. – GFF 14, 100–160, 214–256.

Holmquist, P.J., 1899: Om Rödöområdets rapakivi och gångbergarter. Mit einem Resumé in deutscher Sprache. – SGU C 181.

Hörnsten, Å., 1959: Blockfynd av Limbata-kalksten på Härnön. – GFF 81, 670–671.

Kornfält, K.-A., 1976: Petrology of the Ragunda rapakivi massif, central Sweden. – SGU C 725.

Kresten, P., 1976: A magnetometric survey of the Alnö Complex. – GFF 98, 361–362.

– 1979: The Alnö Complex. Discussion of the main features. Bibliography. Excursion guide. – Nordic Carbonatite Symposium/Alnö 1979.

– 1980: The Alnö complex: tectonics of dyke emplacement. – Lithos 13, 153–158.

Kresten, P. & Nairis, H.J., 1982: Alnö diamonds. – GFF 104, 210.

Larson, S.Å., 1973: Igneous layering in the Ulvö dolerite, Ångermanland, Central Sweden. – GFF 95, 407–409.

– 1980: Layered intrusions of the Ulvö dolerite complex, Ångermanland, Sweden. – Dissert., Chalmers Tekn. Högsk./Göteborgs Univ. Geol. Inst., A36.

Lundbohm, H., 1899: Praktiskt geologiska undersökningar inom Vesternorrlands län... utförda genom SGU. II Berggrunden – SGU C 177.

Lundegårdh, P.H., 1957: The titaniferous ore-bearing gabbro of Helsingland, central Sweden. – SGU C 549.

– 1960: The miogeosynclinal rocks of eastern central Sweden. – SGU C 570.

– 1967: Berggrunden i Gävleborgs län. Petrology of the Gävleborg County in Central Sweden. With maps to the scale of 1:200 000 and 1:75 000. – SGU Ba 22.

Lundegårdh, P.H., Gorbatschev, R., Kornfält, K.-A., Strömberg, A.G., Karis, L., Zachrisson, E., Sjöstrand, T. & Skoglund, R., 1984: Karta över berggrunden i Jämtlands län. Bedrock geology of Jämtland County. – SGU Ca 53.

Lundqvist, Th., 1979: The Precambrian of Sweden. – SGU C 768.

— in prep: Berggrundskarta över Västernorrlands län (Bedrock geology of Västernorrland County). – SGU Ba 31.

Lundqvist, Th. & Samuelsson, L., 1973: The differentiation of a dolerite at Nordingrå, central Sweden. – SGU C 692.

Magnusson, N.H., 1953: Malmgeologi. – Jernkontoret, Stockholm.

Magnusson, N.H., Thorslund, P., Brotzen, F., Asklund, B. & Kulling, O., 1960: Description to accompany the map of the pre-Quaternary rocks of Sweden. With one map to the scale of 1:1 000 000 (1958). – SGU Ba 16.

Mogensen, F., 1946: A ferro-ortho-titanate ore from Södra Ulvön. – GFF 68, 578–588.

Nilsson, G., 1985: Nickel-copper deposits in Sweden. *In* "Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides", H. Papunen and G.I. Gorbunov (eds.). – Geol. Surv. Finland, Bull. 333, 313–362.

Nordenskiöld, A.E., 1877: Mineralogiska meddelanden. 3. Tantalsyrade mineral från Utö. – GFF 3, 282–286.

Nysten, P. & Annersten, H., 1984: The gold mineralization at Enåsen, central Sweden. – GFF 106, 245–256.

Persson, L., 1978: The Revsund-Sörvik granites in the western parts of the province of Ångermanland, central Sweden. – SGU C 741.

Quensel, P., 1952: The Paragenesis of the Varuträsk Pegmatite. – Geol. Magazine LXXXIX, 49–60.

Rankama, K. & Welin, E., 1972: Joint meeting of the Precambrian stratigraphy groups of Denmark, Finland, Norway, and Sweden in Turku, Finland, March 1972. – Geol. Newsletter 1972 no. 4, 265–267.

Redaelli, L., 1957: A petrological investigation in Lake Norra Dellen by means of frog-man equipment. – SGU C 548.

Smeds, S.-A., 1984: Tennmineral från Li- och Sn-förande pegmatiter i Västernorrland och östra Jämtland, Sverige. Abstract 16. Nordiska Geol. Vintermötet, Stockholm 1984. G. Armands and S. Schager (eds.). – Meddel. Stockh. Univ. geol. inst. 255, 206.

Smeds, S.-A. & Tuuri, E., 1986: Mineral chemical prospecting for spodumene- and cassiterite-bearing pegmatites in north-central Sweden. – Abstract 17e Nordiska Geologmötet, Helsinki.

Sobral, J.M., 1913: Contributions to the geology of the Nordingrå region. – Diss., Univ. Uppsala.

Stålhös, G., 1981: A tectonic model for the Svecokarelian folding in east central Sweden. – GFF 103, 33–46.

Stutzer, O., 1907: Eruptive Kalksteine. – Naturwiss. Wochenschr. N. Folge VI (25), 392–393. Jena.

Svensson, N.-B., 1968: The Dellen Lakes, a probable meteorite impact in Central Sweden. – GFF 90, 314–316.

Welin, E., 1979: Tabulation of recalculated radiometric ages published 1960–1979 for rocks and minerals in Sweden. – GFF 101, 309–320.

Welin, E. & Lundqvist, Th., 1975: K-Ar ages of Jotnian dolerites in Västernorrland County, central Sweden. – GFF 97, 83–88.

Welin, E. & Lundqvist, Th., 1984: Isotopic investigations of the Nordingrå rapakivi massif, north-central Sweden. – GFF 106, 41–49.

PRISKLASS A

Distribution
Liber Distribution
S-162 89 STOCKHOLM
SWEDEN
Tel. 08-739 91 30

Fotosats: ORD & FORM AB
Tryck: Offsetcenter AB
Uppsala 1986

ISBN 91-7158-405-6
ISSN 0348-1352